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EVALUATING THE IMPACT OF

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Appendix of Methods

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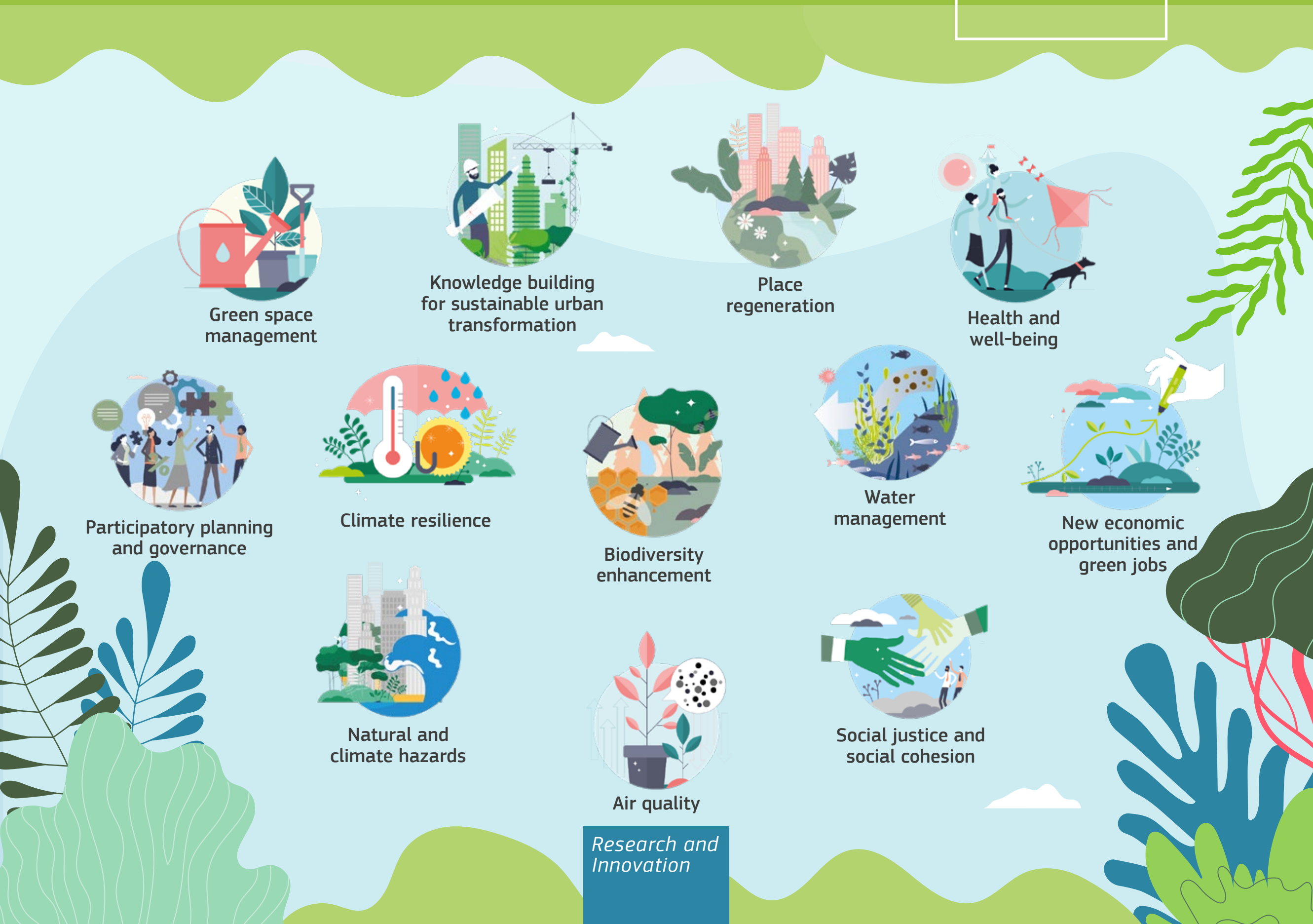

Research and Innovation

Evaluating the Impact of Nature-based Solutions: Appendix of Methods

European Commission
Directorate-General for Research and Innovation
Directorate C — Healthy Planet
Unit C3 — Climate and Planetary Boundaries

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EVALUATING THE IMPACT OF NATURE-BASED SOLUTIONS

Appendix of Methods

Adina Dumitru and Laura Wendling, Eds.

2021

Directorate-General for Research and Innovation
Healthy Planet - Climate and Planetary Boundaries

Table of Contents

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FOREWORD

Evaluating the Impact of Nature-based Solutions: Appendix of Methods is a compilation of methods of determination for indicators of NBS performance and impact. Experts in a wide variety of disciplines from eighteen EU H2020 NBS projects and a number of supporting European programmes were directly involved in the production of this Appendix of Methods, inlcuding (in aplhabetical order):

- CLEARING HOUSE (H2020 Grant Agreement no.821242)
- CLEVER Cities (H2020 Grant Agreement no. 776604)
- CONNECTING Nature (H2020 Grant Agreement no. 730222)
- EdiCitNet (H2020 Grant Agreement no. 776665)
- GROW GREEN (H2020 Grant Agreement no. 730283)
- MAES (JRC-D3-Institutional project)
- NAIAD (H2020 Grant Agreement no. 730497)
- Nature4Cities (H2020 Grant Agreement no. 730468)
- Naturvation (H2020 Grant Agreement no. 730243)
- OPERANDUM (H2020 Grant Agreement no. 776848)
- PHUSICOS (H2020 Grant Agreement no. 776681)
- proGIreg (H2020 Grant Agreement no. 776528)
- RECONECT (H2020 Grant Agreement no. 776866)
- REGREEN (H2020 Grant Agreement no. 821016)
- UNaLab (H2020 Grant Agreement no. 730052)
- URBAN GreenUP (H2020 Grant Agreement no. 730426)
- URBiNAT (H2020 Grant Agreement no. 776783)

INTRODUCTION

Evaluating the Impact of Nature-based Solutions: Appendix of Methods is designed to support the implementation of impact indicators listed in Chapter 4 of the accompanying report, *Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners* by briefly summarising the respective methods of determination for each of the indicators mentioned in the *Handbook for Practitioners*. The methods of indicator determination are organised by the societal challenge area addressed and further grouped as Recommended and Additional, as categorised by the contributing authors.

The 12 societal challenge areas across which methods of indicator determination are grouped are:

1. Climate Resilience
2. Water Management
3. Natural and Climate Hazards
4. Green Space Management
5. Biodiversity Enhancement
6. Air Quality
7. Place Regeneration
8. Knowledge and Social Capacity Building for Sustainable Urban Transformation
9. Participatory Planning and Governance
10. Social Justice and Social Cohesion
11. Health and Wellbeing
12. New Economic Opportunities and Green Jobs

The individual co-authors and respective affiliated project(s) are noted for each method presented here. In addition to a brief description of the technique, each method of indicator determination presented includes a description and justification, a definition of the indicator including units of measurement, notes on the strengths and weaknesses of each method, and advice regarding the scale at which the indicator can be determined. Data souces are addressed, including required data and the type of input data (quantitative or qualitative), the frequency of data collection and level of expertise required to collect and synthesise the data. Synergies with other indicators and connections to the Sustainable Development Goals (SDGs) are also noted, along with identified opportunities for participatory data collection. Additional sources of information for each method are provided with an emphasis on easily available sources (e.g., Open Access journal articles and online reports).

CLIMATE RESILIENCE

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1. Recommended Indicators of Climate Resilience

1.1. Carbon removed or stored in vegetation and soil

Project Name: UNaLab (Grant Agreement no. 730052)

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Total carbon removed or stored in vegetation and soil per unit area per unit time	Climate Resilience
Description and justification	Accounting for C stored in soil and vegetation in an urban area can indicate the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.

Definition	Total carbon removed or stored (tonnes/ha/y or similar units)
Strengths and weaknesses	+ Quantifying removal and sequestration can give the opportunity to mitigate GHG effects - Requires other metrics to evaluate the indicator
Measurement procedure and tool	To evaluate C removal or storage per unit area per unit time: • Determine C storage in vegetation or soil as described in *Carbon storage and sequestration in vegetation* or *Carbon storage and sequestration in soil* indicators, respectively, for the same area at two different points in time • Divide each C storage value obtained by the area assessed to determine C storage per unit area • Subtract the earlier value obtained for C storage and sequestration/unit area from the more recent value, then divide by the length of time between measures to obtain an estimate of C removal or storage per unit area per unit time. The growth rate of a forest has significant impact on its C storage potential. Forest C sequestration (FCS) is usually estimated as a function of forest area, forest type, and forest age: $FCS = (FIA_{rate}/FOREST_{mean-pct}) \times NONF_{mean-pct,i} \times NONF_{area,i}$ where FIA_{rate} is net forest growth rate for the most common type group in county *i*, $FOREST_{mean\text{-}pct}$ is mean canopy cover percentage for all forested pixels in the county *i*, $NONF_{mean\text{-}pct}$ is mean canopy cover percentage for all non-forest pixels in county *i*, and $NONF_{area}$ is area sum of all non-forest pixels in county *i*. The sum of FCS in both forested and non-forest pixels is the total net FCS by urban and community trees in county *i* (Zheng, Ducey, & Heath, 2013). Studies have shown that more accurate estimates of FCS are obtained by classifying forests as recently afforested or mature/remnant forest as tree growth rates vary substantially between these forest types (Smith, Heath, Skog & Birdsey, 2006; Zheng, Heath, Ducey & Smith, 2011).
Scale of measurement	Plot scale to regional scale
Data source	
Required data	Requires C storage to be determined from either *Carbon storage and sequestration in soil* or *Carbon storage and sequestration in vegetation* indicators
Data input type	Quantitative

Data collection frequency	Annually
Level of expertise required	Low – requires the ability to determine C storage from other metrics and follow the calculation procedure
Synergies with other indicators	Requires C storage to be determined from either *Carbon storage and sequestration in soil* or *Carbon storage and sequestration in vegetation* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Smith, J.E., Heath, L.S., Skog, K.E., & Birdsey, R.A. (2006). Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. USDA Forest Service Report GTR-NE-343. Newtown Square, PA: Northeastern Research Station, United States Department of Agriculture, Forest Service. Zheng, D., Ducey, M.J. & Heath, L.S. (2013). Assessing net carbon sequestration on urban and community forests of northern New England, USA. Urban Forestry & Urban Greening, 12, 61-68. Zheng, D., Heath, L.S., Ducey, M.J. & Smith, J.E. (2011). Carbon changes in conterminous US forests associated with growth and major disturbances: 1992–2001. Environmental Research Letters, 6, 014012.

1.2. Avoided greenhouse gas emissions from reduced building energy consumption

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Avoided CO_2 emissions related to building energy consumption	Climate Resilience
Description and justification	Building energy consumption is the fraction of greenhouse gas (GHG) emissions that can be affected by nature-based solutions in an urban environment.
Definition	CO_2 emissions related to building energy consumption (direct via, e.g., residential combustion and indirect via, e.g., electric heating and cooling) with and without NBS implementation (kWh/y and t C/y saved)
Strengths and weaknesses	+ Can be fairly easily measured + Indicates changes in building heating and cooling needs - Not sensitive to energy production details - Analysis can be lacking in accuracy and comparability between different communities and regions
Measurement procedure and tool	First, the community housing energy sources are identified and methods for their quantification on yearly basis are recorded (IPCC, 2006). These energy sources include electrical energy use, as well as supplemental energy sources such as district heating and local combustion for heating. Numerical values for the community as a whole (MWh), as well as population equivalent (MWh/person), are recorded, thus allowing for compensation for population change. All forms of energy need to be taken into account, including electricity consumption, natural gas or thermal energy for heating and cooling, and fuels. CO_2 emissions related to building energy consumption are calculated as follows: $Emissions_{buildings} = Energy\ (MWh/a) \times National\ emission\ factor\ (t\ CO_2/MWh)$ $Decrease\ (\%) = 100\% - \left(\left(\frac{Emission_{buildings\ (after)}}{Emission_{buildings\ (before)}}\right) \times 100\%\right)$

Scale of measurement	Building, street and district scale
Data source	
Required data	Information about building energy sources and electrical energy use, as well as supplemental energy sources such as district heating and local combustion for heating. These data can typically be obtained from municipal sources or from records of building- or district-level energy consumption from the building owner or utility company.
Data input type	Quantitative
Data collection frequency	Annually to enable tracking of changes to CO_2 emissions due to building energy consumption with time; at minimum before and after NBS implementation
Level of expertise required	Low – requires ability to follow the calculation procedure and to convert different units of energy to kWh of energy to achieve the total energy consumption
Synergies with other indicators	Possibility to combine with *CO_2 emissions related to vehicle traffic* indicator to obtain the total decrease due to NBS implementation
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Intergovernmental Panel on Climate Change (IPCC). (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). Hayama, Japan: Institute for Global Environmental Strategies (IGES). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

1.3. TX_x, Monthly mean value of daily maximum temperature

Project Name: CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Maddalen Mendizabal[1]

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Mean of daily maximum temperature (TX)	**Climate Resilience**
Description and justification	Mean of the daily maximum temperatures observed during specific time period, either for a specific year or over a specific period of years[1]. Proposed to detect Tº increment
Definition[2]	Let TX_{ij} be the maximum temperature at day i of period j. Then mean values in period j are given by: $TX_j = \sum_{i=1}^{I} TX_{ij} \Big/ I$
Strengths and weaknesses	It is a good indicator together with the mean of daily minimum temperature that can gives an idea of the high temperature effects in urban comfort and human health.
Measurement procedure and tool	Sensors: measuring instruments (measurement stations or manual instruments e.g., TESTO multi-function); thermography camera (e.g., FLIR). The average of the summer period or a hot summer day can be considered from one specific year or range or years Summer is the most common season in which it is assessed (spring and autumn are considered in relatively fewer studies: e.g., Yan H., Wang X., et al. 2012; Shashua-Bar L., Tsiros I.X., Hoffman M.E. 2010) The maximum is the category most employed in the literature, but the average also is relevant and used. For this indicator the average is proposed.
Scale of measurement	It depends on the sensors network coverage; it can be a point or in case there are several localizations it ca be transformed to a grid (through interpolation)
Data source	
Required data	A time series of air Tº data (measured in ºC)
Data input type	Quantitative

[1] http://glossary.ametsoc.org/wiki/Mean_daily_maximum_temperature_for_a_month
[2] https://eca.knmi.nl/indicesextremes/indicesdictionary.php#8

Data collection frequency	The sensors can collect the data every 10 minutes. In case the effectiveness of a NBS is analysed this should be measured at least hourly. At midday, the cooling effect reaches its maximum so, for example, the heat effect on health can be analysed; at night, the effectiveness is less, but the effect of the night temperature on sleep disturbance can be analysed. Regardless of the adaptation aim, the best time to measure the higher effect on heat reduction is midday, as this is the hottest time of the day where the cooling effect reaches the maximum (Georgi and Dimitriou, 2010; Shashua-Bar et al., 2012; Tan et al., 2016).
Level of expertise required	The sensors must be calibrated and located in the same place during all the measurement period. Not any sensor is valid
Synergies with other indicators	Synergies with the mean of daily minimum temperature.
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible with supervision
Additional information	
References	[1] http://glossary.ametsoc.org/wiki/Mean_daily_maximum_temperature_for_a_month [2] https://eca.knmi.nl/indicesextremes/indicesdictionary.php#8

1.4. TN_n, Monthly mean value of daily minimum temperature

Project Name: CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Maddalen Mendizabal[1]

[1] *TECNALIA, Basque Research and Technology Alliance (BRTA), Mikeletegi Pasealekua 2, 20009 Donostia-San Sebastián, Spain*

Mean of daily minimum temperature (TN)	Climate Resilience
Description and justification	Mean of the daily minimum temperatures observed during specific time period, either for a specific year or over a specific period of years[3]. Proposed to detect Tº increment at night.

[3] http://glossary.ametsoc.org/wiki/Mean_daily_maximum_temperature_for_a_month

	This indicator allows analysing the effect of the night temperature on sleep disturbance.
Definition	**TN** • *Mean of daily minimum temperature (°C)* Let TN_{ij} be the minimum temperature at day *i* of period *j*. Then mean values in period *j* are given by: $TN_j = \sum_{i=1}^{I} TN_{ij} / I$
Strengths and weaknesses	Same as TX indicator
Measurement procedure and tool	Same as TX.
Scale of measurement	Same as TX
Data source	
Required data	Same as TX
Data input type	Quantitative
Data collection frequency	The sensors can collect the data every 10 minutes. In case the effectiveness of a NBS is analysed this should be measured at least hourly. At night, the NBS effectiveness is less, but the effect of the night temperature on sleep disturbance can be analysed
Level of expertise required	Same as TX
Synergies with other indicators	Synergies with the mean of daily maximum temperature.
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible with supervision
Additional information	
References	http://glossary.ametsoc.org/wiki/Mean_daily_maximum_temperature_for_a_month

1.5. Heatwave Incidence

Project Name: CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Maddalen Mendizabal[1]

[1] *TECNALIA, Basque Research and Technology Alliance (BRTA), Mikeletegi Pasealekua 2, 20009 Donostia-San Sebastián, Spain*

Heatwave Incidence	Climate Resilience
Description and justification	A heatwave is a period of consecutive days with hot temperatures where both length and peak temperature are important.
Definition	Several indicators are proposed. Among them 3 are pre-selected to represent heatwave events: • Heatwave number (HWN) as defined by either the Excess Heat Factor (EHF), 90th percentile of TX or the 90th percentile of TN. The number of individual heatwaves that occur each summer (Nov–Mar in southern hemisphere and May–Sep in northern hemisphere). A heatwave is defined as 3 or more days where either the EHF is positive, TX >90th percentile of TX or where TN <90th percentile of TN, where percentiles are calculated from base period specified by user. • Heatwave frequency (HWF) as defined by either the Excess Heat Factor (EHF), 90th percentile of TX or the 90th percentile of TN • Heatwave amplitude (HWA) as defined by either the Excess Heat Factor (EHF), 90th percentile of TX or the 90th percentile of TN
Strengths and weaknesses	There exist a lot of definitions for heatwaves in the literature, which makes important an harmonization or standardization
Measurement procedure and tool	Sensors: measuring instruments (measurement stations or manual instruments, e.g., TESTO multi-function); thermography camera (e.g., FLIR).
Scale of measurement	It depends on the sensors network coverage; it can be a point or in case there are several localizations it ca be transformed to a grid (through interpolation)
Data source	
Required data	A time series of air Tº data (measured in ºC)
Data input type	Quantitative
Data collection frequency	The sensors can collect the data every 10 minutes or daily.

Level of expertise required	The sensors must be calibrated and located in the same place during all the measurement period. Not any sensor is valid
Synergies with other indicators	Synergies with the mean of daily minimum and maximum temperature.
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Perkins, S.E. & Alexander, L.V. 2013. On the Measurement of heatwaves, J. Climate, 26, 4500–17. doi: 10.1175/JCLI-D-12-00383.1

2. Additional Indicators of Climate Resilience

2.1. Carbon storage and sequestration in vegetation

2.1.1 Carbon storage and sequestration in vegetation per unit area per unit time

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

[1] *VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland*

[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Total carbon storage and sequestration in vegetation per unit area per unit time	Climate Resilience
Description and justification	Accounting for C stored in soil and vegetation in an urban area can provide an indication of the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.
Definition	Total amount of carbon (tonnes) stored in vegetation, described per unit area and unit time
Strengths and weaknesses	+ The modelling tool can be used to model potential effects of changes to be made or situation if changes were not made by creating parallel scenarios of the same area with different tree inventories + The inventory can be created from maps and sample measurements - Access to reliable and accurate data may be limited - Analyses may require an external laboratory
Measurement procedure and tool	There are several tools for modelling carbon in trees including the U.S. Forest Service Forest Inventory and Analysis Database, such as the suite of i-Tree tools (USDA Forest Service, 2019). The i-Tree Eco model inputs a database of city trees with information on location, size and species to a geographic information system platform. Alternatively, an estimate of C storage or sequestration in above-ground vegetation can be manually determined

	using a similar approach to the i-Tree Eco application. First, each above-ground vegetation polygon in a digital cartographic dataset can be classified per light detection and ranging (LiDAR) data as, e.g., herbaceous vegetation (grasses and non-woody plants), shrub (woody bushes and trees with mean height typically <2 m), tall shrub (woody bushes and trees with mean height generally 2-5 m), or tree (trees >5 m in height) after Davies, Edmonson, Heinemeyer, Leake, & Gaston (2011). Davies et al. (2011) recommend surveying to ground-truth map data and classification estimates. Species-specific allometric equations are available from the scientific literature to estimate above-ground dry weight biomass of the classified vegetation, and carbon storage calculated using conversion factors also available from the scientific literature. Where there are multiple equations for a given species, the equations can be combined to obtain a general result. Total above ground tree biomass can be converted to C storage using conversion factors based on tree type. The dry-weight of above-ground biomass of each class of vegetation along with the mean C content can also be determined via laboratory analysis.
Scale of measurement	District to regional scale
Data source	
Required data	Requires data on extent of vegetation cover & characteristics of vegetation (e.g., type, age and height), land use, air quality data, and meteorological and other local information for modelling. These can be obtained from forest inventory analysis (FIA), a national land cover database (NLCD) or databases for housing density mapping. Users may need permission to gain access to national databases unless the data are open (freely available).
Data input type	Quantitative
Data collection frequency	Annually to enable tracking of changes to C storage and sequestration with time before and after NBS implementation
Level of expertise required	Moderate – requires understanding of the C storage concept, and ability to combine and apply allometric equations and modelling tools
Synergies with other indicators	Used for evaluating C storage necessary for *Carbon removed or stored per unit area per unit time* indicator
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Opportunities for participatory data collection	Participatory data collection is feasible through sample collection, e.g., air quality measurements
Additional information	
References	Davies, Z.G., Edmonson, J.L., Heinemeyer, A., Leake, J.R., & Gaston, K.J. (2011). Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. Journal of Applied Ecology, 48, 21125-1134. Fong, W.K., Sotos, M., Doust, M., Schultz, S., Marques, A., & Deng-Beck, C. (2015). Global Protocol for Community-Scale Greenhouse Gas Emission Inventories. Washington, D.C.: World Resources Institute. Retrieved from https://www.wri.org/publication/global-protocol-community-scale-greenhouse-gas-emission-inventories Intergovernmental Panel on Climate Change (IPCC). (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). Hayama, Japan: Institute for Global Environmental Strategies (IGES). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/. Intergovernmental Panel on Climate Change (IPCC). (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.). Geneva, Switzerland: IPCC. United States Department of Agriculture (USDA) Forest Service. (2019). i-Tree Eco Manual. Northern Research Station, USDA Forest Service. Retrieved from https://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6_UsersManual.pdf

2.1.2 *Carbon storage and sequestration in vegetation – annual determination*

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Márton Kiss[1], Florian Kraus[2], Barnabás Körmöndi[3]

[1] *University of Szeged, Szeged, Hungary*

[2] *Green4Cities, Vienna, Austria*

[3] *Hungarian Urban Knowledge Center, Budapest, Hungary*

Annual carbon storage and sequestration in vegetation per unit area	**Climate Resilience**
Description and justification	The storing and sequestration of carbon (dioxide) can be quantified and monitored relatively easily, and enable spatial and temporal comparisons of the capacities of different nature-based solutions. The amount of sequestered carbon is directly proportional to biomass growth, for which a sort of biomass functions and equations are available in the fields of forestry and agricultural sciences (McPherson et al. 2016, USDA 2015). The carbon content is around 50% of the amount of biomass. This kind of knowledge is available mainly for trees which can be considered as good indicators of the whole ecosystem's capacity in areas with lack of data (as they have an outstanding role in carbon sequestration and storage). Natural and management-related mortality of biomass (and life of products if relevant) should be considered to get a total carbon balance of the investigated NBS.
Definition	The annual carbon sequestration is a commonly used indicator of the global climate regulation ecosystem service of different vegetation types.
Strengths and weaknesses	
Measurement procedure and tool	Self-developed equations, e.g., in the case of trees: $Cb_{t+1} = Cb_t + Kc[Gb_t – Ms_t – T_t – H_t]$ where: Cb_t: carbon stored in living biomass at time 't' (tC/ha) Gb_t: biomass growth at time 't' T_t: biomass turnover at time 't' Ms_t: tree mortality due to senescence at time 't' H_t: harvest at time t' Gb = Kv * Ys where: Kv: constant to convert volume yields into dry biomass (basic wood density, in tons of dry biomass per m^3 of fresh stemwood volume Ys: the volume yield of stem wood ($m^3ha^{-1}yr^{-1}$) ecosystem-specific proxies

	Tools: - clinometer for tree height, and tape measure for crown diameter and DBH measurement - precipitation and temperature sensors for climatic data - modelling tool (i-Tree Eco, CUFR Tree Carbon Calculator) Measurement unit: tC/ha/year
Scale of measurement	Neighbourhood and city scale
Data source	
Required data	- Measured data of biomass size (e.g., diameter at breast height (DBH), full height, trunk height, crown diameter of trees) - Basic climatic data (average temperatures and sum of precipitation, length of vegetation period) These data can come from: - measurement/monitoring - remote sensing in some cases
Data input type	Quantitative
Data collection frequency	At least before and after the project's implementation, to characterize the vegetation or occasional measurement (and long-period monitoring) of biomass size or continuous measurement of climatic data
Level of expertise required	Low - Relatively easy to understand
Synergies with other indicators	
Connection with SDGs	SDG 3 Good Life and Well-being, SDG 11 Sustainable Cities and Communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	None identified
Additional information	
References	Davies, Z.G, et al. (2011): Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. Journal of Applied Ecology 48, 1125–1134. doi:10.1111/j.1365-2664.2011.02021.x Kiss, M., et al. (2015): The role of ecosystem services in climate and air quality in urban areas: Evaluating carbon sequestration and air pollution removal by street and park trees in Szeged (Hungary). Moravian Geographical Reports 23, 36-46. doi:10.1515/mgr-2015-0016

	Schröder, C., et al. (2013): Methodology proposal for estimation of carbon storage in urban green areas. EEA Research report of Task 262-5-6 "Carbon sequestration in urban green infrastructure" McPherson., G.E., van Doorn, N.S:, Peper, P.J., 2016. Urban Tree Database and Allometric Equations. General Technical Report PSW-GTR-253. USDA Forest Service, USA Russo, A., Escobedo, F.J., Timilsina, N., Schmitt, A.O., Varela, S., Zerbe, S., 2014. Assessing urban tree carbon storage and sequestration in Bolzano, Italy, International Journal of Biodiversity Science, Ecosystem Services & Management 10:1, 54-70, doi:10.1080/21513732.2013.873822 USDA (2015). I-Tree Eco Manual. Northern Research Station, USDA Forest Service, Website. [online] URL: http://www.itreetools.org/resources/manuals/Eco_Manual_v5.pdf Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

2.1.3 Total Leaf Area

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

[1] *Green4Cities GmbH/GREENPASS GmbH*

Leaf Area (LA)	**Green Space Management** **Climate Resilience** **Air Quality**
Description and justification	The LA (Leaf Area) is a Key Performance Indicator of the GREENPASS® system. It expresses the sum of leaf area of NBS within project area. The Leaf Area is the operating surface of NBS and

	therefore decisive for climate regulation, carbon storage and air purification.
Definition	The LA (Leaf Area) describes the total amount of leaf area of all NBS in a project area.
Strengths and weaknesses	+ key performance indicator regarding biodiversity + easy for communication, understanding and decision-making + useful for design optimization + link the NBS performance to a single number - needs area analysis and calculation
Measurement procedure and tool	- NBS analysis of an area and calculation (eg with GREENPASS® system and tools) - numerical value in m^2
Scale of measurement	Object, neighbourhood and city scale
Data source	
Required data	- project area - NBS typologies and areas
Data input type	- numerical analysis of vegetation types incl. characteristics (eg LAI)
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy to understand – for planners and decision makers
Synergies with other indicators	-
Connection with SDGs	SDG 11 Sustainable Cities and Communities, SDG 13 Climate action
Opportunities for participatory data collection	-
Additional information	
References	Kraus, F.; Scharf, B. (2019): Management of urban climate adaptation with NBS and GREENPASS®. Geophysical Research Abstracts. Vol. 21, EGU2019-16221-1, 2019 EGU General Assembly 2019. Kraus, F.; Scharf, B. (2019): Climate-resilient urban planning and architecture with GREENPASS illustrated by the case study 'FLAIR in the City' in Vienna. OP Conf. Ser.: Earth Environ. Sci. 323 012087. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS.

	https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

2.1.4 Carbon Storage Score

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

[1] *Green4Cities GmbH/GREENPASS GmbH*

Carbon Storage Score	**Climate Resilience**
Description and justification	The CSS (Carbon Storage Score) is one out of five Key Performance Scores of the GREENPASS® system. It expresses the carbon storage performance of the NBS in a project area. Carbon dioxide is the most relevant greenhouse gas. The ability to capture carbon dioxide is most relevant in climate change mitigation.
Definition	The CSS (Carbon Storage Score) describes the total amount of stored CO_2 within the vegetation and soil of a project area.
Strengths and weaknesses	+ worldwide standardized key performance score regarding greenhouse gases and carbon sequestration + easy for communication, understanding and decision-making + useful for design optimization - needs simulation (photosynthesis activity)
Measurement procedure and tool	- modelling, simulation tools and GREENPASS® analysis and calculation - numerical value in kg/day
Scale of measurement	Object, neighbourhood and city scale
Data source	
Required data	- project area - NBS typology

Data input type	- 3D model with surface and vegetation types incl. characteristics
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy to understand – for planners and decision makers
Synergies with other indicators	Link to 'Total carbon removed or stored in vegetation and soil per unit area per unit time', 'Total C stored in vegetation assessed per unit area per unit time', 'Total C stored in soil assessed per unit area per unit time'
Connection with SDGs	SDG 11 Sustainable Cities and Communities, SDG 13 Climate action
Opportunities for participatory data collection	None identified
Additional information	
References	Kraus, F. (2017): The GREENPASS® Methodology. Pan European Network – Government 23 publication. October 2017. Scharf, B.; Schnepf, D. (2017): H2020: Special Report: Greenpass – unleash the power of green. Scharf, B. (2018): Coole Städte planen – Mit der „Greenpass-Methode". Neue Landschaft 01/2018. ISSN 0548-2836. Patzer Verlag. Berlin-Hannover. 2018. Scharf, B.; Kraus, F. (2019): Green Roofs and Greenpass. Buildings 2019, 9, 205. Elagiry, M.; Kraus, F.; Scharf B., Costa, A.; De 2019 Lotto, R. (2019): Nature4Cities: Nature-Based Solutions and Climate Resilient Urban Planning and Modelling with GREENPASS® - A Case Study in Segrate/Milano/IT. 16th IBPSA - International Building Performance Simulation Association Conference. Kraus, F.; Scharf, B. (2020): IT-gesteuerte Natur in der dichten Stadt. Neue Landschaft 01/2020. Kraus, F.; Scharf, B. (2019): Management of urban climate adaptation with NBS and GREENPASS®. Geophysical Research Abstracts. Vol. 21, EGU2019-16221-1, 2019 EGU General Assembly 2019. Kraus, F.; Scharf, B. (2019): Climate-resilient urban planning and architecture with GREENPASS illustrated by the case study 'FLAIR in the City' in Vienna. OP Conf. Ser.: Earth Environ. Sci. 323 012087. Kainz, A.; Hollosi, B.; Zuvela-Aloise, M.; Kraus, F.; Scharf, B.; Tötzer, T.; Züger, J.; Reinwald, F. (2019): Modelling the effects of implementing green infrastructure to support urban climate change adaptation and resilient urban

	planning. EMS Annual Meeting Abstracts Vol. 16, EMS2019-341, 2019. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

2.1.5 Measured soil carbon content

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

[1] *VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland*

[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Total carbon storage and sequestration in soil per unit area per unit time	**Climate Resilience Green Space Management**
Description and justification	Accounting for C stored in soil and vegetation in an urban area can provide an indication of the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.
Definition	Total amount of carbon (tonnes) stored in soil per unit area and unit time
Strengths and weaknesses	+ Physical sampling and laboratory analysis of soil C yields accurate information, with improved accuracy of estimated C storage in soil with increasing sampling intensity

	+ Combustion-based analytical methods are relatively simple and widely applicable - Small changes in soil C may be difficult to quantify in carbonate-rich soils, in which case multiple analytical steps may be required to obtain reliable measurements - Soil sample collection is relatively labour-intensive; analyses typically require an external laboratory (rather than analysed in-house)
Measurement procedure and tool	The most reliable and accurate method of determining soil C content is field sampling followed by laboratory analysis. Combustion is an accurate, commonly used analytical technique to quantify total C in soil – including both organic and inorganic soil C. Combustion analysis involves converting all forms of C in the soil to CO_2 by wet or dry combustion, then measuring evolved CO_2. Change in soil C content occurs most readily in the SOC fraction, so observed changes in total soil C content with time are most likely to represent changes to SOC content. Sampling is performed using a measuring tape (for establishment of sampling transect or grid), soil corer, and plastic bags. It may be challenging to detect small changes in soil C content in soils that contain substantial inorganic (mineral) C. A rapid field test of the soil's reactivity to acid can indicate whether it may be necessary to undertake more intensive analyses of soil samples to quantify both the organic and inorganic C fractions, rather than total (inorganic + organic) C by combustion. Rapid assessment of soil carbonate content involves reacting a small sample (ca. 1 g) of soil with 1-2 drops of 1 M hydrochloric acid (HCl) in a glass or porcelain container and observing the reaction for ~5 min. The reaction between soil carbonate minerals and HCl is visible as bubbles/effervescence as bubbles of CO_2 are produced. If the HCl 'field test' indicates the presence of inorganic C then the soil sample should be pre-treated to remove inorganic C prior to determination of organic C content by wet digestion. A sample of the carbonate-containing soil should be treated at room with a mixture of dilute sulphuric acid (H_2SO_4) and ferrous sulphate ($FeSO_4$) for at least 20 min or until effervescence appears to cease. The flask containing the soil and H_2SO_4/$FeSO_4$ mixture should then be heated over a flame and boiled slowly for 1.5 min to destroy any remaining carbonate. Finally, pulverised

	potassium dichromate ($K_2Cr_2O_7$) should be added to the mixture and organic C determined by chromic acid digestion (wet combustion) (Nelson & Sommers, 1996).
Scale of measurement	Plot scale; it is possible to extrapolate results from small number of field samples based on soil maps to approximate soil C storage at landscape (regional) scale
Data source	
Required data	Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3; can be measured or estimated based on soil type). Obtainable from local municipality, department of environment, geological survey.
Data input type	Quantitative
Data collection frequency	Annually, including at a minimum measurement before and after NBS implementation
Level of expertise required	Low to Moderate – field sampling Moderate – combustion analysis in laboratory conditions High – soil sample pre-treatment for determination of organic C content
Synergies with other indicators	Used for evaluating C storage necessary for *Carbon removed or stored per unit area per unit time* indicator
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection is feasible through soil sample collection
Additional information	
References	Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc. Rowell, D.L. (2014). *Soil Science: Methods & Applications*. New York: Routledge. Soil Survey Staff. (2009). *Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt (Ed.).* Lincoln, NE: United States Department of Agriculture, Natural Resources Conservation Service.

2.1.6 *Modelled carbon content of the upper soil layer*

Project Name: PHUSICOS (Grant Agreement no. 776681)

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Modelled carbon content of the upper soil layer	**Climate Resilience** **Green Space Management**
Description and justification	Indicators of Carbon Sequestration in Soil sub-criterion will assess the carbon sequestration in soil.
Definition	In soils and sediments, there are three basic forms of carbon that may be present: elemental, inorganic, and organic C. The quality of organic matter in sediments is critical to the partitioning and bioavailability of sediment-associated contaminants. Elemental carbon forms include charcoal, soot, graphite, and coal. The primary sources for elemental carbon in soils and sediments are as incomplete combustion products of organic matter (i.e., charcoal, graphite, and soot), from geologic sources (i.e., graphite and coal), or dispersion of these carbon forms during mining, processing, or combustion of these materials. Inorganic carbon forms are derived from geologic or soil parent material sources. Inorganic carbon forms are present in soils and sediments typically as carbonates. Naturally-occurring organic carbon forms are derived from the decomposition of plants and animals. In soils and sediments, a wide variety of organic carbon forms are present and range from freshly deposited litter (e.g., leaves, twigs, branches) to highly decomposed forms such as humus. In addition to the naturally-occurring organic carbon sources are sources that are derived as a result of contamination through anthropogenic activities.
Strengths and weaknesses	
Measurement procedure and tool	Model/Sampling/Survey
Scale of measurement	ton/ha
Data source	

Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Additional information	
References	http://bcodata.whoi.edu/LaurentianGreatLakes_Chemistry/bs116.pdf

2.1.7 Soil carbon decomposition rate

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Soil Carbon Decomposition Rate	**Climate Resilience** **Green Space Management**
Description and justification	Indicators of Carbon Sequestration in Soil sub-criterion will assess the carbon sequestration in soil.
Definition	Decomposition of Carbon is a part of the Carbon cycle and is essential for recycling the finite matter that occupies physical space in the biosphere. Decomposition is the process by which organic substances are broken down into simpler organic matter. One can differentiate abiotic from biotic decomposition (biodegradation). The former means "degradation of a substance by chemical or physical processes, e.g., hydrolysis" (Water Quality Vocabulary. IShaO 6107-6:1994). The latter means "the metabolic

	breakdown of materials into simpler components by living organisms", typically by microorganisms.
Strengths and weaknesses	
Measurement procedure and tool	Model/Sampling/Survey
Scale of measurement	%
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	-
Opportunities for participatory data collection	
Additional information	
References	

2.2. Energy use savings due to green infrastructure implementation

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Clara Corbella[1]; Sonia Sanchis[1], Raúl Sánchez[2], Jose Fermoso[2], Silvia Gómez, María González[2], Jose María Sanz[2], Esther San José[2], Alicia Villazán[3], Isabel Sánchez[3]

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Savings in energy use due to improved green infrastructure	**Climate Resilience**
Description and justification	The energy sector is the largest single source of global greenhouse gas emissions, and is responsible for over a quarter of all EU greenhouse gas emissions (European Commission). Green Infrastructure can play a role in reducing the negative impacts of the energy sector, by: (1) reducing energy consumption; (2) providing bioenergy; and (3) providing carbon uptake and storage. The KPI presented aims at quantifying both the energy savings and the bioenergy generated by all the NBS implemented in Valladolid. This KPI will be calculated converting into energy savings the benefits already considered by means of other KPIs. Therefore, in this KPI, all the NBS that provide an ecosystem service which has a direct link to an energy saving or the ones that generate electricity themselves will be considered.
Definition	This KPI is calculated from measured data using a methodology defined by URBAN GreenUP Project. Energy savings due to improved Green Infrastructure (ESGI) will be calculated by converting other KPIs (BASE KPIs, with other units of measurement) into its associated energy saving. Accordingly, from the complete list of KPIs measured at Valladolid DEMOSITE, the ones that imply an energy saving will be considered.
Strengths and weaknesses	- This KPI gives an overview of the direct and indirect energy savings - This KPI requires the management of large amounts of data. - The accuracy of the output will depend on the baseline data and the conversion factors
Measurement procedure and tool	The initial step is the selection of the KPIs that either directly or indirectly generate energy savings (BASE KPI). As an example, at one particular site in the URBAN GreenUP project the following KPIs were selected: tons of carbon

removed or stored per unit area per unit time, energy savings from reduced building energy consumption, temperature reduction in urban areas, intercepted rainfall, water for irrigations purposes or water removed from water treatment system. Once these KPIs are identified, they can be converted into their corresponding energy savings. Initially, units have to be harmonized to the same timescale (referred to the same period of time; daily, monthly, annually).This harmonization will be conducted considering constant values along the time (either if the time should be extended or reduced) as indicated in the table.

	BASE KPI	CONVERSION	TIMESCALE CONVERTED KPI
EXTENSION	m^3/month	BASE KPI x 12 months	m^3/year
REDUCTION	m^3/5 years	BASE KPI/5	m^3/year

Once all the BASE KPIs have the same timescale, their corresponding energy savings will be calculated. Each one of the BASE KPIs considered for this calculation is given in different primary units. Therefore, for the calculation of their associated energy savings, when required, they will be converted into energy units by means of specific conversion factors.

Accordingly, the factors required to convert the primary units into energy units are the ones stablished in the table.

CONVERSION FACTOR	CF_i	Units CF_i
Conversion factor from CO_2 to energy	CF_{CO2}	$kWh/kgCO_2$
Energy consumption per cubic meter of wastewater transported and treated by the municipal wastewater treatment plant	CF_{WW}	KWh/m^3
Energy consumption per cubic meter of potable water (including transport)	CF_{PW}	KWh/m^3
Energy consumption per cubic meter of irrigation water (including transport)	CF_{IW}	KWh/m^3
Energy consumption per cubic meter of wastewater transported and treated by the municipal wastewater treatment plant	CF_{WW}	KWh/m^3

These conversion factors will be provided by the different stakeholders. Once the conversion factors are stablished, energy savings due to improved green infrastructure for each

	specific BASE KPI (KPI_i) will be calculated following the expression: $$ESGI_{KPIi} = BASE\_KPI_i \cdot CF_i$$ **RESULTS** To calculate the final value of the ESGI KPI ($ESGI_{tot}$), and only once all the BASE KPIs are converted into their associated energy savings per period of time ($ESGI_{KPIi}$), all the energy savings will be summed up according to the following expression: $$ESGI_{tot} = \sum_i ESGI_i$$
Scale of measurement	City / neighbourhood
Data source	
Required data	It is measured at the level of the related Demo Sites.
Data input type	See tables above.
Data collection frequency	Annually.
Level of expertise required	Technical / Expert
Synergies with other indicators	(see table below)
Connection with SDGs	SDG3 / SDG4 / SDG8 / SDG10 / **SDG11**
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid.

Synergies with other indicators:

Key performance indicator	Primary units
Tons of carbon removed or stored per unit area per unit time	$tCO_2/m^2 \cdot y$
Energy savings from reduced building energy consumption	kWh/y
Temperature reduction in urban areas	% energy reduction
Intercepted rainfall per period of time	m^3/y
Water for irrigations purposes	$m^3/ha/y$
Volume of water removed from water treatment system	m^3/y

	https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl European Commission. Green infrastructure in the Energy sector.

2.3. Estimated carbon emissions reduction from building energy saving - cooling

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Paul Nolan[1], Clare Olver[1], Raúl Sánchez[2], Jose Fermoso[2], Silvia Gómez, María González[2], Jose María Sanz[2], Esther San José[2]

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[2] *CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain*

Recommended citation: The Mersey Forest, Natural Economy Northwest, CABE, Natural England, Yorkshire Forward, The Northern Way, Design for London, Defra, Tees Valley Unlimited, Pleasington Consulting Ltd, and Genecon LLP (2010). GI-Val: the green infrastructure valuation toolkit. Version 1.6 (updated in 2018). https://bit.ly/givaluationtoolkit

Reduction in carbon emissions from building energy saving - cooling	Climate Resilience
Description and justification	GI-Val is The Mersey Forest's green infrastructure valuation toolkit. The current prototype is free and open source, and can be downloaded under a Creative Commons License from: https://www.merseyforest.org.uk/services/gi-val/. It takes the form of a spreadsheet calculator and a user manual. GI-Val Tool 1.6 can estimate reduced carbon emissions from building energy saving due to the cooling impact of nature-based solutions. It uses data from the US and UK to estimate energy, fuel cost and CO_2 savings as a result of having trees around buildings. An independent assessment of GI Val by the Ecosystems Knowledge Network is available from this link, along with

	links to other tools: https://ecosystemsknowledge.net/green-infrastructure-valuation-toolkit-gi-val
Definition	Estimates the reduction in carbon emissions associated with energy savings for cooling by multiplying the reduction in energy consumption (in kWh) by 0.537. The 0.537 multiplication factor is derived from carbon intensity for grid electricity: 0.537 kg/kWh (Defra/Carbon Trust).
Strengths and weaknesses	- Tool developed using English data. - The toolkit remains a prototype and this means there are some green infrastructure benefits for which it cannot calculate a direct financial value. While there is a rich body of evidence that illustrates and demonstrates the different types of benefits deriving from quality green infrastructure, robust valuation techniques do not yet exist for all benefits. Therefore some valuations come with detailed caveats as they are based on limited evidence at this stage. - The toolkit's calculation is designed to be useful for initial, indicative project appraisal, providing a range of figures indicating the potential impact of a green infrastructure intervention or the value of an existing green infrastructure asset. The toolkit does not assess the quality of the design or detailed management requirements of green infrastructure. It does not replace a full cost benefit analysis, but it provides a basic valuation at a much lower cost. - Valuations such those made with a toolkit or cost benefit analysis also need to be seen as part of a much bigger picture. The valuation should not replace community engagement and local dialogue about what is valued about a place. Calculating economic value of green assets will always be a controversial technique and financial value should only be seen as one factor in decision-making. - The reported GVA values include transfers from one organisation to another, which means that although GVA increases for the beneficiaries, it may not increase for the study area as a whole.
Measurement procedure and tool	The toolkit provides a set of calculator tools, to help assess an existing green asset or proposed green investment. The toolkit uses standard valuation techniques to assess the potential benefits provided by green infrastructure within a defined project area. These benefits are assessed in terms of the functions that the green infrastructure may perform, support or encourage, depending upon the type of project. For example, the diagram below shows how an urban tree planting scheme can result in improved air quality, carbon

	sequestration and reduced health costs, thereby illustrating green infrastructure function, benefit and potential monetisation. Once data is entered into the toolkit, it generates an estimate of annual reduction in energy consumption and CO_2e saving (in units of kg CO_2e/year). The toolkit identifies the marginal benefit, the additional value of the green infrastructure, and also tries to ensure that there is no 'double counting' of value.
Scale of measurement	Street – district – city
Data source	
Required data	General information about area of investigation and local green infrastructure
Data input type	Numeric data
Data collection frequency	Individual assessments
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	Developing the toolkit's next iteration will require wide and sustained collaboration. To facilitate this process, interested parties are invited to pass the toolkit to others who might be able to incorporate it into their work and to provide feedback on their experience in using the toolkit, good and bad! Sources of improved evidence Suggestions for improving the tools Ideas for new tools The consortium who led the development of this toolkit has handed over the responsibilities for co-ordinating future work to the Green Infrastructure Value Network (GIVaN). Further information on the network can be found at: www.bit.ly/givaluationtoolkit
Additional information	
References	URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl http://www.merseyforest.org.uk/services/gi-val/

	Nowak, McPherson and Rowntree, Chicago's urban forest ecosystem: results of the Chicago urban forest climate project, USDA,1994 Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099. SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf

2.4. Energy and CO_2 emissions savings from reduced volume of water entering sewers

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Paul Nolan[1], Clare Olver[1], Raúl Sánchez[2], Jose Fermoso[2], Silvia Gómez, María González[2], Jose María Sanz[2], Esther San José[2]

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[2] CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain

Recommended citation: The Mersey Forest, Natural Economy Northwest, CABE, Natural England, Yorkshire Forward, The Northern Way, Design for London, Defra, Tees Valley Unlimited, Pleasington Consulting Ltd, and Genecon LLP (2010). GI-Val: the green infrastructure valuation toolkit. Version 1.6 (updated in 2018). https://bit.ly/givaluationtoolkit

Estimated energy and CO_2 emissions savings from reduction in the volume of water entering combined sewers	**Climate Resilience** **New Economic Opportunities and Green Jobs**
Description and justification	GI-Val is The Mersey Forest's green infrastructure valuation toolkit. The current prototype is free and open source, and can be downloaded under a Creative Commons License from: https://www.merseyforest.org.uk/services/gi-val/. It takes the form of a spreadsheet calculator and a user manual. Drainage of stormwater run-off into combined municipal sewers results in a proportionate level of energy use and CO_2 emissions associated with stormwater transport and

	treatment. GI-Val Tool 2.1 estimates the energy savings (in kW hr/y) associated with the impact of vegetation on reducing the amount of stormwater entering combined sewers, along with the equivalent carbon emissions savings (in tonnes CO_2e/year). The tool further estimates the economic values of carbon and energy savings. An independent assessment of GI Val by the Ecosystems Knowledge Network is available from this link, along with links to other tools: https://ecosystemsknowledge.net/green-infrastructure-valuation-toolkit-gi-val
Definition	The estimated decrease in energy use and associated CO_2e emissions due to implementation of NBS (increase in land surface vegetation).
Strengths and weaknesses	- Tool developed using English data. - The toolkit remains a prototype and this means there are some green infrastructure benefits for which it cannot calculate a direct financial value. While there is a rich body of evidence that illustrates and demonstrates the different types of benefits deriving from quality green infrastructure, robust valuation techniques do not yet exist for all benefits. Therefore some valuations come with detailed caveats as they are based on limited evidence at this stage. - The toolkit's calculation is designed to be useful for initial, indicative project appraisal, providing a range of figures indicating the potential impact of a green infrastructure intervention or the value of an existing green infrastructure asset. The toolkit does not assess the quality of the design or detailed management requirements of green infrastructure. It does not replace a full cost benefit analysis, but it provides a basic valuation at a much lower cost. - Valuations such those made with a toolkit or cost benefit analysis also need to be seen as part of a much bigger picture. The valuation should not replace community engagement and local dialogue about what is valued about a place. Calculating economic value of green assets will always be a controversial technique and financial value should only be seen as one factor in decision-making. - The reported GVA values include transfers from one organisation to another, which means that although GVA increases for the beneficiaries, it may not increase for the study area as a whole.

Measurement procedure and tool	The toolkit provides a set of calculator tools to help assess an existing green asset or proposed green investment. Tool 2.1 uses Forestry Commission data about water use by trees and other types of land cover to estimate the reduction in runoff to sewers. Input data for estimation of energy and carbon emissions savings as a result of decreased stormwater inflow to combined sewers include: • Land use, including surface cover characteristics • Average local rainfall • Water treatment costs (energy and other inputs) The toolkit uses standard valuation techniques to assess the potential benefits provided by green infrastructure within a defined project area. These benefits are assessed in terms of the functions that the green infrastructure may perform, support or encourage, depending upon the type of project. Once data is entered into the toolkit, it generates financial values for many of the green infrastructure benefits, included the improvement in air quality. The toolkit identifies the marginal benefit, the additional value of the green infrastructure, and also tries to ensure that there is no 'double counting' of value.
Scale of measurement	Street to district scale
Data source	
Required data	Land use and land surface cover characteristics for the area under examination; local rainfall data (yearly mean rainfall); water treatment unit costs, including energy use.
Data input type	Numeric data.
Data collection frequency	Individual assessments
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	Developing the toolkit's next iteration will require wide and sustained collaboration. To facilitate this process, interested parties are invited to pass the toolkit to others who might be able to incorporate it into their work and to provide feedback on their experience in using the toolkit, good and bad! Sources of improved evidence Suggestions

	for improving the tools Ideas for new tools The consortium who led the development of this toolkit has handed over the responsibilities for co-ordinating future work to the Green Infrastructure Value Network (GIVaN). Further information on the network can be found at: www.bit.ly/givaluationtoolkit
Additional information	
References	URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl http://www.merseyforest.org.uk/services/gi-val/ Nowak, McPherson and Rowntree, Chicago's urban forest ecosystem: results of the Chicago urban forest climate project, USDA,1994 Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099. SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf

2.5. Soil Temperature

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

[1] Built Environment Asset Management Centre, Glasgow Caledonian University, Glasgow, Scotland, UK

Soil temperature	**Climate Resilience** **Natural and Climate Hazards** **Green Space Management**
Description and justification	Soil temperature is intrinsically related to soil microbial activity and to biogeochemical and hydrological fluxes in the soil. Different soil temperatures would be preferred by

	different vegetation whose roots would provide strengths and resistance against erosion or sliding.
Definition	The degree or intensity of heat present in soil, especially as expressed according to a comparative scale and shown by a thermometer or perceived by touch.
Strengths and weaknesses	Strengths: standard measurement methods exist; closely linked to air temperature; linked to complex soil biogeochemical processes; Weaknesses: high resolution intrusive investigation is needed; site-specific investigation needed to establish connections with other environmental variables and processes.
Measurement procedure and tool	Trial pits or boreholes excavated and samples taken or thermometer and/or thermocouples inserted and measurement taken in situ
Scale of measurement	Micro / point measurement
Data source	
Required data	Temperature
Data input type	Value (units of temperature)
Data collection frequency	continuous
Level of expertise required	Low
Synergies with other indicators	Soil strength, soil type, aggregate stability, soil matric suction, plant evapotranspiration, soil water flux, soil carbon flux
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Yes
Additional information	
References	Gonzalez-Ollauri. A., Stokes, A., Mickovski, S.B., 2020. A novel framework to study the effect of tree architectural traits on stemflow yield and its consequences for soil-water dynamics. Journal of Hydrology, 582 (124448)

2.6. Total surface area of wetlands

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik, Laura Wendling, Ville Rinta-Hiiro, Arto Laikari, Malin zu-Castell Rüdenhausen

VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland

Total surface area of wetlands within a defined area	Climate resilience Water Management
Description and justification	Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as "… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide." Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.
Definition	Total surface area covered with wetlands within a defined area (ha)
Strengths and weaknesses	+ Straightforward assessment of the surface area occupied by wetlands - Requires access to local records or international/local spatial datasets
Measurement procedure and tool	The extent of the surface area covered by wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual surface area calculation.
Scale of measurement	City; municipality
Data source	
Required data	Land-use raster of the area of interest; local records; satellite imagery
Data input type	Quantitative
Data collection frequency	Annually

Level of expertise required	Moderate – requires knowledge of GIS software Low – when assessing visually using satellite images
Synergies with other indicators	Direct relation to *Water management* and *Biodiversity* challenge categories
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management
Additional information	
References	Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017. Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010. Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010. Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013. Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds.). *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

2.7. Surface area of restored and/or created wetlands

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik, Laura Wendling, Ville Rinta-Hiiro, Arto Laikari, Malin zu-Castell Rüdenhausen

VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland

Total surface area of constructed and/or restored wetlands within a defined area	Climate resilience Water Management
Description and justification	Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as "… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide." Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.
Definition	Surface area of constructed and/or restored wetlands within a defined area (ha)
Strengths and weaknesses	+ Straightforward assessment of the surface area occupied by constructed and/or restored wetlands - Requires access to local records or international/local spatial datasets
Measurement procedure and tool	The extent of the surface area covered by constructed and/or restored wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual area calculation.
Scale of measurement	City; municipality
Data source	
Required data	Land-use raster of the area of interest; local records; satellite imagery
Data input type	Quantitative
Data collection frequency	Annually

Level of expertise required	Moderate – requires knowledge of GIS software Low – when assessing visually using satellite images
Synergies with other indicators	Direct relation to *Water management* and *Biodiversity* challenge categories
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management
Additional information	
References	Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017. Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010. Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010. Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013. Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds*.). Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

2.8. Aboveground tree biomass

Project Name: PHUSICOS (Grant Agreement no. 776681)

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[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Aboveground Tree Biomass	Climate Resilience
Description and justification	Indicators of Aboveground *C* Cycle sub-criterion will assess the forest carbon storage and sequestration.
Definition	One of seven key agriculture, forestry, and land-use carbon pools. It includes trees defined as generally 5 cm or greater diameter at breast height (4.3 feet above ground). (Finance and Carbon Markets Lexicon prepared by the Forest Carbon, Markets and Communities (FCMC) Program and Tetra Tech ARD and reviewed by the United States Agency for International Development (USAID).
Strengths and weaknesses	
Measurement procedure and tool	Survey/GIS
Scale of measurement	ton/ha
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	

References	

2.9. Human Comfort

2.9.1 Universal Thermal Climate Index (UTCI)

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Universal Thermal Climate Index (UTCI)	**Climate Resilience Natural and Climate Hazards Health and Wellbeing**
Description and justification	UTCI index represents air temperature of the reference condition with the same physiological response as the actual condition. The UTCI provides a one-dimensional value that reflects the human physiological reaction to the multi-dimensional outdoor thermal environment (Bröde et al., 2012). It can predict both whole body thermal effects (hypothermia and hyperthermia; heat and cold discomfort), and local effects (facial, hands and feet cooling and frostbite). Applications of the UTCI include weather forecasts, bioclimatological assessments, bioclimatic mapping, urban design, engineering of outdoor spaces, outdoor recreation, epidemiology and climate impact research.
Definition	The UTCI is the air temperature that would produce under reference conditions the same thermal strain as the actual thermal environment. In other words, the UTCI is the reference environmental temperature causing strain.
Strengths and weaknesses	+ Mathematical expression of a person's thermal comfort in the outdoors + The output is expressed in easily understandable temperature units, e.g., °C - Less reliable in areas with low wind speed - Requires a great deal of data for evaluation

Measurement procedure and tool	The human body core temperature must be maintained within a narrow range around 37°C to ensure proper function of the body's inner organs and the brain, thus optimising human comfort, performance and health. In contrast, the temperature of the skin and extremities can vary widely, depending upon environmental conditions. This variation in the temperature of extremities is one of the mechanisms to equilibrate heat production and heat loss. The heat exchange between the human body and environment can be described in the form of the energy balance equation: $$M + W + C + K + E + Q + Res \pm S = 0$$ where M=heat produced by metabolism; W=heat generated by muscular activity; C=sensible heat flux (heat transferred by convection); K=heat transferred through conduction contact with solid bodies); E=latent heat flux (evaporative heat flux); Q=radiative heat transfer; Res=heat transfer through respiration; and, S=heat content of the body. The UTCI is derived from this mathematical model of thermoregulation with an integrated adaptive clothing model that also accounts for predicted votes of the dynamic thermal sensation based on core and skin temperature (Fiala et al., 1999, 2001, 2003; Havenith et al., 2011). The deviation of UTCI temperature from measured air temperature depends on measured values of air temperature (T_a) and mean radiant temperature (T_{mrt}), wind speed at a height of 10 m (v_a) and humidity expressed as water vapour pressure (p_a) or relative humidity (rH): $$UTCI(T_a, T_{mrt}, v_a, p_a) = Ta + Offset(T_a, T_{mrt}, v_a, p_a)$$ The model reference condition is walking at 4 km/h (135 W/m²) with T_{mrt}=T_a, v_a=0.5 m/s, rH=50% (T_a >29°C) and p_a=20 hPa (T_a >29°C) (Bröde et al., 2012). The UTCI dynamic model response can be determined using the online calculator available from http://utci.org. The relationship between UTCI temperature (expressed in °C) and physiological stress is shown in the table below (adapted from Błażejczyk et al., 2010). <table><tr><th>UTCI (°C) range</th><th>Stress category</th></tr><tr><td>Above +46</td><td>Extreme heat stress</td></tr></table>

	+38 to +46 / Very strong heat stress +32 to +38 / Strong heat stress +26 to +32 / Moderate heat stress +9 to +26 / No thermal stress 0 to +9 / Slight cold stress -13 to 0 / Moderate cold stress -27 to -13 / Strong cold stress -40 to -27 / Very strong cold stress Below -40 / Extreme cold stress
Scale of measurement	Plot – street – neighbourhood – district
Data source	
Required data	Air temperature, T_a (°C) Mean radiant temperature, T_{mrt} (degrees Kelvin) Water vapour pressure (hPa) Relative humidity (%) Wind speed at a height of 10 m (m/s)
Data input type	Quantitative
Data collection frequency	Frequency as desired. UTCI can be calculated frequently with measurement intervals determined by (automated) weather data acquisition.
Level of expertise required	Low-Moderate
Synergies with other indicators	Direct relation to *Heatwave incidence* and *Number of combined tropical nights and hot days* indicators Similar to *Physiological equivalent temperature (PET)*
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through direct participation in weather data collection
Additional information	
References	Błażejczyk, K., Broede, P., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kampmann, B. & Kunert, A. (2010). Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. Miscellanea Geographica, 14, 91-102. Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. & Havenith, G. (2012). International Journal of Biometeorology, 56, 481-494.

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2.9.2 *Thermal Comfort Score (TCS)*

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

[1] *Green4Cities GmbH/GREENPASS GmbH*

Thermal Comfort Score (TCS)	Climate Resilience
Description and justification	The TCS (Thermal Comfort Score) is one out of five Key Performance Scores of the GREENPASS® system. It's based on the calculation of the frequency distribution of areas with thermo-physiological stress according to the PET classification. It describes the thermal comfort of humans in one single number for a selected area. The indicator describes the mean thermal comfort, which is the crucial parameter for humans (not air temperature). It allows to understand and compare the thermal comfort of any given area with ease.
Definition	The TCS (Thermal Comfort Score) gives a weighted information of the mean PET on face level.
Strengths and weaknesses	+ worldwide standardized key performance score regarding human thermal comfort + easy for communication, understanding and decision-making

	+ useful for design optimization + applicable for detailed vulnerability group analysis (e.g., Child, Elderly) - needs simulation
Measurement procedure and tool	- modelling, simulation tools and GREENPASS® analysis and calculation - numerical value (TCS score 0-100)
Scale of measurement	Object and neighbourhood scale
Data source	
Required data	- PET (physiological equivalent temperature) at face level - project area incl. geoposition - NBS typology
Data input type	- mean radiant temperature (MRT), relative humidity (RH), wind speed (v), vapour pressure (VP) - 3d model with surface and vegetation types incl. characteristics - human type (age, gender, size, clothing and metabolism,…)
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy to understand – for planners and decision makers
Synergies with other indicators	Based on the input of indicators for 'Human comfort: Physiological equivalent temperature (PET)' and 'Universal Thermal Climate Index (UTCI)'.
Connection with SDGs	SDG 3 Good Health & Well-being, SDG 11 Sustainable Cities and Communities, SDG 13 Climate action
Opportunities for participatory data collection	-
Additional information	
References	Kraus, F. (2017): The GREENPASS® Methodology. Pan European Network – Government 23 publication. October 2017. Scharf, B.; Schnepf, D. (2017): H2020: Special Report: Greenpass – unleash the power of green. Scharf, B. (2018): Coole Städte planen – Mit der „Greenpass-Methode“. Neue Landschaft 01/2018. ISSN 0548-2836. Patzer Verlag. Berlin-Hannover. 2018. Scharf, B.; Kraus, F. (2019): Green Roofs and Greenpass. Buildings 2019, 9, 205. Elagiry, M.; Kraus, F.; Scharf B., Costa, A.; De 2019 Lotto, R. (2019): Nature4Cities: Nature-Based Solutions and Climate

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Kainz, A.; Hollosi, B.; Zuvela-Aloise, M.; Kraus, F.; Scharf, B.; Tötzer, T.; Züger, J.; Reinwald, F. (2019): Modelling the effects of implementing green infrastructure to support urban climate change adaptation and resilient urban planning. EMS Annual Meeting Abstracts Vol. 16, EMS2019-341, 2019.

Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS.

https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions.

Nature4Cities, D2.2 - Expert-modelling toolbox

Nature4Cities, D2.3 – NBS database completed with urban performance data

https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies

Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

2.9.3 Physiological equivalent temperature (PET)

Project Name: UNaLab (Grant Agreement no. 730052)

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Human Comfort: Physiological Equivalent Temperature (PET)	**Climate Resilience** **Natural and Climate Hazards**
Description and justification	Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006).
Definition	Biophysiological equivalent temperature expressed in °C or °K according to international standard calculation method
Strengths and weaknesses	+ Compared to PMV, PET has the advantage to use °C, which allows the results to be easily interpreted by urban or regional planners - Requires extensive amount of data for evaluation
Measurement procedure and tool	To calculate PET (Höppe, 1999): 1. Determine the thermal conditions of the body using the Munich energy-balance model for individuals, MEMI, (1) for a given set of climatic parameters. MEMI is based on the energy balance equation of the human body and is related to the Gagge two-node model (Gagge, Stolwijk, & Nishi, 1972). The MEMI equation is as follows: $$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0 \quad (1)$$ where, *M* is the metabolic rate (internal energy production by oxidation of food); *W* is the physical work output; *R* is the net radiation of the body; *C* is the convective heat flow; E_D is the latent heat flow to evaporate water into water vapour diffusing through the skin; E_{Re} is the sum of heat flows for heating and humidifying the inspired air; E_{Sw} is

	the heat flow due to evaporation of sweat; and, *S* is the storage heat flow for heating or cooling the body mass. As a first step, the mean surface temperature of the clothing (T_{cl}), the mean skin temperature (T_{sk}) and the core temperature (T_c) must be evaluated. These three parameters provide the basis for calculation of E_{Sw}. Two equations are necessary to describe the heat flows from the body core to the skin surface (F_{cs}) as shown in (2), and heat flows from the skin surface through the clothing layer to the clothing surface (F_{sc}) as shown in (3) (Höppe, 1999): $F_{CS} = v_b \times \rho_b \times c_b \times (T_c - T_{sk})$ (2) where, v_b is blood flow from body core to skin (L/s/m^2); ρ_b is blood density (kg/L); and, c_b is the specific heat (W/sK/kg). $F_{CS} = (1/I_{cl}) \times (T_{sk} - T_{cl})$ (3) where, I_{cl} is the heat resistance of the clothing (K/m^2/W). 2. Insert calculated values for mean skin temperature (T_{sk}) and core temperature (T_c) into the MEMI equation (1) and solve the three equations for air temperature, T_a (v☐= 0.1 m/s; water vapour pressure = 12 hPa; T_{mrt} = T_a). This temperature is equivalent to PET.
Scale of measurement	Building or plot scale
Data source	
Required data	Energy balance of the human body, heat flows though the body and clothing
Data input type	Quantitative
Data collection frequency	Annually, and before and after NBS implementation
Level of expertise required	High – requires ability to follow the calculation procedure and units, and to critically evaluate the results
Synergies with other indicators	Directly related to *Incorporation of environmental design in buildings* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Gagge, A., Stolwijk, J.A., & Nishi, Y. (1971). An effective temperature scale based on a simple model of human physiological regulatory response. ASHRAE Transactions, 77(1), 247-257.

	Höppe, P. (1999). The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. International Journal of Biometeorology, 2466, 71-75.

2.9.4 Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD)

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Mean or peak daytime temperature – Predicted Mean Vote-Predicted Percentage Dissatisfied	**Climate Resilience** **Natural and Climate Hazards**
Description and justification	Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006)
Definition	Mean or peak daytime local temperature by PMV-PPD calculation (unitless value)
Strengths and weaknesses	+ Mathematical expression of a person's thermal comfort under indoor steady-state conditions - Subjective evaluation of thermal sensations - The output is **not** expressed in any temperature units, e.g., °C.
Measurement procedure and tool	The model aims to estimate the mean thermal sensation of a group of individuals and their respective percentage of dissatisfaction with the thermal environment, expressed in terms of Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD). The practical

application of the PMV equation and associated variables has been described by Ekici (2016). PMV provides a score that relates to the Thermal Sensation Scale (Fanger, 1970). If the score is zero, the occupant satisfaction regarding the environment is at the maximum level (Ekici, 2016).

Thermal Sensation Scale (Fanger, 1970):

Scale	Description	How it feels
3	Hot	Intolerably warm
2	Warm	Too warm
1	Slightly warm	Tolerably uncomfortable, warm
0	Neutral	Comfortable
-1	Slightly cool	Tolerably uncomfortable, cool
-2	Cool	Too cool
-3	Cold	Intolerably cool

Scale of measurement	Building scale
Data source	
Required data	Metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity (Rupp, Vásquez, & Lamberts, 2015).
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	High – requires the ability to apply the mathematical model and evaluate the results
Synergies with other indicators	Directly related to *Incorporation of environmental design in buildings* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through direct participation in the indicator assessment
Additional information	
References	

Ekici, C. (2016). Measurement uncertainty budget of the PMV thermal comfort equation. International Journal of Thermophysics, 37, 48

Ekici, C. (2013). Review of Thermal Comfort and Method of Using Fanger's PMV Equation. Proceedings of the 5th International Symposium on Measurement, Analysis and Modelling of

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2.10. Urban Heat Island Effect

2.10.1. Urban Heat Island (UHI) incidence

Project Name: UNaLab (Grant Agreement no. 730052)

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Urban Heat Island (UHI) effect	**Climate Resilience** **Natural and Climate Hazards**
Description and justification	The UHI effect is caused by the absorption of sunlight by (stony) materials, reduced evaporation and the emission of heat caused by human activities. The UHI effect is greatest after sunset and reported to reach up to 9°C in some cities, e.g., Rotterdam (Van Hove et al., 2015). Because of the UHI effect, citizens living in urban areas experience more heat stress than those living in the countryside.
Definition	Urban Heat Island (UHI) effect denotes an urban area that is significantly warmer than its rural or undeveloped surrounding areas. Expressed and evaluated as temperature (°C).
Strengths and weaknesses	+ Fairly easy and straightforward assessment of temperature differences - Requires a rather large amount of temperature measurement stations to holistically identify the effect within the urban area - May require modelling expertise

Measurement procedure and tool	1. Identify or install one or more meteorological (temperature) measurement stations within the built environment, and one measurement station outside the city that functions as a reference station. Alternatively, models can be used. 2. Compare the hourly average air temperature measurements of the urban measurement station(s) with the station outside the city (the reference station). 3. Look for the largest temperature difference (hourly average) between urban and countryside areas during the summer months. This temperature difference is an absolute measure of the UHI effect.
Scale of measurement	City to regional scale
Data source	
Required data	Hourly temperature measurements
Data input type	Quantitative
Data collection frequency	Annually; at minimum before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Assessed from *Mean or peak daytime temperature* indicator and connected with *Heatwave Risk* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through geographically referenced direct temperature measurements if these are not automated.
Additional information	
References	Van Hove, L.W.A., Jacobs, C.M.J., Heusinkveld, B.G., Elbers, J.A., van Driel, B.L., & Holtslag, A.A.M. (2015). Temporal and spatial variability of urban heat island and thermal comfort within the Rotterdam agglomeration. Building and Environment, 83, 91-103. United States Environmental Protection Agency. (2006). Excessive Heat Events Guidebook. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/eheguide_final.pdf

2.10.2. Number of combined tropical nights and hot days

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Heatwave incidence expressed as the number of combined tropical nights (>20°C) and hot days (>35°C) per annum	**Climate Resilience** **Natural and Climate Hazards**
Description and justification	Heatwave is a period of prolonged abnormally high surface temperatures relative to those normally expected. Heatwaves can be characterized by low humidity, which may exacerbate drought, or high humidity, which may exacerbate the health effects of heat-related stress such as heat exhaustion, dehydration and heatstroke. Heatwaves in Europe are associated with significant morbidity and mortality. Furthermore, climate change is expected to increase average summer temperatures and the frequency and intensity of hot days (Russo et al., 2014). EEA models indicate an increase in combined tropical nights (minimum temperature >20°C) and hot days (maximum temperature >35°C) under present and future climate conditions[4]. In cities and urban areas, the UHI tends to exacerbate heatwave episodes.
Definition	Number of combined tropical nights (minimum temperature >20°C) and hot days (maximum temperature >35°C)
Strengths and weaknesses	+ Easy and straightforward assessment - Requires substantial amount of external data for modelling
Measurement procedure and tool	This indicator is assessed through continuous monitoring of temperature, and/or estimated by applying meteorological models such as the Weather Research and Forecasting WRF model (NCAR & UCAR, n.d.; NOAA, n.d.) "Tropical nights" are defined as days when the daily minimum temperature is >20°C. The number of tropical nights is equal to the number of days annually when the daily minimum temperature is >20°C (ETCCDI;

[4] https://www.eea.europa.eu/data-and-maps/figures/increase-in-the-number-of

	http://etccdi.pacificclimate.org/list_27_indices.shtml). For the purposes of this indicator, "hot days" are defined as days when the daily maximum temperature is >35°C.
Scale of measurement	Neighbourhood to regional scale
Data source	
Required data	For modelling: initial and boundary conditions, topography, land use and urban parameters (building height, width, number of road lanes) (Emmons et al., 2010; Pineda, Jorba, Jorge & Baldasano, 2004). These data can be obtained through national statistics, municipal departments, Corine Land Cover, and a mapping application such as OpenStreetMap. For direct measurements: hourly mean values of ambient air temperature
Data input type	Quantitative
Data collection frequency	Annually, and before and after NBS implementation
Level of expertise required	Low – for continuous temperature monitoring High – for applying meteorological models
Synergies with other indicators	Assessed from *Mean or peak daytime temperature* indicator and connected with *Urban Heat Island* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through sample collection, e.g., air temperature measurements if these are not automated
Additional information	
References	Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). *Geoscientific Model Development*, *3*, 43-67. National Center for Atmospheric Research (NCAR) & University Corporation for Atmospheric Research (UCAR). (n.d.). Weather Research and Forecasting (WRF) Model Users' Page. Retrieved from http://www2.mmm.ucar.edu/wrf/users/ National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/ Pineda, N., Jorba, O., Jorge, J. & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological

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2.10.3 Thermal Storage Score

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

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Thermal Storage Score	**Climate Resilience**
Description and justification	The TSS (Thermal Storage Score) is one out of five Key Performance Scores of the GREENPASS® system. It expresses the stored energy within materials in an urban area. A high value indicates elevated probability of overheating and urban heat island risk. The indicator is relevant for the urban heat island mitigation and influenced by the application of NBS.
Definition	The TSS (Thermal Storage Score) describes the stored energy in urban materials on a standardized heat day.
Strengths and weaknesses	+ worldwide standardized key performance score regarding thermal storage capacity and energy + easy for communication and decision-making + useful for design optimization - needs simulation
Measurement procedure and tool	- modelling, simulation tools and GREENPASS® analysis and calculation - numerical value in J
Scale of measurement	Object and neighbourhood scale
Data source	
Required data	- air temperature (Ta) - incoming shortwave radiation (direct & diffuse) - physical parameters of surfaces and materials

	- project area incl. geo-position - NBS typology
Data input type	- climate framework conditions (solar irradiance, windspeed, relative humidity, air temperature, …) - 3d model with surface and vegetation types incl. characteristics
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy understand – for planners and decision makers
Synergies with other indicators	-
Connection with SDGs	SDG 11 Sustainable Cities and Communities, SDG 13 Climate action
Opportunities for participatory data collection	-
Additional information	
References	Kraus, F. (2017): The GREENPASS® Methodology. Pan European Network – Government 23 publication. October 2017. Scharf, B.; Schnepf, D. (2017): H2020: Special Report: Greenpass – unleash the power of green. Scharf, B. (2018): Coole Städte planen – Mit der „Greenpass-Methode“. Neue Landschaft 01/2018. ISSN 0548-2836. Patzer Verlag. Berlin-Hannover. 2018. Scharf, B.; Kraus, F. (2019): Green Roofs and Greenpass. Buildings 2019, 9, 205. Elagiry, M.; Kraus, F.; Scharf B., Costa, A.; De 2019 Lotto, R. (2019): Nature4Cities: Nature-Based Solutions and Climate Resilient Urban Planning and Modelling with GREENPASS® - A Case Study in Segrate/Milano/IT. 16th IBPSA - International Building Performance Simulation Association Conference. Kraus, F.; Scharf, B. (2020): IT-gesteuerte Natur in der dichten Stadt. Neue Landschaft 01/2020. Kraus, F.; Scharf, B. (2019): Management of urban climate adaptation with NBS and GREENPASS®. Geophysical Research Abstracts. Vol. 21, EGU2019-16221-1, 2019 EGU General Assembly 2019. Kraus, F.; Scharf, B. (2019): Climate-resilient urban planning and architecture with GREENPASS illustrated by the case study 'FLAIR in the City' in Vienna. OP Conf. Ser.: Earth Environ. Sci. 323 012087. Kainz, A.; Hollosi, B.; Zuvela-Aloise, M.; Kraus, F.; Scharf, B.; Tötzer, T.; Züger, J.; Reinwald, F. (2019): Modelling the effects of implementing green infrastructure to support urban

	climate change adaptation and resilient urban planning. EMS Annual Meeting Abstracts Vol. 16, EMS2019-341, 2019. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

2.10.4 Thermal Load Score

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

[1] *Green4Cities GmbH/GREENPASS GmbH*

Thermal Load Score	**Climate Resilience**
Description and justification	The TLS (Thermal Load Score) is one out of five Key Performance Scores of the GREENPASS® system. It enables a statement regarding the contribution of the area to the urban heat island and the thermal load emitted to adjacent and surrounding areas. It's typically assessed for a project area on a heat day (30°C). The cooling capability of NBS has positive influence on the thermal load score and is important for climate adaptation. It's a crucial indicator that describes the impact of retrofit and new urban developments on the urban climate.
Definition	The TLS (Thermal Load Score) describes the mean difference (Delta K/C°) between the hourly average In- and Out-flow Air temperature of an area, from the ground to the roof level (of highest building in area) over the day (typical heat day).
Strengths and weaknesses	+ worldwide standardized key performance score regarding thermal load, air temperature and cooling capability of NBS + easy for communication, understanding and decision-making

	+ useful for design optimization + as a base for regulative definitions (legal prohibition of climate deterioration) - needs simulation or intensive on-site monitoring
Measurement procedure and tool	- modelling, simulation tools and GREENPASS® analysis and calculation - numerical value in °C
Scale of measurement	Object and neighbourhood scale
Data source	
Required data	- project area incl. geoposition - NBS typology - hourly air temperature (Ta) of instreaming air body over a day - hourly air temperature (Ta) of outstreaming air body over a day
Data input type	- air temperature (Ta) - 3d model with surface and vegetation types incl. characteristics (e.g., albedo, emissivity,..)
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy to calculate and understand – for planners and decision makers
Synergies with other indicators	Link to 'Mean daytime local temperature', 'Air cooling'
Connection with SDGs	SDG 13 Climate action
Opportunities for participatory data collection	-
Additional information	
References	Kraus, F. (2017): The GREENPASS® Methodology. Pan European Network – Government 23 publication. October 2017. Scharf, B.; Schnepf, D. (2017): H2020: Special Report: Greenpass – unleash the power of green. Scharf, B. (2018): Coole Städte planen – Mit der „Greenpass-Methode". Neue Landschaft 01/2018. ISSN 0548-2836. Patzer Verlag. Berlin-Hannover. 2018. Scharf, B.; Kraus, F. (2019): Green Roofs and Greenpass. Buildings 2019, 9, 205. Elagiry, M.; Kraus, F.; Scharf B., Costa, A.; De 2019 Lotto, R. (2019): Nature4Cities: Nature-Based Solutions and Climate Resilient Urban Planning and Modelling with GREENPASS® - A Case Study in Segrate/Milano/IT. 16th IBPSA -

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Kraus, F.; Scharf, B. (2019): Climate-resilient urban planning and architecture with GREENPASS illustrated by the case study 'FLAIR in the City' in Vienna. OP Conf. Ser.: Earth Environ. Sci. 323 012087.
Kainz, A.; Hollosi, B.; Zuvela-Aloise, M.; Kraus, F.; Scharf, B.; Tötzer, T.; Züger, J.; Reinwald, F. (2019): Modelling the effects of implementing green infrastructure to support urban climate change adaptation and resilient urban planning. EMS Annual Meeting Abstracts Vol. 16, EMS2019-341, 2019.
Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS.
https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions.
Nature4Cities, D2.2 - Expert-modelling toolbox
Nature4Cities, D2.3 – NBS database completed with urban performance data
https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies
Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

2.11 Estimated reduction in peak summer temperature

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Paul Nolan[1], Clare Olver[1], Raúl Sánchez[2], Jose Fermoso[2], Silvia Gómez, María González[2], Jose María Sanz[2], Esther San José[2]

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[2] CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain

Recommended citation: The Mersey Forest, Natural Economy Northwest, CABE, Natural England, Yorkshire Forward, The Northern Way, Design for London, Defra, Tees Valley Unlimited, Pleasington Consulting Ltd, and Genecon LLP (2010). GI-Val: the green infrastructure valuation toolkit. Version 1.6 (updated in 2018). https://bit.ly/givaluationtoolkit

Reduced peak summer temperature	Climate Resilience
Description and justification	GI-Val is The Mersey Forest's green infrastructure valuation toolkit. The current prototype is free and open source, and can be downloaded under a Creative Commons License from: https://www.merseyforest.org.uk/services/gi-val/. It takes the form of a spreadsheet calculator and a user manual. Tool 1.4 estimates the reduction in peak temperature, a key factor in improving the liveability of urban areas during summer months. An independent assessment of GI Val by the Ecosystems Knowledge Network is available from this link, along with links to other tools: https://ecosystemsknowledge.net/green-infrastructure-valuation-toolkit-gi-val
Definition	Estimated decrease in peak summer temperature experienced as a result of NBS intervention.
Strengths and weaknesses	- Tool developed using English data. - The toolkit remains a prototype and this means there are some green infrastructure benefits for which it cannot calculate a direct financial value. While there is a rich body of evidence that illustrates and demonstrates the different types of benefits deriving from quality green infrastructure, robust valuation techniques do not yet exist for all benefits. Therefore some valuations come with detailed caveats as they are based on limited evidence at this stage. - The toolkit's calculation is designed to be useful for initial, indicative project appraisal, providing a range of figures indicating the potential impact of a green infrastructure intervention or the value of an existing green infrastructure asset. The toolkit does not assess the quality of the design or detailed management requirements of green infrastructure. It does not replace a full cost benefit

	analysis, but it provides a basic valuation at a much lower cost. - Valuations such those made with a toolkit or cost benefit analysis also need to be seen as part of a much bigger picture. The valuation should not replace community engagement and local dialogue about what is valued about a place. Calculating economic value of green assets will always be a controversial technique and financial value should only be seen as one factor in decision-making. - The reported GVA values include transfers from one organisation to another, which means that although GVA increases for the beneficiaries, it may not increase for the study area as a whole.
Measurement procedure and tool	The toolkit provides a set of calculator tools to help assess an existing green asset or proposed green investment. They are organised under eleven key benefits of green infrastructure: Input data for evaluation of reduction in peak summer temperature include the baseline level of green cover in the area under investigation, and the increase in green cover as a result of NBS implementation. The toolkit uses standard valuation techniques to assess the potential benefits provided by green infrastructure within a defined project area. These benefits are assessed in terms of the functions that the green infrastructure may perform, support or encourage, depending upon the type of project.
Scale of measurement	Street to district
Data source	
Required data	General information about green infrastructure
Data input type	Numeric data.
Data collection frequency	Individual assessments
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	Developing the toolkit's next iteration will require wide and sustained collaboration. To facilitate this process, interested parties are invited to pass the toolkit to others who might be able to incorporate it into their work and to

	provide feedback on their experience in using the toolkit, good and bad! Sources of improved evidence Suggestions for improving the tools Ideas for new tools The consortium who led the development of this toolkit has handed over the responsibilities for co-ordinating future work to the Green Infrastructure Value Network (GIVaN). Further information on the network can be found at: www.bit.ly/givaluationtoolkit
Additional information	
References	URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl http://www.merseyforest.org.uk/services/gi-val/ Nowak, McPherson and Rowntree, Chicago's urban forest ecosystem: results of the Chicago urban forest climate project, USDA,1994 Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099. SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf

2.12 Maximum surface cooling

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Tom Butlin[1], Paul Nolan[1], Clare Olver[1], Raúl Sánchez[2], Jose Fermoso[2], Silvia Gómez, María González[2], Jose María Sanz[2], Esther San José[2]

[1] *The Mersey Forest Offices, Risley Moss, Ordnance Avenue, Birchwood, Warrington, WA3 6QX*
[2] *CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain*

Projected maximum surface temperature reduction	**Climate Resilience**
Description and justification	The surface temperature tool can be used to model the maximum surface temperature expected in a neighbourhood, taking into account the evaporative cooling effect of the vegetation. Since the implementation of

	nature-based solutions will usually result in an increase in vegetation cover, it should be possible to observe a decrease in the modelled maximum surface temperature under each climate change scenario (including the baseline).
Definition	The STAR Tools are surface temperature and runoff tools for assessing the potential of green infrastructure in adapting urban areas to climate change. They are freely available at http://maps.merseyforest.org.uk/grabs/.
Strengths and weaknesses	This KPI requires and is based in specific software; however, this software is freely available online.
Measurement procedure and tool	The software includes scenarios for different parameters (temperature, precipitation and land cover, etc.). However, these scenarios were developed for a concrete area (North West England). Therefore, information must be provided to build the scenarios in other cities outside this area.
Scale of measurement	Neighbourhood to metropolitan area
Data source	
Required data	Data need to be provided in the case of locations outside North West England (temperature scenarios, land cover scenarios, precipitation scenarios, etc.).
Data input type	
Data collection frequency	Not applicable, it is a model.
Level of expertise required	Technician
Synergies with other indicators	This KPI is directly related to KPI which measures temperature values, such as *Decrease in mean or peak daytime local temperatures* and *Temperature reduction in urban areas*. In addition its results can be related with the changes in energy consumption, such as *Saving in energy use due to improved* GI. KPIs related with people's well-being can be affected by these measures, as the temperature reduction means a better thermal comfort: *Perceptions of citizens on urban nature, increase in walking and cycling in and around areas of interventions*.
Connection with SDGs	This KPI is directly related with SDG 13 and indirectly is related with SDG 15. KPIs related with people's well being can be affected by these measures, as the temperature reduction means a better thermal comfort, so this KPI is related with the SDG 3.
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	

References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl The Mersey Forest & The University of Manchester (2011). STAR tools: surface temperature and runoff tools for assessing the potential of green infrastructure in adapting urban areas to climate change. Part of the EU Interreg IVC GRaBS project. www.ginw.co.uk/climatechange.

2.13 Mean or peak daytime temperature

2.13.1 Mean or peak daytime temperature - Direct temperature measurement

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Mean or peak daytime temperature – Direct measurements	**Climate Resilience**
Description and justification	Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction

	in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment. A simulation of the surrounding buildings showed the potential for a 10% decrease in the cooling load due to the presence of the green area in the vicinity (Yu & Hien, 2006).
Definition	Mean or peak daytime local temperature by direct measurement (°C)
Strengths and weaknesses	+ Straightforward assessment of ambient air temperature + Reliable in the long run - Requires a rather large amount of monitoring stations to be installed to monitor various NBS intervention areas
Measurement procedure and tool	Ambient air temperature can be assessed through continuous monitoring of temperature, near the NBS intervention area, and calculation of mean and peak daytime temperature before and after NBS implementation.
Scale of measurement	Plot to district scale
Data source	
Required data	Automated continuous monitoring of ambient air temperature
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	A prerequisite for *Heatwave Risk* and *Urban Heat Island* indicators, and a requirement for *Depth to groundwater* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through direct temperature measurements if these are not automated
Additional information	
References	Cheng, C.Y., Cheung, K.K.S., & Chu, L.M. (2010). Thermal performance of a vegetated cladding system on facade walls. Building and Environment, 45(8), 1779-1787. Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment

	of green urban infrastructure. Journal of Environmental Management, 146, 107-115. Yu, C., & Hien, W.N. (2006). Thermal benefits of city parks. Energy and Buildings, 38, 105-120.

2.13.2 Mean or peak daytime temperature - Temperature modelling

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Mean or peak daytime temperature – Temperature modelling	Climate Resilience
Description and justification	Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment. A simulation of the surrounding buildings showed the potential for a 10% decrease in the cooling load due to the presence of the green area in the vicinity (Yu & Hien, 2006).
Definition	Mean or peak daytime local temperature by meteorological modelling (°C)
Strengths and weaknesses	+ Allows the calculation with an hourly resolution at the grid, neighbourhood or city scale neighbourhood - Requires high level of expertise and external data
Measurement procedure and tool	Difference in temperature can be assessed through application of a meteorological model such as the Weather Research and Forecasting model (WRF) (NCAR & UCAR, n.d.; NOAA, n.d.)

Scale of measurement	District to regional scale
Required data	Initial and boundary conditions, topography, land use and urban parameters (building height, width, number of road lanes) (Emmons et al., 2010; Pineda, Jorba, Jorge & Baldasano, 2004). These data can be obtained through national statistics, municipal departments, Corine Land Cover, and a mapping application such as OpenStreetMap.
Data input type	Quantitative
Data collection frequency	Annually; at minimum before and after NBS implementation
Level of expertise required	High – requires ability to use forecasting models and assess the accuracy of results
Synergies with other indicators	Contributes to *Drought vulnerability* indicator group and to *Climate resilience strategy development* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). *Geoscientific Model Development*, *3*, 43-67. National Center for Atmospheric Research (NCAR) & University Corporation for Atmospheric Research (UCAR). (n.d.). Weather Research and Forecasting (WRF) Model Users' Page. Retrieved from http://www2.mmm.ucar.edu/wrf/users/ National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/ Pineda, N., Jorba, O., Jorge, J. & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model. *International Journal of Remote Sensing*, *25*(1), 129–143. Weather Research and Forecasting Model (WRF): https://www.mmm.ucar.edu/weather-research-and-forecasting-model

2.14 Daily Temperature Range (DTR)

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Daily temperature range (DTR) – Direct measurements	Climate Resilience
Description and justification	Nature-based solutions can support climate change adaptation by reducing local ambient air temperature. They can also provide insulation from cold and/or shelter from wind. By moderating the urban microclimate, green infrastructure can support reduction in energy use and improved thermal comfort (Demuzere et al., 2014).
Definition	The range between minimum and maximum mean monthly local temperatures determined by direct measurement (°C)
Strengths and weaknesses	+ Straightforward assessment of ambient air temperature + Reliable in the long run - Requires a rather large amount of monitoring stations to be installed to monitor various NBS intervention areas
Measurement procedure and tool	Ambient air temperature can be assessed through continuous monitoring of temperature, near the NBS intervention area, and calculation of the average minimum and maximum monthly temperature before and after NBS implementation. The daily temperature range (DTR) is calculated as $DTR_j = \frac{\sum_{i=1}^{I}(TX_{ij} - TN_{ij})}{I}$ where TX_{ij}=daily maximum temperature on day *i* in period *j* TN_{ij}= daily minimum temperature on day *i* in period *j* *I*=the number of days in period j
Scale of measurement	Plot to district scale
Data source	

Required data	Automated continuous monitoring of ambient air temperature
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Evaluated from TX_x, *Monthly mean value of daily maximum temperature*, TN_n, *Monthly mean value of daily minimum temperature*; related to *Warm spell duration index (WSDI)* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through direct temperature measurements if these are not automated
Additional information	
References	http://etccdi.pacificclimate.org/list_27_indices.shtml Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. Journal of Environmental Management, 146, 107-115.

2.15 Cooling of ambient air

2.15.1 Air cooling

Project Name: Naturvation (Grant Agreement no. 730243)

Author/s and affiliations: Peter Olsson[1]

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Air cooling (°C)	**Climate Resilience**
Description and justification	The air cooling indicator measures the lowering of air temperature by a nature-based solutions (NBS). Green and blue infrastructure can cool the air by providing shade and by evapotranspiration, the process by which water is transferred from the land to the atmosphere by evaporating from the soil, water surfaces or plants (e.g., 1). Cooling the air can be a climate action for adaptation to

	a warmer climate, as well as mitigate the negative effects of the urban heat island effect. In a warmer climate, air-cooling can become important for health and well-being, especially in an urban environment that is generally warmer than its surrounding areas (2). Some urban environments may need regenerated nature areas to adapt to a warmer climate or urban heat islands, thus air-cooling may be an important aspect of urban regeneration & development.
Definition	The air cooling indicator measures the lowering of air temperature by a nature-based solutions (NBS).
Strengths and weaknesses	
Measurement procedure and tool	Air temperature can be measured directly in the air but also predicted by models for air temperature close to NBS in cities. Air cooling by NBS has two measurable effects: (A) lowering the air temperature and (B) the decrease of temperature cooling by distance from the NBS. Air cooling effects thus measure or predict temperatures under, next to, or at a distance to a nature-based solution. Generally, efficient cooling distances are within 100 to 150 meters from tree patches (3), while large parks can cool up to 440 meters (4). Blue areas cool air in longer distances, between 350 and 1,500 meters (5). Refined scoring methodology is available (6) and assess the effectiveness of cooling capabilities of different NBS as a function of climate zone, size of area and tree coverage. Research on what types of NBS and their mitigation potential for cooling urban environments has been reviewed (7).
Scale of measurement	The temperature reductions were normalized evenly across scores from 1-5. Score 1 corresponds to <1°C cooling; score 2 to 1-1.7°C cooling; score 3 to 1.7-2.3°C cooling; score 4 to 2.3-3°C cooling and score 5 to >3°C cooling. When data for benefits of an NBS towards an urban challenge was not present in the literature it was denoted as not applicable (NA).
Data source	
Required data	
Data input type	Temperatures
Data collection frequency	
Level of expertise required	

Synergies with other indicators	
Connection with SDGs	*SDGs:* 3, 9 &13
Opportunities for participatory data collection	
Additional information	
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2.15.2 Air temperature reduction

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Air temperature reduction (Applied and EO/RS combined)	**Climate Resilience**
Description and justification	NBS can contribute to reducing air temperature, thus reducing energy demand for cooling and reducing associated carbon emissions. Increasing NBS can reduce local temperatures through evapotranspiration and shading, ameliorating urban heat

	islands and heat stress. Metrics are based on changes in air temperature and can be employed on a range of scales. Local scale monitoring metrics would be more appropriate for small-scale projects; large-scale NBS projects, or city-wide replication of small-scale projects, might have a detectable impact at a city-wide scale (urban boundary layer). Basic measurements are typically: air temperature (Ta), apparent temperature, land surface temperature (LST), mean radiant temperature (Tmrt), Physiological Equivalent Temperature (PET) and are usually quantified in relation to specific thresholds e.g., decrease in mean/peak daytime local temperatures, % change in annual/monthly temperatures (citywide); heat stress, heatwave risk and urban heat island. Data on the reduction of air temperature by nature-based solutions collected in these ways can be used to: • Quantify the benefits of NBS in terms of providing thermal comfort zones for residents; • Quantify reduction in temperature extremes/heatwaves on a city-wide scale; • Contribute towards health and well-being evaluation linked to temperature extremes.
Definition	Measurement of the cooling effect of NBS by evapotranspiration and/or shading using applied methods or using high-resolution satellite images and thermal infrared (TIR) data to understand the thermal effect of urban fabric properties and the mechanism of urban heat island (UHI) formation.
Strengths and weaknesses	**Applied methods:** Robustness of evidence depends upon the level of precision of the equipment, the spatial design of the monitoring and the duration of temperature recording. Generally direct measurement can provide greater confidence than microclimate simulations, particularly for small-scale interventions. **EO/RS methods:** A great number of research projects confirm the usefulness of deriving air temperature from satellites, but the number of weather stations that regularly detect and collect air temperature records is limited and their distribution scattered, with a stronger concentration in developed countries, mainly USA and EU. The resulting records are often patchy in both space and time. An innovative method to enhance the quality of global air temperature information by analysing the land surface temperature records collected by weather stations and detected by satellites was recently developed. Based on this, a statistical model was developed that can improve monthly predictions of global air temperature. Satellites can access remote areas of the planet with few weather stations or poor-quality information.

Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. ***Applied/participatory methods*:** Temperature parameters are usually quantified in relation to specific thresholds: • Decrease in mean/peak daytime local temperatures (in relation to mean radiant temperatures); • Percentage change in annual/monthly temperatures (citywide); • Heat stress (in Europe - exposure of people to temperatures >30°C); • Heatwave risk (number of combined tropical nights (>20°C) and hot days (>35°C)); • Urban heat island (temperature difference between urban areas and surrounding rural landscapes). For local measurements of air temperature, a variety of thermometers/thermocouples can be used, usually in combination with dataloggers. When using the most basic types of thermometers and thermocouples, it is important that they are kept shaded. If the equipment is exposed to direct solar radiation, it can heat them and the reading thus measures heating due to solar radiation rather than the true air temperature. To avoid this, thermometers/thermocouples need to be combined with some kind of insulation from solar radiation to ensure they are measuring air temperature (Yu and Hien 2006). An example of a very basic solution to this is the combination of datalogging thermocouples with polystyrene insulation to measure the air temperature above green roofs (Connop et al. 2013). By using networks of such insulated thermocouples, it is possible to measure temperature at increasing distances away from an NbS such as a living wall or park (Doick et al. 2014; Eisenberg et al 2015; Ottelé et al. 2017; Morakinyo et al. 2019). For broader area measurements, standard practice for local temperature measurement involves the use of weather stations to monitor climatic parameters such as air temperature, windspeed, humidity. Such an approach is useful as it provides data on a wider range of temperature parameters in addition to air temperature, it also provides other climate parameters that can have synergies with other NbS indicators. Weather stations can range in size from off-the-shelf systems that have versatility in terms of installation location, to more accurate location-based monitoring, typically using a platinum resistance thermometer (*PRT*) inside a station fixed to the ground. The thermometer is exposed to air flow by natural ventilation through side louvers. This equipment includes a datalogger that takes readings at pre-programmed intervals to capture temperature changes for

calculation of daily, monthly or annual temperature fluctuations (MET Office 2019).

Ambient air temperature quantification is commonly calculated using combined ventilated temperature and relative humidity sensors (Jänicke et al. 2014). Apparent air temperature, or the temperature equivalent perceived by people, is measured by Dry- and Wet-bulb temperatures. These are common parameters measured to assess the apparent temperature regulation associated with NbS implementation (Shashua-Bar et al. 2009; Fung and Jim 2017). Typically, values recorded are referenced to climatic data from a nearby meteorological station (Shashua-Bar et al. 2009).

Frequency or duration of exposure to heat stress is typically measured using Wet Bulb Globe Temperature (WBGT) heat stress meters. It is a measure of the heat stress in direct sunlight, combining temperature, humidity, wind speed, sun angle and cloud cover (solar radiation). These meters can be used to measure the effects of NbS on evapotranspiration/cooling in relation to how somebody would feel at different distances from an NbS.

Emerging approaches to thermal temperature analysis also include the use of thermal imaging cameras to measure air temperatures. Thermal cameras have previously been used to capture the impact of NbS interventions (Connop and Clough 2016; Ottelé et al. 2017), however this method generally captures a measure of surface temperature rather than air temperature. Surface temperature is assumed to correlate with air temperature as it is strongly affected by the mean radiant temperature (Matzarakis et al. 1999*), as such it should give a good indication of local human comfort. However, the magnitude of any cooling effect in relation to distance from the NbS will be correlated with the scale of the NbS in comparison to surrounding hard surfaces. This correlation makes assumptions on the impact of small-scale NbS on air temperatures unreliable for distances greater than a few centimetres from the NbS. However, methods for capturing air temperatures using thermal cameras are now being developed using white test sheets and foil (to estimate background radiation), and might have potential as a small-scale rapid method to measure local air temperatures (Chui et al. 2018).

Many studies investigating the performance of NbS combine the use of dataloggers with dynamic simulation tools for microclimate analysis (Toparlar et al. 2017). Such simulation enables potential cooling benefits of NbS interventions to be calculated at a planning stage (Zölch et al. 2019), and for NbS to be appraised compared to predicted values following installation (Chow et al. 2011). The software ENVI-met (Bruse and Fleer 1998) has emerged as the industry standard simulation technique with good results when compared to physical monitoring (Tsoka et al. 2018). However, there are limitations to the ENVI-met simulation results (Tsoka et al. 2018), with some evidence to suggest that its reliability decreases with decreasing NbS scale of NbS intervention (López-Cabeza et al. 2018).

For evaluation of larger-scale NbS interventions or city-wide impacts, surface temperature modelling approaches have generally been adopted (Rizwan et al. 2008; Hall et al. 2012; Li et al. 2018). Drones are also increasingly used to measure surface temperatures over large scales (Honjo et al 2017). Networks of automatic weather stations have also been utilised to quantify urban heat islands over entire city scales (Yang et al. 2013).

***Remote sensing/Earth Observation methods*:**
In order to assess exposure to heat stress, different methodological approaches can be applied. Along with the analysis of a single parameter, such as air temperature (Ta), surface temperature, or mean radiant temperature (Tmrt), either by taking regular measurements, the use of **remote-sensing or modelling-based approaches**, which are spatially explicit, are recognised in several research papers (e.g., Alavipanah et al., 2015; Chen et al., 2014; Lindberg & Grimmond, 2011).

The combined usage of high-resolution satellite images and thermal infrared (TIR) data helps understanding the thermal effect of urban fabric properties and the mechanism of urban heat island (UHI) formation. In particular, it is suggested to undertake typical urban functional zoning, e.g., of downtown, for quantifying the relationship between fine-scale urban fabric properties and their thermal effect. As a result, a particular number of land surfaces and a number of aggregated land parcels extracted from, for instance, a QuickBird image can be used to characterize urban fabric properties. The thermal effect can be deduced from land surface temperature (LST), intra-UHI intensity, blackbody flux density (BBFD) and blackbody flux (BBF). The net BBF can be retrieved from the Landsat 8. The products should be resampled to fine resolution using a geospatial sharpening approach and further validated. The final results can show for instance that:

(i) On the level of urban functional zones, there is a significant thermal differential among land surfaces. Water, well-vegetated land, high-rises with light color and high-rises with glass curtain walls exhibited relatively low LST, UHI intensity and BBFD. In contrast, mobile homes with light steel roofs, low buildings with bituminous roofs, asphalt roads and composite material pavements showed inverse trends for LST, UHI intensity, and BBFD;

(ii) It can be found that parcel-based per ha net BBF, which offsets the “size-effect” among parcels, is more reasonable and comparable when quantifying excess surface flux emitted by the parcels;

(iii) When examining the relationship between parcel-level land surfaces and per ha BBF, a partial least squares (PLS) regression model can show that buildings and asphalt roads are major contributors to parcel-based per ha BBF, followed by other impervious surfaces. In contrast, vegetated land and water contribute with a much lower per ha net BBF to parcel warming.

Remote-sensing based indices used for this purpose:

- Temperature condition index (TCI) – Singh et al. 2003
- Satellite remote sensing with on-the-ground observations (combination of methods) - Lotze-Campen and Lucht, 2001

Methods for acquiring the surface air temperature include:

- temperature-vegetation index approaches (TVX)
- statistical approaches
- neural network approaches
- and energy balance approaches.

As underlined by a number of studies, remote sensing is one of the most used techniques to investigate the cooling effects of green infrastructures because large areas can be monitored and analysed simultaneously and continuously (Liwen et al., 2015). However, remote sensing does not allow for the prediction of the effects of possible NBS, or the prediction of how the NBS will develop in the future. For this purpose, modelling approaches are useful tools, that allow simulation of non-existing/future scenarios. The literature review has revealed that there are several studies which followed this methodology. Table 1 summarizes the reviewed studies that analysed NBS and urban temperature. However, in reality, heat stress is determined by multiple parameters, the most important being Ta, Tmrt, wind patterns and humidity (from the meteorological perspective), and metabolic rate, activity, age and clothing (from the physiological perspective) (Höppe, 1999). In this regard, use of ecosystem-based approaches can also have positive effects on a larger scale – for example a district of a city, or the whole city. Studies using remote sensing approaches (e.g., Alavipanah et al., 2015) or meso-scale climate modelling (e.g., Fallmann et al., 2014) show that the urban heat island effect can be significantly reduced by increasing the vegetative cover within a city, e.g., through green roofs or parks. Changes in albedo change the radiation balance of the urban environment, and lower surface temperatures (Zölch et al. 2016, 2017, 2018).

Table 1 Summary of the reviewed studies that analysed NBS and Urban temperature

Studies	Objective	Model
Boukhabla and Alkama, 2012	Study the impact of vegetation on air temperature	ENVI-MET
Feyisa et al., 2014	Examine the relationship between characteristics of the vegetation and observed temperature	LINEAR MIXED-EFFECT MODEL
Hu, et al., 2016	Quantify land surface temperature	MODIS LST
Kim et al. , 2016	Understand the cooling effect of changes in land cover on surface and air temperatures in urban micro-scale environments	ENVI-MET
Kong et al., 2014	Explore and quantify the combined effects of factors related to the urban cooling islands intensity	LINEAR REGRESSION MODELS
Kong et al., 2016	Examine the outdoor 3D thermal environmental patterns with and without green spaces	ENVI-Met
Koc et al., 2017	Methodological framework for a more accurate assessment of the thermal performance of green infrastructure	Remote Sensing
Mackey et al., 2012	Attempt to analyse a real large-scale application by observing recent vegetated	LANDSAT

	and reflective surfaces in LANDSAT images	
Lin & Lin, 2016	Characterize the influence of the spatial arrangement of urban parks on local temperature reduction	ENVI-MET
Sun et al., 2017	Assess the impacts of modifications in a park on the thermal comfort improving-effect of urban green spaces	ENVI-Met
Takebayashi, 2017	Examine air temperature rise in urban areas that are on the leeward side of green areas	Numerical Model
Wai et al., 2017	Determine the change in evapotranspiration from the new ecosystems	Variable infiltration capacity
Zölch, et al., 2016	Quantify the effectiveness of three types of UGI in increasing outdoor thermal comfort in a comparative analysis	ENVI-MET
Wu & Chen, 2017	Investigate how different spatial arrangements of trees in residential neighbourhoods affect the cooling effects of vegetation	ENVI-Met
Žuvela-Aloise, 2017	Evaluate the cooling potential of the blue and green infrastructure to reduce the UHI effect when applied to large areas of the city	MUKLIMO_3

As evidenced by the studies in Table 1, there is a plethora of models for studying the effects of NBS on urban air temperature. However, not all models are adequate for all objectives, and given a specific purpose, the models should be chosen accordingly.

In order to properly assess the urban heat component of a site, there is a need to analyse the heat fluxes (EEA, 2017a, 2017b). According to Rafael et al., (2016) the study of energy fluxes can be conducted in three main approaches:

i. studies that only consider the measurements of energy fluxes through the eddy covariance method, and usually compare different types of land;
ii. studies that combine flux measurements with model simulations;
iii. Studies that use models designed to simulate the key processes governing heat, moisture and momentum exchanges of the urban canopy for different applications.

All these approaches offer different benefits and present different challenges, and the chosen method should be dependent on the case study.

For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation

	projects, refer to: Connecting Nature Environmental Indicator Metric Reviews
Scale of measurement	**Applied methods:** Typically, the type of metrics selected are based on the scale of the NBS being implemented. For example, small-scale interventions would not have a quantifiable impact on city-wide temperatures, thus city-wide networks of thermal sensors or remote sensing methods would not be appropriate. Small-scale NBS might, however, provide quantifiable local benefits in terms of creating an oasis from thermal stress for residents. **EO/RS methods:** Remotely sensed data are inherently suited to provide information on urban land cover characteristics, and their change over time, at various spatial and temporal scales. In most cases, however, methods of EO and RS have been used at meso-scales using satellite imagery to map and quantify the cooling effects of green infrastructures (Koc et al., 2017**).**
Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to: Connecting Nature Environmental Indicator Metric Reviews.
Data input type	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to: Connecting Nature Environmental Indicator Metric Reviews
Data collection frequency	Data collection frequency will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to: Connecting Nature Environmental Indicator Metric Reviews
Level of expertise required	**Applied methods:** Some expertise is required for the spatial design of the sampling and choice of instrumentation. Once installed though, basic measurements of air temperature associated data processing require little expertise. For more complex thermal parameters, analysis requires a greater level of expertise if equipment used does not process such data automatically. The ENVI-met microclimate analysis software requires some expertise to operate and collect the environmental data necessary. Once trained, however, data processing is relatively straightforward. **EO/RS methods:** Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.
Synergies with other indicators	**Applied methods:** If weather stations are utilised, there are synergies in relation to capturing additional environmental parameters of relevance for other indicators (e.g., total rainfall

	for stormwater management indicators). Measurement of heat stress is also of relevance to health & well-being indicators associated with exposure to heat. Reducing temperatures in a specific location could also have links to social cohesion and accessibility in relation to people being more likely to use a space. **EO/RS methods:** Once purchased, spatial data can be used for many of the mapping indicators, including those for social and economic indicators.
Connection with SDGs	Reduced impact of thermal stress on poorest communities; Reduced thermal stress impact of population health; Links to environmental education; Clean water and sanitation co-benefit; Job creation; Green infrastructure development; Social equality in relation to thermal stress; Sustainable urban development; Climate change adaptation; Habitat enhancement/creation, reduced thermal stress for locally adapted wildlife; Environmental Justice; Opportunities for collaborative working: SDG1, SDG3, SDG4, SDG6, SDG8, SDG9, SDG10, SDG11, SDG13, SDG15, SDG16, SDG17
Opportunities for participatory data collection	**Applied methods:** Opportunities in relation to carrying out measurements, and downloading and processing data - weather stations located at local schools can be an effective method for engaging local communities in urban heat island education (Clough and Newport 2017); also include use of thermal comfort perception surveys (Canan et al. 2019), wearable sensors to detect thermal stress (Sim et al. 2018) and mobile dataloggers (e.g., attached to bicycles) (Yokoyama et al. 2018).
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2.16 Tree shade for local heat reduction

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Tree shade for local heat reduction	Climate Resilience
Description and justification	Thermal comfort in cities has increased in importance due to impacts from global warming and high-density urbanisation. Metrics to measure the shading services provided by trees are largely based on quantifying differences in local air temperature from unshaded areas. The effect of tree shade on local temperature may be upscaled to a citywide impact if modelled and assessed cumulatively. This indicator principally concerns measuring how tree shade effects urban microclimates, in particular, by intercepting solar radiation preventing warming of the ground and thereby reducing surface temperature. Other basic measures of air temperature covered in Air temperature reduction indicator reviews, such as apparent temperature (the temperature equivalent perceived by humans – based on air temperature, relative humidity and wind speed), and Physiological Equivalent Temperature (thermal perception of an individual including thermal physiology), can also be used to evaluate the human thermal comfort conditions associated with tree shade (e.g., Kàntor et al., 2018). Various factors such as tree species (size, shape, leaf type, seasonality etc), tree age, distance between trees, type of surface beneath the tree, surrounding environment and climate will impact the degree of shade provided. Data on the reduction of air temperature by tree shade collected in these ways can be used to: • Quantify the benefits of trees as nature-based solutions in terms of cooling the local microclimate, reducing building energy use and providing thermal comfort zones for residents; • Target tree planting in areas prone to temperature extremes/UHI and/or to provide optimal shade

	benefit to commuting pedestrians (see also Langenheim et al., 2020); • Contribute towards other environmental and health and well-being indicators linked to temperature, air pollution, carbon storage, flooding and biodiversity.
Definition	Trees as nature-based solutions to create shade in neighbourhoods measured by °C or K per spatial unit (m^2)
Strengths and weaknesses	Robustness of evidence depends upon the level of precision of the equipment, the spatial design of the monitoring and the duration of temperature recording. Generally, direct measurement in the field can provide greater confidence than microclimate simulations, but it can be hard to accurately scale-up local measurements to the whole city. Photographic methods yield good results, but they typically require manual acquisition and processing of fisheye images, which is time consuming and not feasible at the neighborhood or city-scale (Middel et al., 2018). To accurately simulate the thermal performance benefits that trees provide, it is necessary to account for growth and phenological changes in tree shade amount and quality and the influence of street canyon geometry.
Measurement procedure and tool	The classical methodical approach for measuring tree shading was developed by Barlow and Harrison (1999) and considered different factors affecting shading, such as topography, time of day and year and geographical location. They provided mathematical descriptions and procedures used to calculate the length of the shadow and its duration (Barlow & Harrison, 1999). The shade from tree canopies can generate significant surface cooling in cities, particularly over impervious surfaces such as asphalt, where a temperature reduction of about 6°C has been recorded (Rahman et al., 2019). This study examined the vertical temperature gradient beneath two common urban street tree species *Tilia cordata* and *Robinia pseudoacacia*, recording a range of morphological measurements (e.g., diameter at breast height (DBH), tree height, crown projection area (CPA) and leaf area index (LAI) derived from hemispherical photographs), as well as air and surface temperature and various other meteorological data, collected using a combination of temperature loggers at 3 different heights and weather stations installed at the study sites (Rahman et al., 2019). Surface cooling was strongly correlated with LAI, and the relationship was found to be stronger over asphalt than grass, indicating therefore that tree species with higher canopy density might be preferential when planted over asphalt surfaces in cities, but low water using species with lower canopy density could be chosen over grass surfaces (Rahman et al., 2019).

In a meta-analysis of the characteristics of urban tree species that influence cooling potential, a total of 13 studies were analysed that reported on cooling by shading (as measured by surface temperature difference ΔST), and consensus from the review in terms of surface cooling was that the following parameters contributed to ΔST in order of relative importance: climate > below canopy surface > growing size > leaf thickness > LAI > crown shape > plant functional type > habitat > wood anatomy > leaf shape > leaf colour (Rahman et al., 2020). LAI was again reported as the most influential driver of cooling benefits in terms of human thermal comfort, although vertical leaf area densities can also be influential, and species with higher leaf density at the lower crown may ensure better cooling benefits (Rahman et al., 2020). Studies reviewed in the meta-analysis used various methods for gathering data on tree shade effects on surface temperature, for example:

- ***Field measurements***: empirical microclimate measures using for instance temperature sensors attached to dataloggers, infrared thermometers/thermal cameras, globe thermometers (to measure radiant temperature as a determinant of physiological equivalent temperature (PET) which is used to assess human thermal comfort), in combination with weather station data and tree species morphology (i.e., height, canopy spread and LAI (using a LAI analyser/ceptometer or hemispherical images) (Lin & Lin, 2010; Armson et al., 2012 & 2013; Devia & Torres, 2012; Berry et al., 2013 (building walls rather than ground level); Millward et al., 2014; Gillner et al., 2015; Napoli et al., 2016; Rahman et al., 2018; Stanley et al., 2019); also leaf colour (using colorimeter), leaf thickness (using thickness gauge) canopy coverage area (using handheld GPS and walking a transect round the tree canopy edge) and canopy thickness from photographs of individual trees (Lin & Lin, 2010); hemispherical photographs to measure tree shade cover on walls (Berry et al; 2013);
- ***statistical/modelling techniques***: linear mixed model and/or regression analyses of field data (Lin & Lin, 2010; Armson et al., 2012; Milward et al., 2014; Gillner et al., 2015; Rahman et al., 2018; Stanley et al., 2019), shade area analysis (Armson et al., 2013), vertical shading coefficient of walls (Berry et al., 2013); a heat transfer model, which was found to be effective at predicting surface temperatures of pavements and lawn under different trees (Napoli et al., 2016);

Rötzer (2019) presents different techniques for greening cities, particularly through planting trees in all climate zones, as effective tools to mitigate climate change and the Urban Heat Island (UHI), and provides empirical as well as modelling studies of urban tree growth and their services and disservices in cities worldwide, including the dynamics, structures, and functions of urban trees, as well as the influence of climate and climate change on urban tree growth, urban species composition, carbon storage, and biodiversity.

Stanley et al. (2019) analysed urban tree growth and regulating ecosystem services along an urban heat island (UHI) intensity gradient in Salzburg (Austria). For the phenological monitoring in spring March – May (and later verification in autumn), they used the well-established method presented by Wesolowski and Rowinski (2006). They developed a scale of point values from 0 to 2 for assessing the development status of a leaf bud. For each observation day, ten randomly selected apical buds in the upper, south-exposed part of the crown are evaluated and their sum is calculated. The monitoring starts when all buds are closed and thus evaluated as having zero points. As soon as all ten leaves are completely developed and each scores two points, the monitoring is finished. Moreover, for all observation trees, the height, trunk circumference at breast height, and leaf area index (LAI) were measured. Using these data, the tree age, crown area, and crown volume were further calculated. The tree height was measured using a Leica DISTOTM D810 Touch (Leica Geosystems); LAI was determined based on LAI-2200C Plant Canopy Analyzer from LI-COR (Lincoln, NE, USA). The measured values were then edited in the FV2200 software from LI-COR (2.1.1, Lincoln, NE, USA). The microclimate was measured using the difference of the surface temperatures between the crown-shaded area and the full sun-exposed area using an Infrared Radiometer, Model MI-220. Data were assessed using statistical analysis similar to those applied by Gillner et al. (2015). They found out, after leaves have developed, trees cool the surface throughout the whole growing season by casting shadows. On average, the surfaces in the crown shade were 12.2 ◦C cooler than those in the sun. Thus, the tree characteristics had different effects on the cooling performance. In addition to tree height and trunk circumference, age was especially closely related to surface cooling. They conclude, if a tree’s cooling capacity is to be estimated, tree age is the most suitable measure, also with respect to its assessment effort. Practitioners are advised to consider the different UHI intensities when maintaining or enhancing public greenery. The cooling capacity of tall, old trees is needed especially in areas with a high UHI intensity. Species differences should be examined to determine the best adapted species for the different UHI intensities. The results of such studies can be the basis for modelling future mutual influences of microclimate and urban trees.

An alternative methodology to those above used a high-resolution thermal imaging camera to record the crown temperature of trees from above (using a helicopter), and determined that urban tree temperatures are species-specific due to traits such as leaf size, stomatal conductance and canopy structure, and that foliage temperature was mostly influenced by the location of the tree (i.e., park or pavement) (Leuzinger et al., 2010). Generally small-leaved trees were cooler, but this trend did not always hold at temperature extremes (40°C), indicating that the cooling effect of urban trees could be species *and* context specific, which may be useful information for future urban tree planning projects (Leuzinger et al., 2010).

Thermal imaging (in combination with a range of other field measurements and photographic records) has also been used to record the surface temperatures of three common urban surfaces – asphalt, porphyry, and grass – in the shade of 332 single tree crowns, of 85 different species, during the peak temperature period of summer days, to evaluate which tree traits play an important role in cooling (Speak et al., 2020). Measurements at three locations within the shadow of individual trees revealed higher cooling in the centre and at the western edge and cooling was related to a multitude of tree traits, of which Leaf Area Index estimate (LAIcept) and crown width were the most important (Speak et al., 2020). Median average cooling of 16.4, 12.9 and 8.5 °C was seen in the western edge of the tree shade for asphalt, porphyry and grass, respectively (Speak et al., 2020). Tree traits recorded were modelled using descriptive and predictive multiple linear regression models and were able to predict cooling with some success from several of the predictor variables (LAIcept and gap fraction), which has implications for the selection of trees within urban design schemes by altering the weight given to certain tree traits if high shade provision is a desired outcome (Speak et al., 2020).

ENVI-met (a three dimensional microclimate simulation software) can be used to generate a microscale model simulating various tree canopy scenarios under various climate conditions and investigate the relationship between percentage tree canopy cover and temperature reduction at the neighborhood scale (Middel et al., 2015). The study findings suggested the relationship between percent canopy cover and air temperature reduction was linear, with 0.14 °C cooling per percent increase in tree cover for the neighborhood under investigation, although they highlight Envi-met has various shortcomings, for instance in terms of estimating nocturnal cooling under trees and accounting for anthropogenic heat (Middel et al., 2015). Beyond the local scale, the Weather Research and Forecasting (WRF) model has been coupled with urban land surface processes parameterized by urban canopy models (UCMs) to investigate the radiative shading effect of trees over the contiguous United States (Wang et al., 2018). This WRF-urban modelling framework can be informative to researchers and policy makers, but as it omits other biophysical functions of trees such as evapotranspiration, more work is needed to produce a more comprehensive and realistic representation of urban tree shade cooling effects (Wang et al., 2018).

Remotely sensed tree canopy cover has been widely used to estimate the amount of trees in an area. However, where this is limited to two-dimensional calculations, it may not fully evaluate the shading service of trees as the vertical structure and density of trees can also influence the solar radiation reaching ground level (Li et al., 2018). Google Street View (GSV) provides publicly available, high spatial resolution photographs of vegetation along streetscapes, which can be used to quantify the degree of shading under street trees (Richards & Edwards, 2017). The GSV panoramas can be transformed into hemispherical images and pixels classified into classes (i.e., sky, trees, buildings), and combined with remotely sensed data (i.e., LiDAR) to enable estimation of canopy cover provided by street trees (Li et al., 2018). A sky view factor (SVF) calculation - the ratio of sky hemisphere visible from the ground that is not obstructed by buildings, trees and terrain - can been applied to these images to quantify the shading effectiveness of street trees alone (SVF ranges from 0 to 1, indicating totally enclosed and totally open street canyons respectively) (Li et al., 2018). The quantitative information and spatial distribution of shade provision by street trees generated by this method can be used as a reference for urban planners and city officials for urban greening projects, for instance so they can target critical areas for urban heat island (UHI) mitigation (Li et al., 2018).

The influence of vertical and horizontal tree canopy structure on land surface temperature (LST) can also be measured using a combination of a high-resolution vegetation map, Light Detection and Ranging (LiDAR) data and various statistical analysis methods (Chen et al., 2020). Results from this method indicated that composition, configuration and vertical structure of tree canopy were all significantly related to both daytime LST and night-time LST, highlighting the important contribution measuring the vertical structure of tree canopies can have in determining LST in cities (Chen et al., 2020).

The influence of patch size of trees (from 500 m^2 – 80,000 m^2) on shading has been modelled, using a variety of field measurements (e.g., DBH, distance between trees, temperature, weather etc) and simulated using the solar radiation tool embedded in ArcGIS, and found that multiple small patches can provide more total area of shade than a single large one (Jiao et al., 2017). However, they also found a non-linear relationship between patch size and transpiration, both of which are key cooling services provided by trees, therefore there may be a trade-off between shading and transpiration at certain patch sizes, and with different tree species (Jiao et al., 2017).

A study of the effects of street trees in three contrasting street canyon environments found the cooling and human thermal comfort benefits of street trees were localised and highly variable both spatially and temporally, based on factors such as the amount of shading, street geometry, and the local meteorological conditions (Coutts et al., 2015). Thus, depending on their position in the street canyon, the prevailing conditions, and time of day, trees can have either a cooling or warming effect, highlighting the importance of strategic placement of trees to maximize their shade area whilst spacing them sufficiently to allow some nocturnal longwave cooling and ventilation, and reduce potentially detrimental impacts on urban cooling at night (Coutts et al., 2015).

i-Tree Canopy (https://canopy.itreetools.org/) is a web browser application that offers a quick and easy way to produce a statistically valid estimate of land tree canopy cover using aerial images available in Google Maps. This can be used as an easy to understand concept for communicating messages about tree cover to policy makers and the public, and can be linked to shading provision in terms of percentage cover/m^2 gained/lost in an area being an index of potential shading benefits gained/lost. i-Tree Canopy could also be used to map existing canopy cover in order to determine tree-less areas that may benefit from shade. The package i-Tree Design (https://design.itreetools.org/) can be used to evaluate the cooling benefits of shade from individual trees on building energy demand.

Mobile sensors (a fast-response, high-accuracy temperature probe, GPS device and data logger) mounted to bicycles

	have been used to measure temperature variability along urban transects in relation to tree canopy and impervious cover, both of which can interact to influence both daytime and nighttime summer air temperature (Ziter et al., 2019). In this study, generalised additive models were used to test the effect of percentage canopy and impervious cover and distance to nearest lake at 4 scales (10-90 metre radius) surrounding each temperature measurement (Ziter et al., 2019). This fine-scale method detected that canopy cover >40% can counter the warming effect of impervious surfaces during the daytime within a radius of 60-90 m (the scale of a city block). However, the impact at night-time was much less pronounced, indicating that reducing impervious cover as well as tree planting could be key to reducing UHI (Ziter et al., 2019). This method may also be suitable for citizen science projects (Ziter et al., 2019). Citizen science has also been successfully used to collect temperature data in cities using vehicle-mounted temperature sensors and global positioning system devices (GPS), with volunteers undertaking one-hour 'traverses' through study areas in a city to provide a snap-shot of temperatures, which can then be modelled against land use and land cover data to evaluate the role of trees in reducing/amplifying local temperatures and create a heat map for city planners (Shandas et al., 2019). Other participatory methods include the use of wearable sensors to detect human thermal stress (Sim et al. 2018), which could potentially be used to deliver a citizen science project on the effects of urban tree shade. Berland et al. (2019) also confirmed that inventories relying on citizen scientists or virtual surveys conducted remotely using street-level photographs may greatly reduce the costs of street tree inventories since those ones conducted in the field by trained professionals are expensive and time-consuming. However, they pointed here several fundamental uncertainties regarding the level of data quality that can be expected from these emerging approaches to data collection. In particular, 16 volunteers were asked to inventory street trees in suburban Chicago using Google Street ViewTM imagery, and later this was assessed by comparing their virtual survey data to field data from the same locations conducted by experts. The findings suggest that virtual surveys may be useful for documenting the locations of street trees within a city more efficiently than field crews and with a high level of accuracy. However, tree diameter and species identification data were less reliable across all expertise groups, and especially analysts. Based on this analysis, virtual street tree inventories are best suited to collecting very basic information such as tree

	locations, or updating existing inventories to determine where trees have been planted or removed. It should be noted that measuring shade alone will not fully capture cooling services provided by trees, since evapotranspiration also plays a role in regulating temperatures. Also, if tree planting is poorly designed, it can lead to disruption of airflows, causing trade-offs such as localised increases in air pollution concentrations (e.g., Vos et al., 2013) and night-time temperatures (Bowler et al., 2010; Coutts et al., 2015).
Scale of measurement	Typically, tree shade effects on temperature are measured in terms of the local microclimate impact. Wang et al. (2018) propose a modelling framework for the shading effect of trees that can be used at the city and regional scale with moderate accuracy.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data collection frequency	Monitoring methods tend to be adopted for short-term snapshots, for instance to show benefits on days of extreme heat. Monitoring should be undertaken at repeated intervals to capture a more comprehensive overview of the performance of trees and account for change over time and under different climatic conditions. Establishing a network of sensors across the city could provide a useful baseline as tree-planting is upscaled across the city to a scale that impacted city-wide temperatures, if this was planned.
Level of expertise required	Some expertise may be required in relation to appropriately designing studies and with respect to the selection/use of specialist instrumentation and software such as ENVI-met. Expertise in relation to mapping (especially those based on remote sensing and GIS techniques) and modelling will be necessary.
Synergies with other indicators	Strong synergies with Air temperature reduction and with health and wellbeing indicators in relation to heat stress. Reducing temperatures in a specific location could also have links to social cohesion and accessibility as people may be more likely to use a space. Where weather stations are utilised, there are synergies in relation to capturing additional environmental parameters of relevance for other indicators (e.g., total rain fall for stormwater management indicators).
Connection with SDGs	Reduced impact of thermal stress on poorest communities; Reduced thermal stress impact of population health; Links

	to environmental education; Clean water and sanitation co-benefit; Job creation; Green infrastructure development; Social equality in relation to thermal stress; Sustainable urban development; Climate change adaptation; Habitat enhancement/creation, reduced thermal stress for locally adapted wildlife; Environmental Justice; Opportunities for collaborative working: SDG1, SDG3, SDG4, SDG6, SDG8, SDG9, SDG10, SDG11, SDG13, SDG15, SDG16, SDG17
Opportunities for participatory data collection	Opportunities are available for participatory processes in relation to collecting temperature measurements using mobile dataloggers or wearable sensors (Shandas et al., 2019), as well as collecting very basic information such as tree locations, or updating existing inventories to determine where trees have been planted or removed (as based on the findings of Berland et al. (2019).
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2.17 Rate of evapotranspiration

Project Name: UNaLab (Grant Agreement no. 730052)

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Rate of evapotranspiration		Climate Resilience Water Management
Description and justification	Evapotranspiration (ET) is a combination of two separate processes whereby water is lost from the soil surface by evaporation and from vegetation by transpiration. Water evaporates from surfaces when sufficient heat is supplied for liquid water to transition to water vapour. During transpiration, plant tissues vaporise water, which is then released to the atmosphere through stomatal openings on the plant leaf. Nearly all water taken up by plants is released to the atmosphere through transpiration. In addition to the non-uniformity of urban vegetation, shading of urban vegetation by landscape trees and structures and edge effects due to the relatively small scale of urban green space in comparison to commercial crop fields can significantly influence ET (Snyder, Pedras, Montazar, Henry, & Ackley, 2015).	
Definition	Measured or modelled evapotranspiration (typically expressed in mm per unit time, e.g., mm/day)	
Strengths and weaknesses	+ The reference evapotranspiration, ET_o, provides a standard to which: (a) evapotranspiration at different periods of the year or in other regions can be compared; (b) evapotranspiration of other crops can be related (Allen, Pereira, Raes, & Smith, 1998). + Standard, widely-applied technique - Challenging and expensive to measure directly - Requires high level of expertise to apply	
Measurement procedure and tool	Evapotranspiration is measured involving specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters. In practice, ET is commonly calculated using meteorological data. Commercially-available ET monitoring stations are generally meteorological stations that calculate potential ET using monitored temperature, relative humidity, wind speed and direction, solar radiation, and precipitation data. The Penman-Monteith equation is the FAO-recommended	

	standard technique for calculation of reference evapotranspiration, ETo from crops (Allen, Pereira, Raes, & Smith, 1998). The FAO Penman-Monteith method to estimate ETo is presented in Equation 1: $$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$ Where ETo is reference evapotranspiration [mm day-1], Rn is net radiation at the crop surface [MJ m-2 day-1], G is soil heat flux density [MJ m-2 day-1] ,T is mean daily air temperature at 2 m height [°C], u2 is wind speed at 2 m height [m s-1], es is saturation vapour pressure [kPa], ea is actual vapour pressure [kPa], es - ea is saturation vapour pressure deficit [kPa], D is slope vapour pressure curve [kPa °C-1], and g is psychrometric constant [kPa °C-1]. Using the Penman-Monteith equation, ET from plant surfaces under standard conditions is determined using an experimentally-determined coefficient (kc) to relate the ET for a specific crop species, ETc, to ETo. Thus, for a given crop species: $$ET_c = k_c \times ET_0$$ For urban landscapes, the landscape coefficient method (LCM), which uses a different set of coefficients rather than kc to estimate ET, may be more appropriate (Costello, Matheny, Clark, & Jones, 2000): $$ET = k_L \times ET = k_d \times k_s \times k_{mc} \times ET_0$$ where kL is a landscape coefficient defined as a product of kd, a planting density factor, kS, a species-specific factor, and kmc, a microclimate factor. The modifications of the Penman-Monteith equation for plant-specific conditions can be found in the publications by, e.g., Litvak and Pataki (2016) and Litvak, Manago, Hogue, and Pataki (2016).
Scale of measurement	Plot scale, can be extrapolated using land cover data
Data source	
Required data	Radiation, air temperature, wind speed, vapour pressure, soil heat flux density
Data input type	Quantitative
Data collection frequency	Annually, and before and after NBS implementation

Level of expertise required	High – requires ability to apply the Penman-Monteith equation and evaluate the results
Synergies with other indicators	Related to *Daily temperature range, Land surface temperature* and *Surface reflectance - Albedo* indicators; a possible consequence of *Green space management* and *Place regeneration* indicator groups
Connection with SDGs	SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/X0490E/x0490e00.htm#Contents Costello, L.R., Matheny, N.P., Clark, J.R., & Jones, K.S. (2000). A guide to estimating irrigation water needs of landscape plantings in California, the landscape coefficient method and WUCOLS III. Berkeley, CA, USA: University of California Cooperative Extension, California Department of Water Resources. https://ucanr.edu/sites/WUCOLS/ Litvak, E., Manago, K.F., Hogue, T.S., & Pataki, D.E. (2016). Evapotranspiration of urban landscapes in Los Angeles, California at the municipal scale. Water Resources Research, 53(5), 4236-4252. Litvak, E. & Pataki, D.E. (2016). Evapotranspiration of urban lawns in a semi-arid environment: An in situ evaluation of microclimatic conditions and watering recommendations. Journal of Arid Environments, 134, 87-96. Snyder, R.L., Pedras, C., Montazar, A., Henry, J.M., & Ackley, D. (2015). Advances in ET-based landscape irrigation management. Agricultural Water Management, 147, 187-197

2.18 Land surface temperature

Project Name: UNaLab (Grant Agreement no. 730052)

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Land surface temperature	Climate resilience
Description and justification	Radiation balance at the Earth's surface consists of net short-wave radiation and net long-wave radiation. Long-wave radiation (wavelength 3 to 100 µm) is an energy exchange between the Earth's surface and the atmosphere. Short-wave radiation (wavelength 0.3 to 3 µm) coming from the sun can be reflected back or scattered by air molecules or clouds when they are present, although part of it reaches the ground. Surface energy budget for an area consists of net incoming (solar) radiant energy and the outgoing energy fluxes comprising of latent and sensible heat fluxes (Shuttleworth, 1993). Land surface temperature (LST; different from the air temperature) controlling the long-wave radiation emitted by the Earth's surface is an important variable for evaluating the available energy, i.e., the latent and sensible heat fluxes (Trigo *et al.*, 2008), and capturing the extremes, such as the heat waves, and other important variables, such as the concentration of the atmospheric greenhouse gases.
Definition	For earth observation methods: The Earth's radiometric (or skin) temperature derived from the solar radiation, where "surface" denotes any type of surface the satellite captures (snow, vegetation, soil, roofs, etc.) (°C or K). For ground-based methods: Radiance over spatially homogeneous sites.
Strengths and weaknesses	+ Earth observation methods allow for large-scale observations + Direct observation of the changes of the Earth's energy budget - Clear-sky conditions are required for methods observing in the visible and thermal infrared (TIR) spectral ranges - Complicated surfaces obscure the measurements
Measurement procedure and tool	**Earth observation methods** Sensors on-board aircraft or satellites record the land surface emissivity, land surface temperature, or both in the visible, near-infrared and thermal infrared (TIR, 8–13 □m) spectral ranges. Satellite-borne land surface temperature must be validated either against the other sensors on-board of different satellites to ensure quality (e.g., Krishnan *et al.*, 2015).

	Ground-based (*in situ*) methods The *in situ* measurement of land surface temperature (LST) and land surface emissivity (ability to emit infrared energy) can be performed with various instruments. The Surface Radiation Network (SURFRAD) in the United States (NOAA, n.d.), which follows the standards adopted by the Baseline Surface Radiation Network (Driemel *et al.*, 2018; https://bsrn.awi.de/), mentions the following monitoring equipment: • Radiometers (narrowband infrared or thermal infrared) for infrared radiation (Martin *et al.*, 2019) • Pyranometers for global solar radiation, diffuse component of solar irradiance (cloudy days) and solar radiation reflected from the surface • Pyrheliometer for the direct component of solar irradiance (clear-sky) • Pyrgeometer for down-welling and up-welling long-wave radiation The relation between the LST values and surface-emitted radiance can be described with the Planck's law, which relates the radiance emitted by a black body to its temperature. The emissivity (ability to emit infrared energy) of the black bodies is $\varepsilon = 1$. However, the real surfaces do not behave the same way as black bodies, having emissivity values of $0 \leq \varepsilon \leq 1$. Since the LST is evaluated based on the emissivity as temperatures are measured using thermal radiation, it is currently the largest source of error in the LST calculations (Göttsche *et al.*, 2016). Several considerations must be taken into account when selecting a suitable site for the LST measurements, including (a) selecting an area of homogeneous land cover to ensure the uniform temperature distribution, (b) possibility for the continuous observations, (c) long clear-sky periods, and (d) view angles (Trigo *et al.*, 2008).
Scale of measurement	Global and regional (Earth observations); Site (*in situ*)
Data source	
Required data	Land surface temperature obtained from remote-sensed or *in situ* measurements
Data input type	Quantitative
Data collection frequency	Hourly; daily; weekly
Level of expertise required	Very high – for all methods and data retrieval and evaluation

Synergies with other indicators	Directly related to *Albedo*, *Rate of evaporation*, and *Occurrence of heat waves* indicators
Connection with SDGs	SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Copernicus Global Land Service. (n.d.). *Land Surface Temperature*. Retrieved on 17.7.2020 from https://land.copernicus.eu/global/products/lst Driemel, A., Augustine, J., Behrens, K., Colle, S., Cox, C., Cuevas-Agulló, E., ... & König-Langlo, G. (2018). Baseline Surface Radiation Network (BSRN): structure and data description (1992-2017). *Earth System Science Data*, *10*(3), 1491-1501. Freitas, S. C., Trigo, I. F., Macedo, J., Barroso, C., Silva, R., & Perdigão, R. (2013). Land surface temperature from multiple geostationary satellites. *International Journal of Remote Sensing*, *34*(9-10), 3051-3068. Göttsche, F.M., Olesen, F.S., Trigo, I.F., Bork-Unkelbach, A., & Martin, M.A. (2016). Long term validation of land surface temperature retrieved from MSG/SEVIRI with continuous in-situ measurements in Africa. *Remote Sensing*, *8*(5), 410. Krishnan, P., Kochendorfer, J., Dumas, E.J., Guillevic, P.C., Baker, C.B., Meyers, T.P., & Martos, B. (2015). Comparison of in-situ, aircraft, and satellite land surface temperature measurements over a NOAA Climate Reference Network site. *Remote Sensing of Environment*, *165*, 249-264. Martin, M.A., Ghent, D., Pires, A.C., Göttsche, F.M., Cermak, J., & Remedios, J.J. (2019). Comprehensive in situ validation of five satellite land surface temperature data sets over multiple stations and years. *Remote Sensing*, *11*(5), 479. NASA Earth Observations. (n.d.). *Land Surface Temperature (TERRA/MODIS).* Retrieved on 17.7.2020 from https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MOD_LSTD_M National Oceanic & Atmospheric Administration (NOAA). (n.d.). SURFRAD Overview: Surface Radiation Budget Monitoring. Retrieved on 17.7.2020 from https://www.esrl.noaa.gov/gmd/grad/surfrad/overview.html Shuttleworth, W.J. (1993). *Evaporation*. In: Maidment, D.R. (ed.), Handbook of Hydrology. New York: McGraw-Hill. Trigo, I.F., Monteiro, I.T., Olesen, F., & Kabsch, E. (2008). An assessment of remotely sensed land surface temperature. *Journal of Geophysical Research: Atmospheres*, *113*, D17108. Valor, E., Sánchez, J.M., Niclòs, R., Moya, R., Barberà, M.J., Caselles, V., & Coll, C. (2018, July). Comparison of in Situ Land Surface

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2.19 Surface reflectance - Albedo

Project Name: UNaLab (Grant Agreement no. 730052)

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Surface reflectance – Albedo	**Climate resilience**
Description and justification	Radiation balance at the Earth's surface consists of net short-wave radiation and net long-wave radiation. Long-wave radiation (wavelength 3 to 100 µm) is an energy exchange between the Earth's surface and the atmosphere. Short-wave radiation (wavelength 0.3 to 3 µm) coming from the sun can be reflected back or scattered by air molecules or clouds when they are present, although part of it reaches the ground. Albedo is a portion of short-wave radiation that is reflected back once it reaches the ground, and it varies with the land cover (Shuttleworth, 1993).
Definition	Short-wave radiation reflectance coefficient of a surface (0-1, unitless), where 1 denotes full reflection and 0 denotes full absorption. Surface albedo is defined as the instantaneous ratio of surface-reflected radiation flux to incident radiation flux over a given spectral interval (dimensionless) (Wang *et al.*, 2019)
Strengths and weaknesses	+ Surface reflectance can be measured directly + Directly comparable to other variables such as cooling and greenhouse gases emissions + Albedo values for various known surfaces and land-uses already exist - Requires advanced equipment and judgment

Measurement procedure and tool	Surface reflectance can be measured in the laboratory, in the field, and via remote sensing. a. In the laboratory, surface reflectance can be measured using spectrophotometers equipped with integrating spheres over wider spectral ranges than the photopic vision (well-lit conditions) response of a human eye, and using light sources other than natural light (ASTM, 2012). Since the beam illuminates only part of a sample, a spatially uniform sample will yield the most fast and accurate results (Levinson, Akbari & Berdahl, 2010). b. In the field, surface reflectance is typically measures using a pyranometer, a solar radiation meter, which measures the reflected solar irradiance (ASTM, 2016). This method requires a portable and relatively inexpensive equipment and it can be applied to flat and curved surfaces. However, the limitations include the necessity of a clear sky as clouds can lead to erroneous results, and a relatively large size of the surface to prevent the radiation collections from the object's surroundings (Levinson, Akbari & Berdahl, 2010). Ideally, the *in situ* albedo measurements are continuous ahd have temporal resolution of less than 30 minutes (Wang *et al*., 2019). c. Remote sensing options utilise the satellite or aerial systems that that record albedo of larger surfaces (Ban-Weiss, Woods & Levinson, 2015), or the Earth such Clouds and the Earth's Radiant Energy System, or CERES (NASA, 2019). While remote sensing is feasible for measuring albedo at larger scales, this method is nor suitable for finer scale applications, and validations in the filed may be necessary (Wang *et al*., 2019; Williamson, Copland & Hik, 2016). Reference tables exist for certain surfaces and land covers:

Land cover	Albedo
Grass and pasture	0.2 – 0.26†
Snow and ice	0.2 (old) – 0.8 (new)†
Bare soil	0.1 (wet) – 0.35 (dry)†
Asphalt	0.05 – 0.2‡
Red/Brow roof tile	0.1 – 0.35‡

	Open water	0.08†
	†Shuttleworth (1993) ‡US EPA (1992)	
Scale of measurement	Plot scale	
Data source		
Required data	Albedo of various surfaces and land covers	
Data input type	Quantitative	
Data collection frequency	Annually	
Level of expertise required	High when applying direct measurements Low when using reference tables	
Synergies with other indicators	Direct relation to *Rate of evapotranspiration*, *Land surface temperature* and *Urban Heat Island incidence* indicators	
Connection with SDGs	SDG 13 Climate action, SDG 15 Life on land	
Opportunities for participatory data collection	No opportunities identified	
Additional information		
References	ASTM (2009). ASTM C1549-09, Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer. ASTM International, West Conshohocken, PA. ASTM (2012). ASTM E903-12, Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres. ASTM International, West Conshohocken, PA. ASTM (2016). ASTM E1918-16, Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field. ASTM International, West Conshohocken, PA. Ban-Weiss, G. A., Woods, J., & Levinson, R. (2015). Using remote sensing to quantify albedo of roofs in seven California cities, Part 1: Methods. *Solar Energy*, *115*, 777-790. Shuttleworth, W.J. (1993). *Evaporation*. In: Maidment, D.R. (ed.), Handbook of Hydrology. New York: McGraw-Hill. Bonan, G.B. (2008). Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science*, *320*(5882), 1444-1449. Levinson, R., Akbari, H., & Berdahl, P. (2010). Measuring solar reflectance—Part II: Review of practical methods. *Solar Energy*, *84*(9), 1745-1759.	

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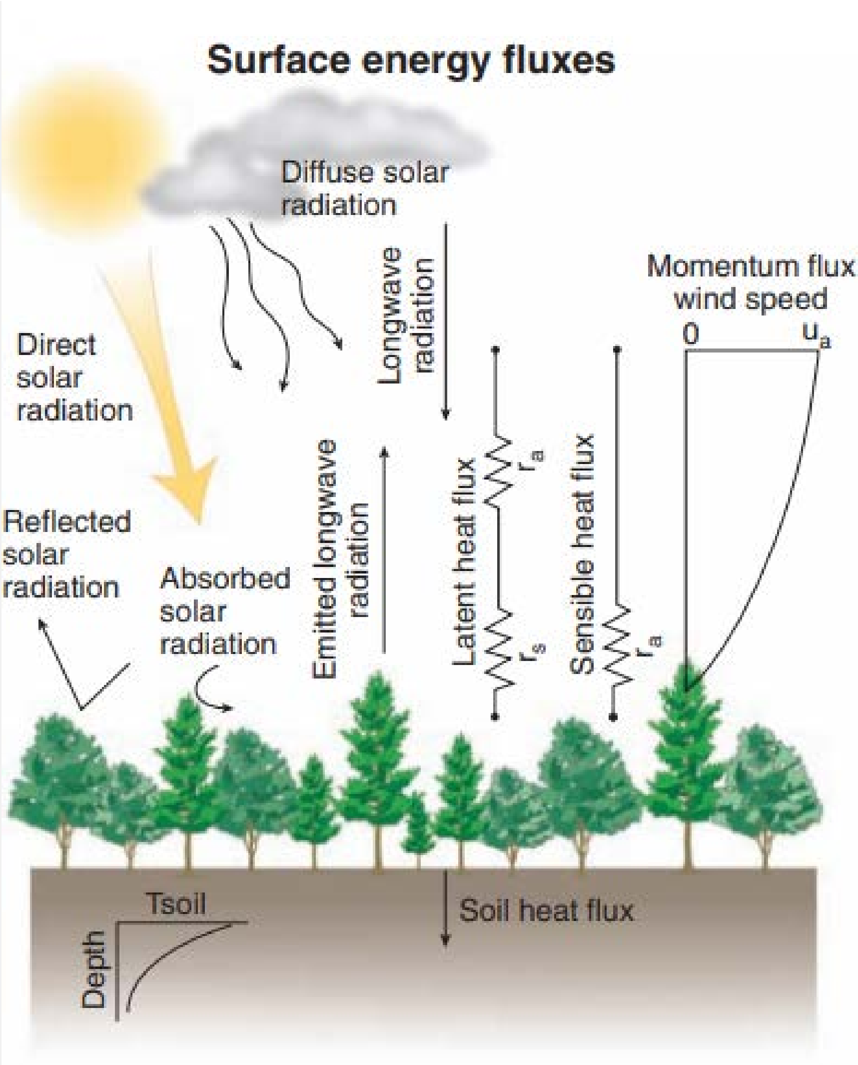

Figure: Surface energy fluxes (adapted from Bonan, 2008)

2.20 Estimated carbon emissions from vehicle traffic

Project Name: UNaLab (Grant Agreement no. 730052)

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CO_2 emissions related to vehicle traffic	Climate Resilience
Description and justification	Vehicle traffic emissions are the fraction of greenhouse gas (GHG) emissions that can be affected by nature-based solutions in the urban environment.
Definition	CO_2 emissions related to vehicle traffic (t C/y)
Strengths and weaknesses	+ Straightforward assessment of vehicle-related GHG emissions - Requires suitable data source for estimating fuel consumption
Measurement procedure and tool	1. Suitable available data source measuring the kilometre per person transport in the area should be identified, preferentially giving estimates of consumption of gasoline, diesel, ethanol and natural gas, the most common fuels used in car and rail transport (IPCC, 2006; Toledo & Rovere, 2018). 2. These consumed fuels, as well as potential consumed electricity by electrified rail systems, are converted to emission using emission factors for different fuels. Preferred method is to locate country specific net-calorific-values and CO_2-emission factors, when available, but general default values are presented (IPCC, 2006). 3. CO_2 emissions related to vehicle traffic are calculated as follows: $$Emissions_{traffic} = Estimated\ use\ of\ fuel\ (t) \times Emission\ factor\ (t\ CO_2/t)$$ $$Decrease\ (\%) = 100\% - \left(\left(\frac{Emission_{traffic\ (after)}}{Emission_{traffic\ (before)}}\right) \times 100\%\right)$$ Emission factors for fuels, adapted from IPCC 2006 Guidelines Vol 2. Tables 1.2 & 1.4. (IPCC, 2006):

	Petrol	Diesel	Ethanol	Natural gas

	t CO_2 / t fuel 3.07 3.19 1.91 2.69
Scale of measurement	District scale
Data source	
Required data	Fuel consumption data or travel distance data. In a community-scale study, only travel distance represented by amount of traffic measurements are seen feasible.
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low – requires ability to follow the calculation procedure
Synergies with other indicators	Possibility to combine with *CO_2 emissions related to building energy consumption* indicator to obtain the total decrease due to NBS implementation
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Intergovernmental Panel on Climate Change (IPCC). (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). Hayama, Japan: Institute for Global Environmental Strategies (IGES). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

WATER MANAGEMENT

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3 RECOMMENDED INDICATORS OF WATER MANAGEMENT

3.13 Surface runoff in relation to precipitation quantity

3.13.1 Direct measurement

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

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Runoff coefficient – direct measurement	Water Management
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil

	characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff coefficient in relation to precipitation quantities (m^3/s, L/s or depth-equivalent mm)
Strengths and weaknesses	+ Traditional, well-studied method for open channel flow measurement + Scalable for different purposes - Requires judgement in case of equipment malfunction
Measurement procedure and tool	Direct measurement of runoff (and its characteristics) using standard approaches, including weirs, pressure transducers/loggers, tipping-bucket gauges, etc. (e.g., Stovin et al., 2012). Large scale: Weirs, flumes, orifices. Weirs obstruct the flow making the head behind the weir being a function of flow velocity and flow rate though the weir. Flumes are another traditional method for open channel flow measurement in a channel with converging and diverging sections. The operation principle of the flumes is that the water level is higher in the converging section than in the diverging section, and that there is direct relationship between water depth and flow rate (Adkins, 2006). Small scale: tipping-bucket gauges, pressure transducers for discharge monitoring. Tipping-bucket gauges record runoff volumes as numbers of bucket tips per 24-h period. The depth of the daily runoff is then calculated by dividing the volume of daily runoff by the area of the test plot (Armson, Stringer, and Ennos, 2013). Pressure transducers allow for automatic continuous monitoring and data collection at certain intervals (e.g., 1-min) (Stovin, Vesuviano, and Kasmin, 2012).
Scale of measurement	Plot or building scale to district scale
Data source	
Required data	Runoff measurements
Data input type	Quantitative

Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Moderate – ability to evaluate the accuracy of measurements is required (in case of equipment malfunction)
Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Adkins, G.B. (2006). Flow Measurement Devices. Utah Division of Water Rights, Utah. Armson, D., Stringer, P. & Ennos, A.R. (2013). The effect of street trees and amenity grass on -urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening, 12, 282-286. Stovin, V., Vesuviano, G. & Kasmin, H. (2012). The hydrological performance of a green roof test bed under UK climatic conditions. Journal of Hydrology, 414-415, 148-161

3.13.2 Curve Number method

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

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Runoff coefficient – Curve Number	**Water Management**
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are

	affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (mm)
Strengths and weaknesses	+ The most widely used modelling method to estimate runoff from rainfall + Particularly useful for comparing pre- and post-development peak rates, volumes, and hydrographs - Curve number varies due to differences in rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature
Measurement procedure and tool	USDA Curve Number – Taking into account losses (interception, infiltration and storage) as well as antecedent moisture conditions – runoff is estimated for storm events. Published Curve Numbers (CN) can be used in the equation. CN values are function of soil, hydrological conditions and landcover (can be weighted). Widely used worldwide. Soil Conservation Service (1972). Used in context of NBS (Gill et al, 2007). Steps to produce the value for the storm runoff include: 1. Determine the value of *CN* for the specific cover type, hydrologic condition, and hydrologic soil group, using Table 9-1 in the USDA National Engineering Handbook (2004). 2. Determine the value for *S* based on the *CN* value, using Table 10-1 in the USDA National Engineering Handbook (2004) or equation for the *CN*. 3. Determine the runoff (*Q*) either using the graphical solution or tables provided by the USDA National Engineering Handbook (2004). For the determination, values for rainfall and *CN* are needed. Other possibility to determine the runoff is to use the runoff equation where values for rainfall and *S* are needed. The curve number equation to estimate runoff from rainfall is:

	$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad P > I_a$ $Q = 0 \qquad P \leq I_a$ Where *Q* is depth of runoff (in), *P* is depth of rainfall (in), I_a is initial abstraction (in), and *S* is maximum potential retention (in). The initial abstraction (I_a) consists mainly of interception, infiltration during early parts of a storm, and surface depression storage. The initial abstraction can be determined from rainfall-runoff events for small watersheds. However, estimation of the initial abstraction is not easy and I_a has been assumed to be a function of the maximum potential retention (*S*). An empirical relationship between I_a and *S* has been expressed as (USDA, 2004): $I_a = 0.2S$ With this relationship, the original runoff equation can be written in a more simplified form: $Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad P > I_a$ The runoff based on curve number can be determined based on graphs or tables provided by USDA (2004). The parameter *CN* is a transformation of potential maximum retention, *S* (in mm): $CN = \frac{1000}{10 + \frac{S}{25.4}}$
Scale of measurement	District scale to metropolitan area scale
Data source	
Required data	Hydrologic soil group (HSG), land use/cover, hydrologic surface condition and antecedent moisture condition
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires ability to execute the calculations, use the graphical solutions and evaluate the results

Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	United States Department of Agriculture (USDA). (2004). National Engineering Handbook Part 630 Hydrology. Washington, D.C.: United States Department of Agriculture, Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=STELPRDB1043063

3.13.3 Rational method

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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Runoff coefficient – Rational method	**Water Management**
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a

	heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (m^3/s or L/s)
Strengths and weaknesses	+ A widely used method, which gives an empirical relation between rainfall intensity and peak flow - Requires significant judgment and understanding from the designer - For the method, several assumptions that are seldom met under natural conditions must be made
Measurement procedure and tool	Rational Method for estimating 'peak' flow rates for simple urban watersheds/sewers. Often used for design discharges. Requires rainfall intensity, the runoff-coefficient (can be derived from published value) and watershed area (Kuichling, 1889). A simplified outline of the necessary steps to determine peak runoff using the Rational Method is: 1. Determine the runoff coefficient (C). Typical values are listed in textbooks and manuals (e.g., Viessman & Lewis, 2003; VDOT, 2002). If needed, use a saturation factor (C_f) for storms with a recurrence intervals less than 10 years. These higher intensity storms require modification to estimation of runoff. Saturation factors are given by reference books and design manuals. Note that the saturation factor C_f multiplied by the runoff coefficient C should not exceed 1.0. Saturation factors (C_f) for rational formula (VDOT, 2002). **Recurrence Interval (Years)** — C_f **2, 5 and 10** — 1.0 **25** — 1.1 **50** — 1.2 **100** — 1.25 2. Determine the time of concentration (T_c) to estimate the average rainfall intensity (i). The methods for determining the time of concentration are described by, e.g., VDOT (2002). One of them is that the time of concentration is the time required for water to flow from the hydraulically most remote point in the drainage area to the point of study. 3. Determine the rainfall intensity (i). It is assumed that the duration is equal to the time of concentration. The rainfall intensity can be selected from the IDF curve. 4. Solve the equation of the Rational Method to obtain the estimated peak runoff:

	$$Q = C_f C i A$$ Where Q is maximum rate of runoff (cfs), C_f is saturation factor, C is runoff coefficient representing a ratio of runoff to rainfall (dimensionless), i is average rainfall intensity for a duration equal to the time of concentration for a selected return period (in/hr), and A is drainage area contributing to the point of study (ac).
Scale of measurement	Plot or building scale to district scale. Used mostly for relatively small drainage areas, such as parking lots. The use should be limited to drainage areas <20 acres (ca. 8 ha).
Data source	
Required data	Rainfall intensity, drainage area, saturation factor, runoff coefficient
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires significant judgement on adequacy of calculated values
Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Dhakal, N., Fang, X., Asquith, W.H. & Cleveland, T. (2013). Return period adjustment for runoff coefficients based on analysis in undeveloped Texas watersheds. Journal of Irrigation and Drainage Engineering, June 2013 Hayes, D.C., & Young, R.L. 2005. Comparison of Peak Discharge and Runoff Characteristic Estimates from the Rational Method to Field Observations for Small Basins in Central Virginia. Scientific Investigations Report 2005-5254. Reston, VA: United States Geological Survey. Viessman, W. & Lewis, G.L. (2003). Introduction to Hydrology. 5th edition. Upper Saddle River, NJ: Prentice Hall Virginia Department of Transportation (VDOT). (2019). Drainage Manual. Location and Design Division. Issued April 2002. Rev. March 2019. Richmond, VA: Virginia Department of Transportation. Retrieved from

	http://www.virginiadot.org/business/resources/LocDes/DrainageManual/Combined_Drainage_Manual.pdf

3.13.4 Intensity-Duration-Frequency (IDF) curve method

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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Runoff coefficient – IDF curves	Water Management
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (L/s or m^3/s)
Strengths and weaknesses	+ IDF analysis provides a convenient tool for summarizing regional rainfall information and thus it is useful in municipal stormwater management practices - Requires significant judgment and understanding from the designer - Requires fairly extensive historic rainfall data
Measurement procedure and tool	Statistical estimation of 'peak' runoff rates for return periods of 5,10,100 years based on rainfall and

	catchment characteristics (area, channel slope, length, soil permeability). E.g. IH124 or FEH methods (UK). A summary of the steps necessary to create IDF curves is given by Mirrhosseini et al. (2013): 1. Obtain annual maximum series of precipitation depth for a given duration (15 min, 30 min, 45 min, 1 h, 2 h, 3 h, 6 h, 12 h, 24 h, and 48 h) 2. Use a suitable probability distribution (e.g., generalized extreme value per Mirrhosseini et al., 2013) to find precipitation depths for different return periods (2, 5, 10, 25, 50, and 100 y). One of the most common probability distributions used in the IDF analysis is Gumbel's extreme value distribution (Wang & Huang 2004). 3. Repeat the first two steps for different durations 4. Plot rainfall intensity versus duration for different frequencies In addition, other possible probability distributions can be used. Another possibility to create IDF curves is to use the equation (MTO 1997): $i = A / (t_d + B)^c$ Where *i* is average rainfall intensity (mm/h), t_d is rainfall duration (min) and *A, B*, and *c* are coefficients. The coefficients can be solved by least squares method described in the Ontario Drainage Management Manual produced by the Ministry of Transportation of Ontario (MTO, 1997). When the coefficients are solved, the above equation can be used to produce plots of rainfall intensity vs. duration for different return periods (Wang & Huang 2004).
Scale of measurement	Different sizes of catchments, district scale to region scale
Data source	
Required data	Recorded rainfall data (historic) and catchment characteristics (area, channel length, soil permeability)
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires ability and significant judgement to execute statistical analyses
Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators

Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Al Mamoon, A., Joergensen, N.E., Rahman, A., & Qasem, H. (2014). Derivation of new design rainfall in Qatar using L-moment based index frequency approach. International Journal of Sustainable Built Environment, 3(1), 111-118. Fadhel, S., Rico-Ramirez, M.A., & Han, D. (2017). Uncertainty of Intensity-Duration-Frequency (IDF) curves due to varied climate baseline periods. Journal of Hydrology, 547, 600-612. Ministry of Transportation of Ontario (MTO). (1997). Ministry of Transportation of Ontario Drainage Management Manual. Ontario, Canada: Ministry of Transportation of Ontario. Retrieved from http://www.mto.gov.on.ca/english/publications/drainage-management.shtml Mirrhosseini, G., Srivastava, P., & Stefanova, L. (2013). The impact of climate change on rainfall Intensity-Duration-Frequency (IDF) curves in Alabama. Regional Environmental Change, 13(S1), 25-33. Prodanovic, P., & Simonovic, S.P. (2007). Development of Rainfall Intensity Duration Curves for the City of London Under the Changing Climate. Water Resources Research Report No. 058. London, Ontario, Canada: Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering. Wang, X., & Huang, G. (2014). Technical Report: Developing Future Projected IDF Curves and a Public Climate Change Data Portal for the Province of Ontario. Submitted to Ontario Ministry of the Environment. Saskatchewan, Canada: Institute for Energy, Environment and Sustainable Communities (IEESC) of the University of Regina. Retrieved from http://www.ontarioccdp.ca/final_tech_report.pdf

3.13.5 Process-based hydraulic modelling

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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Runoff coefficient – Process-based hydraulic modelling	**Water Management**
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (mm)
Strengths and weaknesses	+ Possibility to extrapolate the measurements spatially and temporally + Allows for future predictions and forecasts given the available measurements - Modelling includes numerous simplifications and approximations (adequacy of process parametrizations, data limitations and uncertainty, and computational constraints on model analysis) - Multiple challenges arise when choosing the approach to modelling
Measurement procedure and tool	One-dimensional and two-dimensional drainage system modelling exist. There are many examples of models applied in an urban context. Existing approaches used to evaluate GI/NBS are the Stormwater Management Model (SWMM [USA]), CityCat (Newcastle), MIKE (DHI) and InfoWorks for

Sustainable Drainage Systems (SUDS [UK]). Impact of climate change on runoff can be evaluated using the design storms. The models typically require multiple parameters for accurate results.

1. The modelling process starts with a perceptual model, which is the summary of perceptions of how the catchment responds to rainfall under different conditions. In the conceptual model, mathematical descriptions are formed where hypotheses and assumptions are taken into account.

2. If the equations decided in the conceptual model cannot be solved analytically given some boundary conditions for the real system, an additional stage of approximation is necessary using the techniques of numerical analysis to define a procedural model. This is given in a form of code that will run on the computer.

3. In the next phase, the parameters used in the model needs to be calibrated. The most commonly used method in the model calibration is matching the model predictions and observations from the direct measurements if they are available.

4. After the calibration of parameters, simulations with the model could be made. Results of the simulations should then be reviewed and the model validated. The validation can be done by comparing the results to direct measurements, e.g., observed discharges, if they are available (Beven 2012).

When choosing a conceptual model, the following procedure can be used (Beven, 2012):

- Prepare a list of the models under consideration.
- Prepare a list of the variables predicted by each model. Decide if the model under consideration will give the needed output.
- Prepare a list of the assumptions made by the model. Reject models where the assumptions are estimated to be too inaccurate.
- Make a list of the inputs required by the model, for specification of the flow domain, the boundary and initial conditions and the parameter values.
- Determine whether you have any models left on your list. If not, the criteria should be reviewed again and then review the previous steps.

Comparison of the basic structure for rainfall- runoff models (adapted from Sitterson et al., 2017):

	Empirical	**Conceptual**	**Physical**

Method	Non-linear relationship between inputs and outputs, black box concept	Simplified equations that represent water storage in catchment	Physical laws and equations based on real hydrologic responses
Strengths	Small number of parameters needed, can be more accurate, fast run time	Easy to calibrate, simple model structure	Incorporates spatial and temporal variability, very fine scale
Weaknesses	No connection between physical catchment, input data distortion	Does not consider spatial variability within catchment	Large number of parameters and calibration needed, site specific
Best Use	In ungauged watersheds, runoff is the only output needed	When computational time or data are limited	Have great data availability on a small scale
Examples	Curve Number, Artificial Neural Networks[a]	HSPF[b], TOPMEDEL[a], HBV[a], Stanford[a]	MIKE-SHE[a], KINEROS[c], VIC[a], PRMS[d]

[a] Devia, Ganasri, & Dwarakish, 2015

[b] Johnson, Coon, Mehta, Steenhuis, Brooks, & Boll, 2003

[c] Woolhiser, Smith, & Goodrich, 1990

[d] Singh, 1995

Scale of measurement	All scales depending on the type of model used
Data source	
Required data	Rainfall measurements, spatial drainage area characteristics (e.g., area, slope)
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires ability to apply hydrologic models and assess the output

Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Beven, K.J. (2012). Rainfall-Runoff Modelling: The Primer. Second Edition. Chichester, West Sussex, U.K.: Wiley-Blackwell. Clark, M.P., Bierkens, M.F.P., Samaniego, L., Woods, R.A., Uijlenhoet, R., Bennett, … Peters-Lidard, C.D. (2017). The evolution of process-based hydrologic models: historical challenges and the collective quest for physical realism. Hydrology and Earth System Sciences, 21, 3427-3440 Devia, G.K., Ganasri, B.P., & Dwarakish, G.S. (2015). A Review on Hydrological Models. Aquatic Procedia, 4, 1001-1007. Johnson, M.S., Coon, W. F., Mehta, V.K., Steenhuis, T.S., Brooks, E.S., & Boll, J. (2003). Application of two hydrologic models with different runoff mechanisms to a hillslope dominated watershed in the northeastern US: a comparison of HSPF and SMR. Journal of Hydrology, 284(1-4), 57-76. Singh, V.P. (Ed.). (1995). Computer Models of Watershed Hydrology. Highlands Ranch, CO: Water Resources Publications, LLC. Sitterson, J., Knightes, C., Parmar, R., Wolfe, K., Muche, M., & Avant, B. (2017). An Overview of Rainfall-Runoff Model Types. EPA Report Number EPA/600/R-17/482. September 2017. Athens, GA: Office of Research and Development National Exposure Research Laboratory. Woolhiser, D.A., Smith, R.E., & Goodrich, D.C. (1990). KINEROS, A kinematic runoff and erosion model: Documentation and user manual. ARS-77. Washington, D.C.: United States Department of Agriculture, Agricultural Research Service. Retrieved from https://www.tucson.ars.ag.gov/unit/Publications/PDFfiles/703.pdf

3.14 Water Quality – general urban

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Water quality – general urban	Water Management
Description and justification	Run-off water in cities represents a threat to water quality by conveying high pollutant loads into receiving water bodies and ground water aquifers. NBS can help manage and improve urban water quality through settlement, filtration, bioretention and phytoremediation. Emerging techniques using remote sensing technology includes using high resolution satellite or airborne optical imagery (visible and infrared), DSM (Digital Surface Model) height information and existing building out- lines maps (footprints) to estimate the percentage of vegetated areas on building roofs and to identify potential green roof sites, providing municipalities with the opportunity to use this data for urban planning decisions in the field of climate modelling, drainage system calculation and biodiversity networks. Recent and planned launches of satellites with improved spectral and spatial resolution sensors should lead to greater use of remote sensing techniques to assess and monitor water quality parameters. Data on the water quality performance of nature-based solutions collected in these ways can be used to: • Quantify the benefits of NBS in terms of stormwater/waterway quality improvement; • Assess any negative impact on water quality of diverting rainwater through NBS; • Calculate total pollution loading being released from an NBS (when combined with flow rate calculations); • Assess compliance with Water Framework Directives; Provide easily accessible data to communities and decision-makers to change perceptions of SuDS.
Definition	Calculating/predicting the change in water quality caused by diverting rainfall or surface water flow through an NBS (e.g., green roof, tree pit, bioretention pond, rain garden, wet woodland, naturalised waterway, etc). Implementing an NBS can result in a positive or negative impact on water quality. This is dependent upon: the quality of water entering the system, the type of NBS, the age of NBS, and the water quality parameters being investigated. Both

	positive and negative impacts of NBS on water quality are of relevance for this indicator. Remote sensing and earth observation approaches are only generally used to provide background/mapping data that can be fed into water quality modelling.
Strengths and weaknesses	**Applied methods:** Robustness of evidence depends upon the precision and accuracy of the method adopted. Frequency and design of sampling is also linked to the strength of evidence. For example, regular sampling may provide long-term and seasonal patterns but may miss significant short-term events such as 'first flush' of urban areas following long dry periods. **EO/RS methods:** Methods can provide robust data, but the range of water quality parameters that EO/RS can provide is limited.
Measurement procedure and tool	*Applied/participatory methods*: Basic measurements of water quality associated with NbS have included: • NO_3, NO_2 and NH_3 (Payne et al., 2014; Batalini de Macedo et al. 2019) • Phosphorus (Bratieres et al. 2008a) • Heavy metals (Blecken et al. 2011; Batalini de Macedo et al. 2019) • Suspended/Sedimentary solids (Hatt et al 2008; Batalini de Macedo et al. 2019, Fowdar et al. 2017) • Micropollutants (such as hydrocarbons and pesticides) (Zhang et al. 2014) • Colour (Batalini de Macedo et al. 2019) • Turbidity (Batalini de Macedo et al. 2019) • Chemical Oxygen Demand (Batalini de Macedo et al. 2019; Leroy et al. 2016) • Biological Oxygen Demand (Fowdar et al. 2017; Leroy et al. 2016) • Pathogens (Bratieres et al. 2008b) • Hydrocarbons (Hong et al. 2006) • Total organic carbon (TOC) and dissolved organic carbon (DOC) (Fowdar et al. 2017) Choice of parameter to measure should be related to issues of water pollution, the type of plant species and substrates used in the bioretention process, physio-chemical processes, and the desired quality of water at the end of processing (Dagenais et al. 2018; Payne et al. 2018, Batalini de Macedo et al. 2019). Sampling can be done using in-situ stormwater sampling equipment (e.g., Teledyne ISCO 6712/7400 (Hong et al.

2006), ISCO GLS auto-sampler (Lucke and Ncihols 2015), ISCO Model 6712 Portable Sampler (Stagge et al. 2012)). This allows continuous and simultaneous sampling. Where this is not possible, or is prohibited by cost, v-notch weirs installed to monitor flow rate can be used to create a reservoir that can be sampled using a manual sampling technique (Hong et al. 2006). Alternatively, artificial drain/reservoir features can be incorporated into the NbS design from which water samples can be collected (Leroy et al. 2016). Laboratory analysis of each parameter is then carried out based on standardised analytical methods (e.g., Standard Methods for Examination of Water and Wastewater (APHA, 2015)).

An alternative, and more participatory method of monitoring water quality can be achieved through the use of biological indicators to monitor moving or still waterbodies. An example of this is the Biological Monitoring Working Party (BMWP) scoring system (Armitage et al. 1983) or adapted versions of this protocol (e.g., Romero et al. 2017). Samples are typically collected by kick sampling or surber sampling (Everall et al. 2017), providing opportunities for community engagement (including as part of school curricular activities). Wetland plants have also been used as biological indicators of water chemistry in wetland areas (US EPA 2002).

Simulated storm events with artificially created water pollution can be used as a mechanism to validate performance of NbS (Lucke and Nichols 2015). This is of particular value to ensure continuity of performance as the NbS ages/matures.

Remote sensing/Earth observation methods:

Remote sensing and earth observation approaches are only generally used to provide background/mapping data that can be fed into water quality modelling. However, some remote sensing techniques are emerging. Methods for delivering this include:

a) In general:

The remote sensing technology uses high resolution satellite or airborne optical imagery (visible and infrared), DSM (Digital Surface Model) height information and existing building out- lines maps (footprints) to estimate the

	percentage of vegetated areas on building roofs and to identify potential green roof sites. The new remote sensing technology provides municipalities with the opportunity to use this data for urban planning decisions in the field of climate modelling, drainage system calculation and biodiversity networks. According to Ritchie et al. (2003), remote sensing techniques can be used to monitor water quality parameters (i.e., suspended sediments (turbidity), chlorophyll, and temperature). Optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information needed to monitor changes in water quality parameters for developing management practices to improve water quality. Recent and planned launches of satellites with improved spectral and spatial resolution sensors should lead to greater use of remote sensing techniques to assess and monitor water quality parameters. Integration of remotely sensed data, GPS, and GIS technologies provides a valuable tool for monitoring and assessing waterways. Remotely sensed data can be used to create a permanent geographically located database to provide a baseline for future comparisons. The integrated use of remotely sensed data, GPS, and GIS will enable consultants and natural resource managers to develop management plans for a variety of natural resource management applications. In addition, Massoudieh et al. (2017) developed a modelling framework to predict the water quality impacts of urban stormwater green infrastructure systems. Shi et al. 2017 demonstrated links between urban water quality and different landuse patterns that could be used to predict improvements in water quality. For further information, see: Connecting Nature Environmental Indicator Metrics Review Report
Scale of measurement	**Applied methods:** Implementation is typically on a component or site level. It can be scaled-up to much larger scales through replication. However, it is more typical to model the impacts of up-scaling once results have been obtained that can be fed into the model. **EO/RS methods:** Typically used on medium/large scale monitoring as resolution of satellite imagery can create a barrier to monitoring smaller scale areas.

Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report
Data input type	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report
Data collection frequency	Data collection frequency will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report
Level of expertise required	**Applied methods:** Some expertise required for installation of equipment and/or sampling methodology. Expertise required for sample analysis depends on the level of automation of the sampling equipment (e.g., in stream dataloggers carry out sample analysis automatically). Samples taken may require specialist analytical methods, these are typically carried out through an accredited laboratory. Data analysis/interpretation against statutory guidelines can be very basic once systems are in place. **EO/RS methods:** Data processing expertise is needed.
Synergies with other indicators	**Applied methods:** There are synergies in relation to measuring flowrates as such data is necessary for calculating total pollutant loads over time. BMWP scoring can be linked to biodiversity indicators. Improved water quality can have correlations with nature, health and social value of a waterway. **EO/RS methods:** Synergies with other water management and blue space area indicators.
Connection with SDGs	SDG3, SDG4, SDG6, SDG8-SDG12; SDG14-SDG17: Clean water supply; Links to environmental education; Clean water; Job creation; Social equality in relation to water quality; Sustainable urban development; More sustainable water management; Improved water quality (for life below water); Improved water quality (for life on land); Environmental Justice; Opportunities for collaborative working
Opportunities for participatory data collection	**Applied methods:** Opportunities are available for a participatory process, particularly in relation to carrying out visual inspection of water (e.g., in relation to combined sewage overflow occurrences and water sampling (Farnham et al. 2017; Jollymore et al. 2017). Water quality analysis can be linked to local schools/universities, especially through schemes that use BMWP methodologies to monitor

	water quality in waterways. Automated dataloggers offer less opportunity for such participation with participation limited to observing and processing the data produced. There are also opportunities for stewardship of equipment or nature-based solution, etc. **EO/RS methods:** Limited opportunities for participation
Additional information	
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3.15 Total Suspended Solids (TSS) content

Project Name: CLEVER Cities (Grant Agreement no. 776604), GrowGreen (Grant Agreement no. 730283) and UNaLab (Grant Agreement no. 730052)

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TSS content	Water Management
Description and justification	Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material and can have adsorbed pollutants. High concentrations of suspended solids can affect the health and productivity of the aquatic life. TSS and turbidity are simple indicators of water quality. Sources of TSS include, e.g., sediment runoff from agricultural fields, logging activities, construction sites, roadways, waste discharge, or

	excessive algal growth. The TSS content often increases sharply during and immediately following a rainfall event. The EU Freshwater Fish Directive (2006/44/EC) recommends ≤25 mg/L TSS for salmonid and cyprinid fish health (European Parliament, 2006), whilst the concentration of TSS in wastewater treatment plant effluents is limited to ≤35 mg/L by Wastewater Directive 91/271/EEC (European Parliament, Council of the European Union, 1991).
Definition	Total suspended solids (TSS) or turbidity (%, mg/L and total; units dependent upon measurement technique). A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids".
Strengths and weaknesses	+ Simple evaluation + In turbidity measurements, Secchi disk is very commonly used visual method because it is easy to use, inexpensive, and relatively accurate. The turbidity meter method is very accurate - Laboratory measurement of TSS directly quantifies the amount of fine particulate material suspended in water but is relatively time-intensive. - Time consuming TSS measurements, non-continuous compared to turbidity
Measurement procedure and tool	Total suspended solids (TSS) are typically quantified in the laboratory using a gravimetric process, yielding TSS measurement in units of mass per volume (e.g., mg/L or ppm). Measurement of TSS involves filtration of a water sample followed by drying and weighing of the particulates removed. Simply, this means anything that is captured by filtering the sample aliquot through a specific pore size filter. A measured volume (no more than 1 L) of sample is passed through a prepared, pre-weighed filter paper. The filter is dried at 104 ± 1°C. After drying, the filter is reweighed and the TSS is calculated. A semi-quantitative, rapid assessment of TSS can be accomplished by evaluating sample turbidity, a measure of the relative transparency of a water sample. Turbidity measurements rely on comparison of light scattering with standard solutions (turbidity meter) or visual assessment (Secchi disk, transparency tube). Turbidity meters use a light beam with defined characteristics to provide a semi-quantitative measure of the particulates present in the water, providing an integrated measure of light scattering and absorption. The measurement is provided in nephelometric turbidity units (NTU). Turbidity (in NTU) can

	be directly related to TSS (in mg/L) via creation of a standard curve (TSS versus turbidity) for a given location/type of fine particulate material. • Measuring turbidity *in-situ*: o Secchi disk, which is lowered into the water and the level where the disk disappears is registered. o Turbidity meter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90° angle by the particles in the sample. o Transparency tube is a clear, narrow plastic tube marked in units with a light and dark pattern painted on the bottom. Water is poured into the tube until the pattern disappears, and the depth is recorded.
Scale of measurement	Plot scale to district scale
Data source	
Required data	TSS or turbidity measurement data
Data input type	Quantitative and semi-quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection for turbidity is possible under supervision
Additional information	
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3.16 Nitrogen and phosphorus concentration or load

Project Name: UNaLab (Grant Agreement no. 730052)

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Water Quality: Nitrogen and phosphorus concentration or load	**Water Management**
Description and justification	Nutrients, including nitrogen (N) and phosphorus (P), can have significant impact on water quality, including effects on plant growth, oxygen concentration, water clarity, and sedimentation rates. Some major anthropogenic sources of nutrients are agricultural and industrial emissions, discharged wastewater and atmospheric deposition. Nitrogen and phosphorus are present in water in many different forms, or as many different chemical species. The forms of N and P that are quantified can include some or all of the following: • <u>Nitrogen</u>: total N (N_{tot}), total Kjeldahl N (TKN), dissolved organic N (DON), nitrate (NO_3^-), nitrite (NO_2^-) and ammonia/ammonium (NH_3/NH_4^+) • <u>Phosphorus</u>: total P (P_{tot}), acid-hydrolysable P (AHP), orthophosphate (PO_4^{3-})
Definition	Nitrogen and phosphorus in surface water and/or groundwater (%, expressed as total annual N or P load and/or reduction of maximum annual concentration)
Strengths and weaknesses	+ Laboratory analyses are accurate but can be quite costly. A full suite of analyses can be done for multiple chemical species of N and P. + Ion selective electrodes (ISEs) are less expensive and easier to use alternative. Whilst ISEs for various N species (NO_2^-, NO_3^-, NH_3/NH_4^+) are readily available from multiple suppliers,

	ISEs for phosphate are less common. ISEs have a potential for permanent installation at a given sampling point. - Test kits obtain a rapid result, but are in general less accurate than analyses performed in an accredited laboratory. Photometers are generally quite accurate but can be expensive to purchase and maintain. Test kits based on colour comparison, either of test strips or solutions, are relatively less costly but can have limited accuracy at low nutrient concentrations
Measurement procedure and tool	Different nitrogen and phosphorus species can be quantified in a water sample either in the field, using a test kit or ion selective electrode (ISE), or via laboratory analyses. Laboratory analyses can be done for multiple chemical species of N and P. Ion selective electrodes are analogous to a pH electrode and are used in much the same way as a pH electrode (pH electrodes are essentially ion selective electrodes that are sensitive to the H^+ ion) ISEs have a potential for permanent installation at a given sampling point. It is possible to program a data logger connected to an *in-situ* ISE to measure and record a value at a prescribed frequency. Test kits are usually used on site (in the field). Test kits typically involve the addition of chemical reagents to a water sample and yield results based on test strip colour comparison, solution colour comparison to a colour wheel or colour chart, or measurement with a photometer. The spectrophotometer measures the quantity of a chemical based on its characteristic absorption spectrum.
Scale of measurement	Plot scale to district scale, depending on location of sampling point
Data source	
Required data	Measurement data of a water sample
Data input type	Quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 13 Climate action, SDG 14 Life below water

Opportunities for participatory data collection	Participatory data collection possible with test kits and ion selective electrodes under supervision
Additional information	
References	EPA method 300.1: Determination of inorganic anions in drinking water by ion chromatography; https://www.epa.gov/sites/production/files/2015-06/documents/epa-300.1.pdf ISO 29441:2010: Water quality — Determination of total nitrogen after UV digestion — Method using flow analysis (CFA and FIA) and spectrometric detection, https://www.iso.org/standard/45480.html ISO 15681-1:2003 Water quality — Determination of orthophosphate and total phosphorus contents by flow analysis (FIA and CFA) — Part 1: Method by flow injection analysis (FIA), https://www.iso.org/obp/ui/#iso:std:iso:15681:-2:ed-2:v1:en ISO 15681-2:2018 Water quality — Determination of orthophosphate and total phosphorus contents by flow analysis (FIA and CFA) — Part 2: Method by continuous flow analysis (CFA), https://www.iso.org/standard/66474.html Orhel, R.L., & Register, K.M. (2006). Volunteer Estuary Monitoring. A Methods Manual. Second edition. Washington, D.C: United States Environmental Protection Agency. Reedyk, S., & Forsyth, A. (2006). *Using field chemistry kits for monitoring nutrients in surface water*. Publication number PRO-121-2006-1. Ottawa, Ontario, Canada: Agriculture and Agri-Food Canada PFRA. Retrieved from http://pfra.ca/doc/Water%20Quality/Water%20Quality%20Protection/using_field_chem_kits_final.pdf

3.17 Metal concentration or load

Project Name: CLEVER Cities (Grant Agreement no. 776604), GrowGreen (Grant Agreement no. 730283) and UNaLab (Grant Agreement no. 730052)

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Water Quality: Metal concentration or load	Water Management
Description and justification	Metals and metalloids (herein referred to simply as metals) are ubiquitous in the natural environment and can potentially accumulate to toxic levels for the aquatic environment and humans as metals do not degrade with time. As such, metals can have a significant impact on water quality and its fit-for-purpose use. Natural sources of metals include weathering of geologic materials (rocks and soil) and volcanic activity. The primary reservoir of metals is geological substrate. Human activity has greatly accelerated natural biogeochemical cycles, resulting in anthropogenic emissions of metals to the atmosphere one to three orders of magnitude greater than natural fluxes. Anthropogenic sources of metals include point sources such as mining and industrial activities, and non-point sources such as fossil fuel combustion and agricultural activities. Stormwater may transport heavy metals from industries, municipalities and urban areas at different quantities, which are accumulated in soil, sediments and water bodies. Removal can be achieved by appropriately designed NBS. Some of the more common metal pollutants are: aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb) and mercury (Hg), selenium (Se), vanadium (V) and zinc (Zn).
Definition	Metal pollutants in surface water and/or groundwater (%, expressed as total annual metal pollutant load and/or reduction of maximum annual concentration). (Concentration of heavy metals before NBS treatment - Concentration of heavy metals after NBS treatment)/ Concentration of heavy metals before NBS treatment)*100
Strengths and weaknesses	+ ICP analyses are highly precise and accurate to very low concentrations

	- ICP analyses can be quite costly and with the high number of metals (Cd, Cr, Pb, Hg, Ni, Zn, Cu…) some of which could be at very low concentration levels, this can add to the expense. - There is usually a significant delay between the time of sample collection and receipt of water quality data from the laboratory + Test kits and ion selective electrodes (ISEs) can provide rapid results + ISEs can be installed in-situ to take measurements at regular intervals - A separate kit or ISE is required for each element of interest, and the limit of detection for a given element of interest may be substantially higher than the respective accredited laboratory analysis technique - Analysis of individual metals using field test kits can be time-intensive and/or require trained personnel to conduct the tests
Measurement procedure and tool	Metals in water samples are typically quantified in an accredited laboratory using a suite of standardised analyses. Ion-coupled plasma spectrophotometry (ICP) coupled with atomic emission spectrometry (MS), with or without pre-treatment/pre-concentration, is a well-recognised analytical method for the quantification of trace metals in waters. Multiple elements can be analysed from a single sample. Methods may vary depending on the water matrix and metals to be analysed, but generally the method compromised the following steps: • Sample preparation which may include weighing of the sample, solubilisation of the solids with acids with/without heat (for total recovery analysis), separation of undissolved material • Calibration of the equipment • Sample analysis The nature of ICP analyses means that the analysed samples represent a single point in time (the time at which the sample was collected), and metal concentrations may vary substantially in urban waters due to the contribution of run-off from urban surfaces. Field test kits are available for on-site testing of some metals (e.g., As, Cd, Cu, Pb, Mo, etc.) whilst other metals can be detected using an ion-selected electrode (ISE; e.g., Cd, Pb, Zn, etc.). Field test kits vary greatly and range from semi-quantitative paper test strips for multiple metals, to quantitative colourimetric-type analyses. Some field test kits may involve the use of portable laboratory

	equipment such as a photometer, fluorometer or similar. With ISEs there is a potential to install a testing unit in-situ to take measurements at regular intervals and save results to a data logger or upload to a central data repository.
Scale of measurement	Plot scale to district scale, depending on location of sampling point for concentrations ranging from ng/L to mg/L
Data source	
Required data	Water samples. Relatively small sample volume is required (typically 100 mL or less)
Data input type	Quantitative and semi-quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Low to Moderate for sampling High for analysis
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection possible with test kits and ion selective electrodes under supervision
Additional information	
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3.18 Total faecal coliform bacteria

Project Name: UNaLab (Grant Agreement no. 730052) and PHUSICOS (Grant Agreement no. 776681)

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Total faecal coliform bacteria in NBS effluents	Water Management
Description and justification	Faecal coliform bacteria are a subgroup of a larger total coliform group referring to the Gram-negative, rod-shaped bacteria. Faecal coliform bacteria denote a group of thermotolerant coliform organisms, optional aerobic or anaerobic, which grow at 44 ± 0.5 °C and ferment lactose to produce acid and gas (Bartram & Pedley, 1996; Doyle & Erickson, 2006). Although coliform bacteria are easy to detect, their presence does not imply the faecal contamination due to the natural occurrence of some faecal coliform organisms of non-faecal origin. Thus, the pathogenic strains of *Escherichia coli (E. coli)* are usually analysed to determine the sanitary contamination of water

	(ISO, 2014). Presence of faecal coliform bacteria in the natural waters may indicate the faecal contamination and degradation of the water bodies originating from diffuse sources such as urban runoff and transport from sewer overflows (Davies et al., 1995; Davies & Bavor, 2000).
Definition	Observed number of faecal coliform colony units determined by direct counting (Colony Forming Unit (CFU)/100 mL or CFU/100 g) or most probable number (MPN) methods (MPN/100 mL or MPN/g)
Strengths and weaknesses	+ Almost always implies the faecal contamination of water + Standardized methodology for analyses - Analyses require expert knowledge and judgement
Measurement procedure and tool	a. Membrane filtration and direct counting The traditional way of evaluating the water samples for bacteria is the membrane filtration method. First, the water sample is filtered through a membrane, then the bacteria are cultured on an agar medium in a Petri dish and incubated at a specified temperature for a specified period of time depending on the type of bacteria analysed. Later, the number of the target organisms in the sample is calculated. The background bacterial growth may inhibit the enumeration of coliform bacteria, so this method is not deemed suitable for shallow and surface waters. b. Most probable number (MPN) method MPN is a statistical method used for enumeration of the viable target organisms by sequential inoculation and incubation in a liquid medium in ten-fold dilutions. Several assumptions must be made when using the MPN method, such as assuming the random distribution of the organisms in the sample (implying that no bacterial clustering and repelling is present), and assuming that the tubes will produce detectable growth. The advantages of the MPN method include the possibility for adjustment of the accuracy of the results when increasing the number of tubes per dilution, and larger sample size than in the plate count method. The MNP method is suitable for all types of water.
Scale of measurement	Plot scale
Data source	
Required data	Microbiological analyses of water
Data input type	Quantitative

Data collection frequency	At minimum before and after NBS implementation
Level of expertise required	High – requires familiarity with the laboratory practices and expertise for conducting the microbiological analyses and evaluating the outcomes
Synergies with other indicators	Together with other *Water Management* indicators determines the overall status of water quality in an area
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection is possible under direct qualified staff supervision
Additional information	
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4 Additional Indicators of Water Management

4.13 Measured infiltration rate and capacity

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Infiltration rate Infiltration capacity	**Water Management**
Description and justification	Surface imperviousness is characteristic of urban areas and an important environmental indicator (Arnold & Gibbons, 1996; Strohbach et al., 2019). As surface imperviousness increases, the volume and velocity of surface runoff increases and there is a corresponding decrease in water infiltration. A high proportion of surfaces in urban areas are impermeable and the impermeability of surfaces in the cities is increasing as cities become more densely populated. The impermeability of urban surfaces originates from constructing buildings, roads, parking areas, etc., with materials that are not permeable to water.
Definition	Infiltration capacity (%; change in precipitation infiltration capacity measured using ring infiltrometer & extrapolated/modelled for full unsealed area)
Strengths and weaknesses	+ Straightforward assessment of infiltration capabilities of soil + Fairly easy to run the experiments - Several measurement locations may not represent the situation holistically - Potential sources of errors during the measurement procedure
Measurement procedure and tool	When measuring water flow parameters in the field (field-saturated parameters), the measurements in the unsaturated or vadose zone (above the water table), are typically conducted using various ring infiltrometer and borehole or well permeameter methods. In the saturated zone (below the water table), water flow parameters (saturated parameters) are usually measured using auger hole methods, and at greater depths using piezometer methods.

Measurements of water flow parameters of the soil in the vadose zone using ring infiltrometers can be conducted with the following steps (Reynolds et al., 2002):

1. The cylinder is inserted 3-10 cm into the soil. The contact between the soil and the inside cylinder should be lightly tamped to prevent flow or leakage around the cylinder walls.

2. A constant depth of water is ponded inside the measuring cylinder and also inside the buffer cylinder if the concentric-ring infiltrometer is used. The ponding depth is usually 5-20 cm depending on the circumstances.

3. The water infiltration rate through the measuring cylinder is measured. The infiltration rate through the buffer cylinder can also be measured if single-ring and concentric-ring infiltration rate results are compared. Quasi-steady flow in the near-surface soil under the measuring cylinder is assumed to occur when the discharge becomes effectively constant. The field-saturated hydraulic conductivity, K_{fs}, can be calculated using the Equation 1.

$$q_s/K_{fs} = Q/(\pi a^2 K_{fs}) = [H/(C_1 d + C_2 a)] + \{1/[\alpha^*(C_1 d + C_2 a]\} + 1 \qquad (1)$$

where q_s (L T^{-1}) is quasi-steady infiltration rate, K_{fs} (L T^{-1}) is the field-saturated hydraulic conductivity, Q (L^3 T^{-1}) is the corresponding quasi-steady flow rate, a (L) is the ring radius, H (L) is the steady depth of ponded water in the ring, d (L) is the depth of ring insertion into the soil, C_1=0.316π and C_2=0.184π are dimensionless quasi-empirical constants that apply for $d \geq 3$ cm and $H \geq 5$ cm (Reynolds & Elrick, 1990; Youngs, Leeds-Harrison, & Elrick, 1995). The macroscopic capillary length, α (L^{-1}), can be estimated from soil structure and texture or measured using independent methodology. Some values for α:

Table 1: Soil texture-structure categories for site-estimation of the parameter "α" (Reynolds et al., 2002, adapted from Elrick, Reynolds & Tan, 1989).

Soil texture and structure category	**α* (cm^{-1})**
Compacted, structureless, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments	0.01
Soils that are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04

<table>
<tr><td></td><td><table>
<tr><td>Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.</td><td>0.12</td></tr>
<tr><td>Coarse and gravelly sands; may also include highly structured or aggregated soils, as well as soils with large and/or numerous cracks, macropores.</td><td>0.36</td></tr>
</table>
The following instructions for measuring infiltration of a water permeable pavement are based on the ASTM C1701/C1701M-09 (infiltration rate of in situ pervious concrete). More detailed instructions are provided in the standard.
• Install the infiltration ring. The joint between the ring and the pavements should be made watertight using, e.g., plumber’s putty.
• Conduct pre-wetting. Pour a total of 3.60 ± 0.05 kg of water inside the ring so that the head maintains between lines marked inside the ring. The timing starts when the water hits the surface and it stops when there is no free water left on the surface.
• Conduct the test. The test shall start within 2 min after the completion of the pre-wetting. Similar procedure for the test is used than in the pre-wetting. However, if the elapsed time in the pre-wetting was less than 30 s, a total of 18.00 ± 0.05 kg of water is used in the test. </td></tr>
<tr><td>Scale of measurement</td><td>Plot scale to street scale</td></tr>
<tr><td colspan="2">Data source</td></tr>
<tr><td>Required data</td><td>Soil texture and structure category, infiltration rate of soil</td></tr>
<tr><td>Data input type</td><td>Quantitative</td></tr>
<tr><td>Data collection frequency</td><td>Annually, and before and after NBS implementation</td></tr>
<tr><td>Level of expertise required</td><td>Moderate – requires ability to perform the experiment
High – for executing the calculations</td></tr>
<tr><td>Synergies with other indicators</td><td>Indirect relation to the whole Water Management indicator group</td></tr>
<tr><td>Connection with SDGs</td><td>SDG 11 Sustainable cities and communities, SDG 13 Climate action</td></tr>
<tr><td>Opportunities for participatory data collection</td><td>Participatory data collection is feasible through conducting an infiltration rate experiment under supervision</td></tr>
</table>

Additional information	
References	Arnold, C.L., Jr., & Gibbons, C.J. (1996). Impervious surface coverage: The emergence of a key environmental indicator. Journal of the American Planning Association, 62(2), 243-258. ASTM C1701/C1701M-09. Standard test method for infiltration rate of in place pervious concrete. Reynolds, W.D., Elrick, D.E., & Youngs, E.G. (2002). Ring or Cylinder Infiltrometers (Vadose Zone). In J.H. Dane & G.C. Topp (Eds.), Methods of Soil Analysis. Part 4 Physical Methods. Madison, Wisconsin: Soil Science Society of America, Inc. Strohbach, M.W., Döring, A.O., Möck, M., Sedrez, M., Mumm, O., Schneider, A.-K., … Schröder, B. (2019). The "hidden urbanization": Trends of impervious surface in low-density housing developments and resulting impacts on the water balance. Frontiers in Environmental Science, 7, 29. Youngs, E.G., Leeds-Harrison, P.B., & Elrick, D.E. (1995). The hydraulic conductivity of low permeability wet soils used as landfill lining and capping material: analysis of pressure infiltrometer measurements. Journal of Soil Technology, 8, 153-160.

4.14 Calculated infiltration rate and capacity

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Infiltration rate **Infiltration capacity**	**Water Management**
Description and justification	It refers to the speed at which water moves into and through the soil profile. It is normally expressed as the volume of water (measured in terms of water column) infiltrating within a given soil area per unit of time. It is related to the soil's ability to allow water movement within the soil profile, to the storage of water in the soil, the water available to plants, or the generation of runoff. Calculated infiltration rate can be derived from classic soil infiltration models, from pedotransfer functions, or from simple soil water mass balances.
Definition	Volume of water infiltrating a soil volume per unit of time

Strengths and weaknesses	+ Driving variable and boundary condition in water-driven systems and processes + Bridges the atmosphere, plant, soil continuum under wetting/rainfall conditions + Can be estimated from well-established models and heuristic approaches - Computational effort can be high and needs expertise - Soil and meteorological information is needed - Some variables involved in the existing models are difficult to quantify
Measurement procedure and tool	Calculation of soil infiltration rate is generally based on Darcy's law, i.e., an equation that describes the flow of a fluid through a porous medium. Soil infiltration models normally assume that infiltration occurs vertically from a ponded surface to an isotropic soil profile of uniform water content (Rawls et al., 1989). The infiltrating water is assumed to travel as a piston flow with a sharp division between the saturated soil above the wetting front and the dry soil below (Fig. 1; Neitsch et al., 2011). The most commonly used infiltration models are the Philip model, the Green-Ampt model, and the Smith and Parlange model (e.g., Morbidelli et al., 2018). Model outcomes should be compared against site-specific infiltration tests (e.g., Guelph permeater test) to establish which model replicates infiltration best. However, the most widely used model is the Green-Ampt model due to its physically-based, integrated nature and ability to portray soil infiltration realistically. Information on the soil saturated hydraulic conductivity (Ks) and matric suction of the wetting front is needed to implement Green-Ampt, which can be retrieved from pedotransfer functions knowing the soil's particle size distribution and organic matter content (e.g., Saxton and Rawls, 2006; Toth et al., 2015). After setting up the initial moisture conditions and knowing the rainfall intensity and duration, one can estimate how far the wetting front travels in the vertical direction, how long it takes, what is the infiltration rate at that stage and how much water runs off or enters the soil profile. The equations for the Green-Ampt model are gathered for example in Neitsch et al. (2011). Alternatively, a heuristic approach can be followed to calculate soil infiltration under the assumption that infiltration occurs at a rate equal to Ks. A soil water mass balance can be established for a given rainfall event if rainfall intensity and duration are known. Accordingly, runoff (RF) can be calculated as RF=Pg-Ks.tr, where Pg is the rainfall depth (mm), Ks the saturated hydraulic conductivity (mm/h) and tr the duration of a given rainfall event (h). Actual infiltration (AI) can be then calculated as

	AI=Pg-RF. The depth of the wetting front (Zwf) can be calculated as Zwf= AI/(θs-θi), where θs and θi is the soil moisture content at saturation and initial conditions (both in mm^3/mm^3), respectively.
Scale of measurement	Soil column to catchment scale
Data source	
Required data	Soil texture, soil organic matter and rainfall intensity and duration
Data input type	Quantitative
Data collection frequency	Daily (rainfall), and before and after NBS implementation (soil attributes)
Level of expertise required	High – for executing the calculations
Synergies with other indicators	Direct relation to *soil stress under wetting (rainfall) conditions, water available to plants, runoff estimations*
Connection with SDGs	SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	Participatory data collection is feasible through collecting rainfall data
Additional information	
References	Morbidelli, R., Corradini, C., Saltalippi, C., Flammini, A., Dari, J., Goviandaraju, R. S., 2018. Rainfall infiltration modelling: A review. Water, 10: 1873; doi:10.3390/w10121873 Neitsch, S., Arnold, J., Kiniry, J., Williams, J., 2011. Soil and Water Assessment Tool; Theoretical Documentation. Water Resources Institute Technical Report No 406, Texas. RAWLS W., STONE J., BRAKENSIEK D. (1989) Infiltration. In L. Lane, & M. Nearing, USDA-Water Erosion Prediction Project: Hillslope profile model documentation (Vol. 2, pp. 68-79). West Lafayette, Indiana: USDA-ARS National Soil Erosion Research Laboratory. Saxton, K., Rawls, W., 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. soil sci. Soc. Am. J. 70, 1569–1578. Toth, B., Weynants, M., Nemes, A., Mako, A., Bilas, G., Toth, G., 2015. New generation of hydraulic pedotransfer functions for Europe. Eur. J. Soil Sci. 66, 226–238.

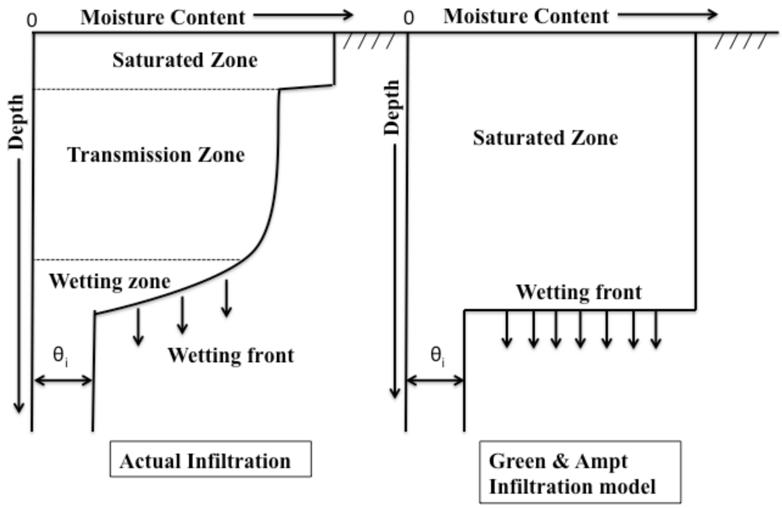

Figure: Soil moisture content distribution in the soil profile modelled by the Green-Ampt model (right) and a typically observed distribution (left) (Neitsch et al., 2011)

4.15 Evapotranspiration rate

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Rate of evapotranspiration	**Climate Resilience Water Management**
Description and justification	Evapotranspiration (ET) is a combination of two separate processes whereby water is lost from the soil surface by evaporation and from vegetation by transpiration. Water evaporates from surfaces when sufficient heat is supplied for liquid water to transition to water vapour. During transpiration, plant tissues vaporise water, which is then released to the atmosphere through stomatal openings on

	the plant leaf. Nearly all water taken up by plants is released to the atmosphere through transpiration. In addition to the non-uniformity of urban vegetation, shading of urban vegetation by landscape trees and structures and edge effects due to the relatively small scale of urban green space in comparison to commercial crop fields can significantly influence *ET* (Snyder, Pedras, Montazar, Henry, & Ackley, 2015).
Definition	Measured or modelled evapotranspiration (typically expressed in mm per unit time)
Strengths and weaknesses	+ The reference evapotranspiration, ET_o, provides a standard to which: (a) evapotranspiration at different periods of the year or in other regions can be compared; (b) evapotranspiration of other crops can be related (Allen, Pereira, Raes, & Smith, 1998). + Standard, widely-applied technique - Challenging and expensive to measure directly - Requires high level of expertise to apply
Measurement procedure and tool	Evapotranspiration is measured involving specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters. In practice, ET is commonly calculated using meteorological data. Commercially-available ET monitoring stations are generally meteorological stations that calculate potential ET using monitored temperature, relative humidity, wind speed and direction, solar radiation, and precipitation data. The Penman-Monteith equation is the FAO-recommended standard technique for calculation of reference evapotranspiration, ET_o from crops (Allen, Pereira, Raes, & Smith, 1998). The FAO Penman-Monteith method to estimate ETo is presented in Equation 1: $$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (1)$$ Where ET_o is reference evapotranspiration [mm day^{-1}], R_n is net radiation at the crop surface [MJ m^{-2} day^{-1}], G is soil heat flux density [MJ m^{-2} day^{-1}] ,T is mean daily air temperature at 2 m height [°C], u_2 is wind speed at 2 m height [m s^{-1}], *es* is saturation vapour pressure [kPa], *ea* is actual vapour pressure [kPa], *es - ea* is saturation vapour pressure deficit [kPa], *D* is slope vapour pressure curve [kPa °C-1], and *g* is psychrometric constant [kPa °C^{-1}]. Using the Penman-Monteith equation, ET from plant surfaces under standard conditions is determined using an experimentally-determined coefficient (k_c) to relate the ET for

	a specific crop species, ET_c, to ET_o. Thus, for a given crop species: $$ET_c = k_c \times ET_0 \quad (2)$$ For urban landscapes, the landscape coefficient method (LCM), which uses a different set of coefficients rather than k_c to estimate ET, may be more appropriate (Costello, Matheny, Clark, & Jones, 2000): $$ET = k_L \times ET = k_d \times k_s \times k_{mc} \times ET_0 \quad (3)$$ where k_L is a landscape coefficient defined as a product of k_d, a planting density factor, k_S, a species-specific factor, and k_{mc}, a microclimate factor. The modifications of the Penman-Monteith equation for plant-specific conditions can be found in the publications by, e.g., Litvak and Pataki (2016) and Litvak, Manago, Hogue, and Pataki (2016).
Scale of measurement	Plot scale, can be extrapolated using land cover data
Data source	
Required data	Radiation, air temperature, wind speed, vapour pressure, soil heat flux density
Data input type	Quantitative
Data collection frequency	Annually, and before and after NBS implementation
Level of expertise required	High – requires the ability to apply the Penman-Monteith equation and evaluate the results
Synergies with other indicators	Related to *Daily temperature range, Land surface temperature* and *Surface reflectance - Albedo* indicators; a possible consequence of *Green space management* and *Urban regeneration* indicator groups
Connection with SDGs	SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/X0490E/x0490e00.htm#Contents

	Costello, L.R., Matheny, N.P., Clark, J.R., & Jones, K.S. (2000). *A guide to estimating irrigation water needs of landscape plantings in California, the landscape coefficient method and WUCOLS III*. Berkeley, CA, USA: University of California Cooperative Extension, California Department of Water Resources. https://ucanr.edu/sites/WUCOLS/ Litvak, E., Manago, K.F., Hogue, T.S., & Pataki, D.E. (2016). Evapotranspiration of urban landscapes in Los Angeles, California at the municipal scale. *Water Resources Research*, 53(5), 4236-4252. Litvak, E. & Pataki, D.E. (2016). Evapotranspiration of urban lawns in a semi-arid environment: An in situ evaluation of microclimatic conditions and watering recommendations. *Journal of Arid Environments*, 134, 87-96. Snyder, R.L., Pedras, C., Montazar, A., Henry, J.M., & Ackley, D. (2015). Advances in ET-based landscape irrigation management. *Agricultural Water Management*, 147, 187-197

4.16 Peak flow variation

Project Name: Nature4Cities (Grant Agreement no. 730468)

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Peak Flow Variation	**Water Management**
Description and justification	The peakflow is the maximum value of the flowrate due to a given rain event. It indicates how much the discharge in a river or a stormwater network is impacted by the use of NBS. It can be used to : • assess one NBS type benefit • assess the impact of a combination of NBS set on one large catchment
Definition	Peakflow variation is defined by the relative error in peakflow between the peakflow of the catchment with NBS and the peakflow of a catchment without NBS (% (but flowrates are in l/s or l/s/ha (in case of different catchments comparison))).
Strengths and weaknesses	This indicator will directly assess the impact of NBS in the reduction of the flowrate, which peakflow is a characteristic value.

Measurement procedure and tool	This indicator can be calculated as the average value of a sample of peakflows deduced from a rain/runoff time series (typically one year) and may be obtained with observed runoff (if pre- and post- NBS setting is available) or simulated runoff (Nature4Cities, D2.1). Calculation method : measurement and modelling for evaluation of greening scenarios over a defined period Required tool : • hydrological model for NBS scenario evaluation It can be calculated by HYDRUS-1D/2D, URBS, and TEB-Hydro, models respectively at the object, neighbourhood and city scales (Nature4Cities, D2.2). • observations (with and without NBS) Data sources: • Hydrological modelling • Measurement/Monitoring Data required for the estimation of the indicator have to be calculated either from a model, or from monitoring. In case of model estimation, it requires input data provided by national meteorological services (typically rainfall and potential evapotranspiration). In case of model estimation, once meteorological data is available, calculation makes it necessary to run the appropriate hydrological model. Then the indicator can be estimated from the model results by standard software. Nature4Cities built a simplified model for early stage assessement of this indicator called PFVar (Nature4Cities, D2.4). The PFVar highlights the peak flow variation between two stages with or without NBS. It is expressed in percentage and is calculated for Garden and parks, street trees and greenroofs. For the two later, the calculation needs more evaluation. Such a KPI indicates how much the discharge in a river or a stormwater network is impacted by the use of NBS. Based on the study of two spatial scales (catchment and city) by the mean of two different urban hydrological models. The model URBS (Rodriguez et al, 2008) was applied at the catchment scale while the model TEB-Hydro (Stavropulos-Lafaille et al, 2018) was applied at the City scale. An equation is deduced from regression method for each following studied NBS: • Gardens and parks • Street tree scenarios • Green Roofs

	Database used to build the model is composed of data that were collected during the project VegDUD (financed by the French research agency from 2010 to 2013) and measured data from ONEVU (Nantes Urban Environment Observatory) (Nature4Cities, D2.3).
Scale of measurement	☒ City ☒ Neighbourhood/catchment ☒ Object
Data source	
Required data	• Flowrate data (in case of observed coefficient estimation) in pre- and post-NBS setting • Simulated flowrates (in case of simulated coefficient estimation)
Data input type	Quantitative
Data collection frequency	It can be calculated before an urban planning option in order to evaluate its impact
Level of expertise required	Easy to calculate but requires data. This indicator reveals a potential indirect effect. Both decision makers and citizens are probably not familiar with this indicator and needs to be trained.
Synergies with other indicators	Synergies with other hydrological modelling indicators and greenspace mapping indicators.
Connection with SDGs	
Opportunities for participatory data collection	
Additional information	
References	Rodriguez, F., Andrieu, H., Morena, F., 2008. A distributed hydrological model for urbanized areas – Model development and application to case studies. J. Hydrol. 268– 287. https://doi.org/10.1016/j.jhydrol.2007.12.007 Stavropulos-Laffaille, X., Chancibault, K., Brun, J.-M., Lemonsu, A., Masson, V., Boone, A., Andrieu, H., 2018. Improvements of the hydrological processes of the Town Energy Balance Model (TEB-Veg, SURFEX v7.3) for urban modelling and impact assessment. Geosci. Model Dev. Discuss. 1–28. https://doi.org/10.5194/gmd-2018-39 Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions

	Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

4.17 Flood peak reduction and delay

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: S. Connop[1], D. Dushkova[2], D. Haase[2], C. Nash[1]

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Flood peak reduction/delay (Applied and EO/RS combined)	Water Management
Description and justification	NBS can help tackle flood risk, for instance by increasing infiltration and evapotranspiration. Changing precipitation patterns due to climate change are expected to exacerbate flooding problems, for instance more intense rainfall events that exceed existing sewage system capacity. Applied approaches to flood peak reduction/delay include monitoring of SuDS performance using in-situ gauges. Typically, a weather station or weather radar data is used in combination with flowrate or water depth monitoring devices (e.g., datalogging v-notch weirs, tipping bucket rain gauges, in-line turbine flowmeters, depth sensors, soil moisture sensors, and infiltrometers). The weather data is used to calculate total rainfall entering the study area (e.g., rainfall depth/unit time x catchment area). Monitoring devices are then used to calculate the rate that water enters and/or leaves a nature-based solution feature. If compared to a control feature (without nature-based solution) or a baseline calculated for the site before the nature-based solution was installed, it is possible to calculate the percentage reduction in absolute height of peak floodwaters and the delay to peak flow. Remote sensing and GIS technologies coupled with computer modelling are useful tools for examining flood events in comparison with flood extent obtained for the annual rainfall using HEC-HMS and HEC-RAS. Using remote sensing data with the help of Flood Hazard Maps for different return periods (10, 20, 50 and 100 years) it is possible to develop, demonstrate and

	validate an information system for flood forecasting, planning and management, which supports assessment of the population vulnerability and physical vulnerability of the lowest administrative division subjected to floods. Key drivers for such monitoring include: • ensuring that systems installed perform as designed following installation; • to assess long-term performance and inform management requirements; • proof of concept for testing new/novel systems; • community engagement with new SuDS installations.
Definition	Assessment of co-benefits/dis-benefits of different SuDS options - in relation to peak flow reduction (e.g., % reduction in absolute height of peak floodwaters) and/or delay (e.g,. increase in time to flood peak in hours)
Strengths and weaknesses	**Applied methods:** Strong evidence in terms of local performance. Can be scaled-up across many sites. Results need to be added into flood management models in order to understand the overall impact across a city/neighbourhood/site. **EO/RS methods:** Most non-structural measures like flood forecasting, proper early warnings and conducting awareness programs among the flood affected community, etc., can be very effective. Modelling of watersheds with modern technology makes this more achievable. Application of GIS and remote sensing technology to map flood areas will make it easy to plan non-structural measures which reduce the flood damages and risks involved.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. **Applied/participatory:** Monitoring of SuDS performance using in-situ gauges. Typically, a weather station or weather radar data is used in combination with flowrate or water depth monitoring devices (e.g., datalogging v-notch weirs, tipping bucket rain gauges, in-line turbine flowmeters, depth sensors, soil moisture sensors, and infiltrometers). The weather data is used to calculate total rainfall entering the study area (e.g., rainfall depth/unit time x catchment area). Monitoring devices are then used to calculate the rate that water enters and/or leaves a nature-based solution feature. If compared to a control feature (without nature-based solution) or a

baseline calculated for the site before the nature-based solution was installed, it is possible to calculate the percentage reduction in absolute height of peak floodwaters and the delay to peak flow.

Several projects have reported the methods and results of such monitoring (Asleson et al. 2009; Royal Haskoning 2012; Alves et al. 2014; Perales-Momparler et al. 2014; 2017; Philadelphia Water Department 2014; Connop et al. 2013; 2018; Connop and Clough 2016; Clough and Newport 2017; De-Ville et al. 2018; Susdrain 2018).

A review of selected SuDS that were monitored to test hydrologic/hydraulic efficiency can be found in Lampe *et al.* (2005).

Key drivers for such monitoring include:

- ensuring that systems installed perform as designed following installation;
- to assess long-term performance and inform management requirements;
- proof of concept for testing new/novel systems;
- community engagement with new SuDS installations.

Earth Observation/Remote Sensing:

The use of remote sensing and GIS in water monitoring and management has been long recognized.

Potential application and management is identified in promoting the concept of sustainable water resource management. In conclusion remote sensing and GIS technologies coupled with computer modelling are useful tools in providing a solution for future water resources planning and management to government, especially in formulating policy related to water quality.

Different studies have extracted flood extent from satellite images available for flood events that occurred in a particular period. That can then be compared with the flood extent derived from the flood extent obtained for the annual rainfall using HEC-HMS and HEC-RAS. Based on the flood extent, it is possible to develop, demonstrate and validate an information system for flood forecasting, planning and management using remote sensing data with the help of Flood Hazard Maps for different return periods (10, 20, 50

	and 100 years). This supports assessment of the population vulnerability and physical vulnerability of the lowest administrative division subjected to floods.
Scale of measurement	**Applied methods:** Implementation is typically on a site or street level. It can be scaled-up to much larger scales. However, it is more typical to model the impacts of up-scaling once results have been obtained. **EO/RS methods:** Techniques are applicable at range of geographical scales. Automated methods are particularly valuable for large-scale analyses. High resolution data is needed for finer-scale analysis.
Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report.
Data input type	Data input types will depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report.
Data collection frequency	Data collection frequency will depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report.
Level of expertise required	**Applied methods:** Expertise needed for design and implementation and management of equipment. Relatively straightforward data analysis once systems are in place. **EO/RS methods:** Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.
Synergies with other indicators	**Applied methods:** Data can be fed into large-scale hydraulic modelling to improve accuracy. Can also be combined with broader ecosystem service provision of SuDS (e.g., biodiversity, thermal cooling, air quality, water quality, place-making). **EO/RS methods:** Much of the spatial data required can be used for many other of the mapping indicators, including those for social and economic indicators.
Connection with SDGs	All except SDG5 and SDG7: Reduced impact of flooding; Better irrigation for food production; Reduction of health impacts of flooding; Links to environmental education; Clean water and sanitation possible co-benefit; Job creation; More sustainable infrastructure; Social equality

	in relation to water management; Sustainable urban development; More sustainable water management; Climate change adaptation; Improvements in water management and quality; Habitat enhancement/creation; Environmental Justice; Opportunities for collaborative working
Opportunities for participatory data collection	**Applied methods:** Can include participation in terms of data download, stewardship, etc. **EO/RS methods:** A participatory approach to monitoring flood extent can supplement remote sensing approaches. This can help to strengthen and increase awareness of non-structural measures like flood forecasting and early warning systems.
Additional information	
References	**Applied methods:** Alves, L., Lundy, L., Ellis, J.B., Wilson, S. and Walters, D. The Design and Hydraulic Performance of a Raingarden for Control of Stormwater Runoff in a Highly Urbanised Area. In: ICUD (International Conference on Urban Drainage), 13th International Conference on Urban Drainage, Urban Drainage in the Context of Integrated Urban Water Management: A Bridge between Developed and Developing Countries, Sarawak, Malyasia, 7-12 September 2014. London, Middlesex University. Asleson, B. C., Nestingen, R. S., Gulliver, J. S., Hozalski, R. M. and Nieber, J. L. (2009), Performance Assessment of Rain Gardens. JAWRA Journal of the American Water Resources Association, 45: 1019–1031. Clough, J and Newport, D. (2017) Renfrew Close Rain Gardens – Year two monitoring and project evaluation report, May 2017. London: University of East London. Connop, S. and Clough, J. (2016) LIFE+ Climate Proofing Housing Landscapes: Interim Monitoring Report. London: University of East London. Connop, S., Clough, J., Alam, R. and Nash, C. (2018) LBHF Climate Proofing Housing Landscapes: Monitoring Report 3 - October 2016 to September 2017. London: University of East London. Connop, S., Nash, C., Gedge, D. Kadas, G, Owczarek, K and Newport, D. (2013) TURAS green roof design guidelines: Maximising ecosystem service provision through regional design for biodiversity. TURAS FP7 Milestone document for DG Research & Innovation De-Ville, S., Menon, M. and Stovin, V. (2018) Temporal variations in the potential hydrological performance of extensive green roof systems. Journal of Hydrology 558, pp. 564-578. Lampe L, Barrett M, Woods Ballard B, Kellagher R, Martin P, Jefferies C, Hollon M (2005). Post Project Monitoring of

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Susdrain (2018) Counters Creek SuDS Retrofit Pilot Study, London. Susdrain case study: https://www.susdrain.org/case-studies/pdfs/suds_awards/005_18_03_28_susdrain_suds_awards_counters_creek_suds_retrofit_pilot_study_london.pdf

EO/RS methods:

Awadallah, A., and N. Awadallah, (2013) A novel approach for the joint use of rainfall monthly and daily ground station data with TRMM data to generate IDF estimates in a poorly gauged arid region. Open Journal of Modern Hydrology, 3, 1–7, doi:10.4236/ ojmh.2013.31001.

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	Operation of Water Resources Systems (Proceedings of Rabat Symposium S3, April 1997). IAHS Publ. no. 242, 1997.

4.18 Height of flood peak and time to flood peak measurement

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Height of flood peak **Time to flood peak**	**Water Management** **Natural and Climate Hazards**
Description and justification	Rapid urbanisation and industrialisation have led to reduced vegetative cover and decreased water storage in the subsurface, as well as the concentration and accumulation of surface runoff in sewage systems due to reduced infiltration into the soil. As a result, the volume of surface runoff as well as the velocity and time to peak storm runoff and baseflow are all increased. Urbanisation also reduces the land coverage of forests and vegetation that help to dissipate the flow energy (Devi, Ganasri & Dwarakish, 2015; Liu, Gebremeskel, De Smedt, Hoffman & Pfister, 2004). The detrimental effects of urbanisation on hydrologic systems are expected to increase in the future due to both increasing urbanisation as well as changes to the global climate, including rising sea levels, glacial retreat, changing precipitation patterns and an increasing frequency of extreme events (Kiehl, 2011).
Definition	Flood peak height is the highest point of the rising limb of a flood hydrograph (describing discharge over time) (m^3/s, cfs, L/s or similar units) Time to flood peak (h)
Strengths and weaknesses	+ Straightforward assessment of degree to which the changes in the local land-use (i.e., change in imperviousness) had an effect on reducing/promoting runoff - Requires *in situ* measurements
Measurement procedure and tool	Assessment of the effectiveness of flood management methods can be performed by different methods. For example, the assessment of runoff can be performed by

	in situ measurements before and after construction of a flood management structure. In the studies reviewed by Iacob et al. (2014), the assessment of natural management methods was performed either by hydrologic and hydraulic modelling or by direct monitoring. Parameters used for the assessment of the performance of natural flood management measures were: (a) flood peak reduction for different flood event return periods (e.g., 1, 2, 25, 50, or 100 years); (b) increase in time to flood peak; (c) decrease in annual probability of flood risk for the selected area.
Scale of measurement	Site to catchment scale
Data source	
Required data	*In situ* runoff measurements
Data input type	Quantitative
Data collection frequency	At the time of precipitation events and/or daily, monthly and yearly continuous monitoring before and after construction of the area and/or installation of NBS
Level of expertise required	Moderate
Synergies with other indicators	Direct relationship to *Surface runoff in relation to precipitation quantity* indicator, and partial relationship to *Measured infiltration rate and capacity* and *Evapotranspiration rate* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Iacob, O., Rowan, J.S., Brown, I.M., & Ellis, C. (2014). Evaluating wider benefits of natural flood management strategies: An ecosystem-based adaptation perspective. *Hydrology Research*, *45*(6), 774-787.

4.19 Flood excess volume (FEV)

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: Guillaume Piton[1], Jean-Marc Tacnet[1]

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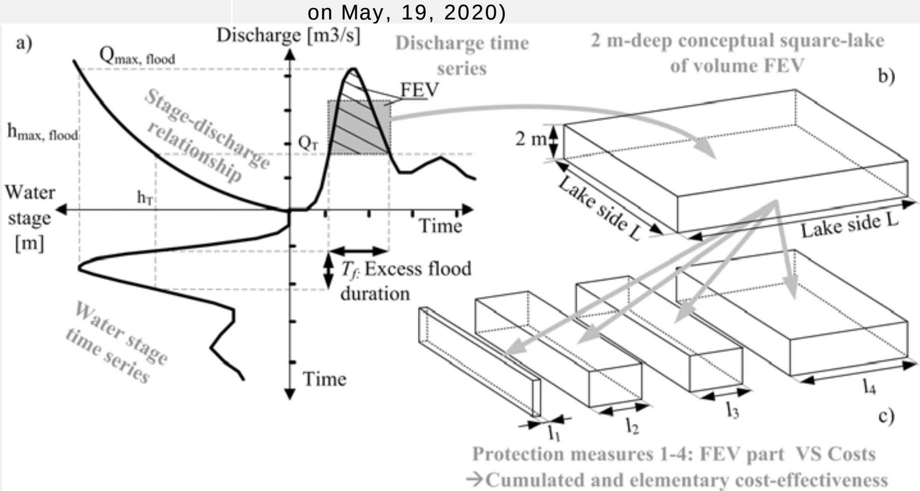
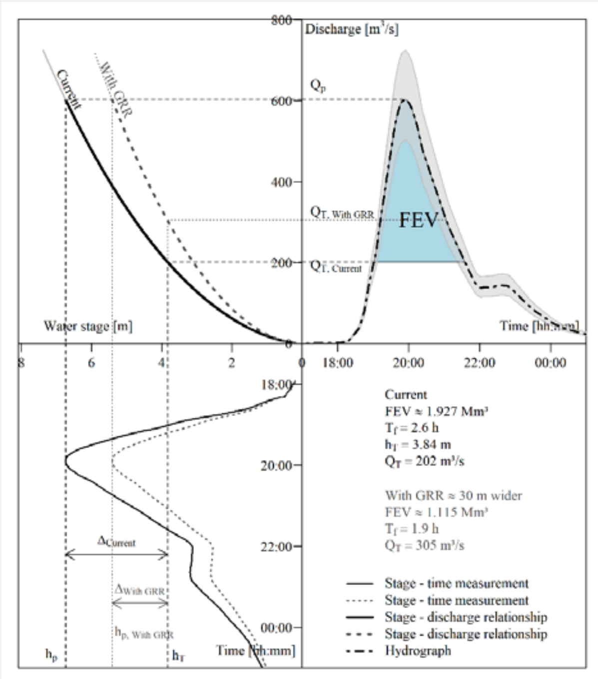
Flood-Excess Volume (FEV)	Natural and Climate Hazards Water Management
Description and justification	Flooding adverse consequences occur when flow levels exceed channel banks and reach areas with assets. Knowing the whole volume of the flood hydrograph is interesting but insufficient to determine whether the flood will trigger adverse consequences or not: it is also necessary to know the discharge times series (i.e., the hydrograph), the flow level over which flooding starts and to know the stage – discharge relationship to determine which fraction of the total volume can actually be harmful. The FEV is a computation of this hydrograph fraction: the hydrograph volume in excess compared to the channel capacity. In essence, when implementing water retention measures for flood protection, one does not want to buffer the whole hydrograph volume, just the FEV. The FEV method enables first to compute this water excess volume. In a second step, it is possible to compute how much of the FEV several protection measures can handle. If costs of each measures are available, it is finally possible to compute the cost-efficacy ratio of the whole strategy as well as of each measure (Cost per percentage of FEV). Overall, the FEV framework enables fast and straightforward computation of the amount of water causing problems, the design of the number and size of a panel of measures required to mitigate the associated problems and a fast assessment of the measure and strategy cost-efficacy ratio.
Definition	The FEV of a given flood event at a certain location is defined as (Bokhove et al., 2019): the water volume causing flood damage due to river levels h exceeding a relevant threshold h_T such that, some or major flooding issues occur for $h > h_T$. The data required to compute it are: (i) event hydrograph, i.e., discharge time series Q(t), (ii) water stage – discharge relationship, i.e., channel conveyance capacity h(Q) and (iii) the threshold value for flooding in term of discharge Q_T or of flow level $h_T = h(Q_T)$.
Strengths and weaknesses	+ The FEV framework is fast and simple to implement, has great educational potential and was tried and tested with success on several sites across Europe (Brague River FR, Aire and Calder Rivers UK, Glinščica River SLO). + Flood mitigation strategies usually relies on both water retention measures and works on the channel to increase its conveyance capacity. Usual indicators focus on one

	aspect or the other while the FEV encapsulates both. The example provided as attached figure shows how giving room to the river (GRR) enables changing the channel capacity and then decrease the remaining FEV nearly by half. - Fast and straightforward methods necessarily rely on several simplification hypothesis and thus provide imperfect assessments. Among limitations of FEV discussed by Bokhove et al. (2020) (i) Three-dimensional flood dynamics is reduced to the analysis of FEV at or near the most critical point along a river where flooding starts. Generally, river hydraulics are modelled in a one- or two-dimensional manner: it is therefore best to consider FEV-analysis as a diagnostic at the worst spot. (ii) Only the averaged and cumulative effects of retention measures upstream of the point of FEV-analysis are considered. Spatio-temporal considerations en route to the most critical point of flooding are thus ignored. (iii) Only effectiveness is considered here but not benefits, which would require a full economic analysis of damages saved and/or costs incurred.
Measurement procedure and tool	Given an in situ hydrograph Q(t) explicitly as function of time t, or implicitly as a function Q = Q(h) of the in situ river level h = h(t), discretized in time step of duration Δt, and knowing the threshold discharge for flooding $Q_T=Q(h_T)$, the approximation of FEV is: $FEV = \sum_{flood} \left(Q(t) - Q(h_T)\right)\Delta t = \sum_{flood} \left(Q(h(t)) - Q(h_T)\right)\Delta t$ For data-scarce contexts, Bokhove et al. (2020) provides simplified equations.
Scale of measurement	m3
Data source	
Required data	Hydrograph, water stage – discharge curve, threshold depth for flooding.
Data input type	Quantitative
Data collection frequency	Possibly hourly measurement of discharge or flow stage on the duration of the flood event (if possible more frequent for flash floods)
Level of expertise required	Intermediate
Synergies with other indicators	Complementary with Height Of Flood Peak/Time To Flood Peak, Peak Flow, Peak Volume, Flood Peak Reduction, Reduction Of Inundation Risk For Critical Urban Infrastructures.
Connection with SDGs	13

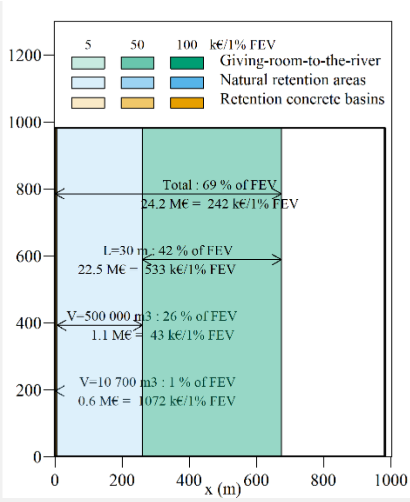
Opportunities for participatory data collection	Fine-tuning of the threshold level for flooding can benefit from local dweller knowledge. Proposition and sizing of protection measures can be performed with stakeholder participation (Arfaoui and Gnolonfin, 2020)
Additional information	
References	Arfaoui N, Gnonlonfin A. 2020. Supporting NBS restoration measures: A test of VBN theory in the Brague catchment. Economics Bulletin 40 : 1272–1280. [online] Available from: https://ideas.repec.org/a/ebl/ecbull/eb-20-00134.html (accessed on May, 19, 2020) Bokhove O., Kelmanson M.A., Kent T., Piton G., Tacnet JM. 2019. Communicating (nature-based) flood-mitigation schemes using flood-excess volume. River Research and Applications 35 : 1402–1414. DOI: 10.1002/rra.3507 Bokhove O., Kelmanson M.A., Kent T., Piton G., Tacnet JM. 2020. A Cost-Effectiveness Protocol for Flood-Mitigation Plans Based on Leeds' Boxing Day 2015 Floods. Water 12 : 1–30. DOI: 10.3390/w12030652 Piton G., Dupire S., Arnaud P., Mas A., Marchal R., Moncoulon D., Curt. T., Tacnet J. 2018. DELIVERABLE 6.2 From hazards to risk: models for the DEMOs - Part 3: France: Brague catchment DEMO . NAIAD H2020 project (Grant Agreement nº 730497) [online] Available from: http://naiad2020.eu/wp-content/uploads/2019/02/D6.2_REV_FINAL.pdf (accessed on May, 19, 2020)



Conceptual flood-excess volume (FEV) representations. (a) Three-panel graph highlighting FEV: (bottom-left) view of river-level time series around a flood event; (top-left) stage–discharge relationship arising from (top-right) discharge data, in which FEV is the hatched ''area'' between the discharge curve $Q(t) = Q(\check{h}) = Q(h(t))$, displayed vertically as function of time horizontally, and a chosen threshold discharge $Q_T = Q(h_T)$ with exceedance time T_f, involving in situ temporal river levels h = h(t). (b) FEV square-lake representation as a D = 2 m-deep square lake, with side-length $L = (FEV/D)^{0.5}$, to facilitate visualisation of FEV ‘‘size.’’ (c) FEV-effectiveness assessment computed for each measure as equivalent FEV fraction, represented as side L of the square lake (Bokhove et al., 2019)



Application example of the FEV at the Brague catchment scale on flood disaster of Oct. 2005 (time return of about 500 years). Current stage – discharge capacity (thick line, upper left panel) triggered flooding above discharge Q_T = 202 m^3/s generating 1,900,000 m^3 of FEV. In a NBS strategy giving room the river (30 m widening) this threshold discharge is increased to 305 m^3/s and the FEV became 1,100,000 m^3 that may be partially handled with complementary water retention measures.



Square lake representation at the Brague catchment scale on flood disaster of Oct. 2005: the full FEV of 1.9 Mm^3 is equivalent to a square lake of side nearly 1 km long and 2 m deep. The existing retention concrete basin of 10,700 m3 handle less than 1% of this total volume at high cost. Giving 30 m of width to the river would cope with 42% of the FEV while the natural retention areas would cope with 26% of the FEV at low cost. 31% of FEV remains and require other measures if one want to protect against the full event.z

4.20 Rainfall interception rate of NBS

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1] , Karen Munro[1]

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Rainfall interception rate of NBS	**Water Management**
Description and justification	The aerial parts of vegetation established as part of the NBS can intercept precipitation and thus decrease and delay the amount of water reaching the soil which, in turn, will decrease the risk of erosion and landslides.
Definition	Interception rate refers to the proportion of precipitation that does not reach the soil, but is instead intercepted by the leaves, branches of plants and the forest floor.

Strengths and weaknesses	+ Well established procedures exist for NBS that include trees; large body of empirical models exist for multiple plant species and biomes. - Requires significant effort and suitably qualified workforce for measurement/monitoring; relatively difficult to measure under non-woody vegetation; it is difficult to capture the complex architecture of the canopy; high interference with dripfall and atmospheric turbulence.
Measurement procedure and tool	The rationale for measurement is to measure rainfall below the canopy and beyond the canopy's influence and compare both through linear regression, subtract throughfall and stemflow quantities from it. These quantities can be measured using a rain gauge/graded container
Scale of measurement	Point (tree or individual vegetation), field (meso scale)
Data source	
Required data	Water volume; canopy crown area; canopy cover fraction; leaf area index
Data input type	Numerical, quantitative
Data collection frequency	During every rainfall event
Level of expertise required	Intermediate to high
Synergies with other indicators	Moisture content, stemflow, throughflow, vegetation type, vegetation cover, precipitation
Connection with SDGs	11,13,1,5,17
Opportunities for participatory data collection	Yes
Additional information	
References	Gonzalez-Ollauri, A. & Mickovski, S.B. (2017). Hydrological effect of vegetation against rainfall-induced landslides, *Journal of Hydrology*, *549*, 374–387. Deguchi, A., Hattori, S., & Park, H. (2006). The influence of seasonal changes in canopy structure on interception loss: application of the revised Gash model. *Journal of Hydrology, 318*, 80–102.

4.21 Runoff rate for different rainfall events

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Runoff rate for different rainfall events	**Water Management**
Description and justification	Runoff occurs when the soil is fully saturated and precipitation arrives more quickly than soil can absorb it. Surface runoff often occurs because impervious areas (such as roofs and pavement) do not allow water to percolate into the ground. Runoff is directly related to water infiltration into the soil (affecting degree of saturation and soil stength) but also to river discharge and flooding.
Definition	The flow of water that occurs when excess stormwater, meltwater, or other sources flow over the ground surface. Runoff includes all the water flowing in the stream channel while the surface runoff includes only the water that reaches the stream channel
Strengths and weaknesses	+ Surface runoff is a major component of the water cycle and the primary agent of soil erosion by water. Large body of reliable process-based models exist for its quantification. Directly related to soil type, land cover and rainfall. - May be difficult to measure at larger scale
Measurement procedure and tool	Field: generally using current meters and calibrated or rated channel cross sections, flumes or standardized weirs, together with water level readings, often by automatic recorders, to give a continuous height record which can be correlated to flow. Modelling: water mass balance coupled with soil infiltration/percolation model
Scale of measurement	Field (meso)
Data source	
Required data	Water volume; soil particle size distribution; soil organic matter
Data input type	Numerical, quantitative
Data collection frequency	During every rainfall event

Level of expertise required	Low to intermediate
Synergies with other indicators	Moisture content, interception, throughflow, stemflow, vegetation type, vegetation cover, precipitation, erosion rate, percolation
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	Yes
Additional information	
References	FAO Soils Bulletin 68, 'Field Measurement of Soil and Runoff

4.22 Run-Off Score

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

[1] *Green4Cities GmbH/GREENPASS GmbH*

Run Off Score (ROS)	**Climate Resilience**
Description and justification	The ROS (Run Off Score) is one out of five Key Performance Scores of the GREENPASS® system. It expresses the ratio of water, which is discharged to the sewage system and is lost for NBS and climate regulation. No water, no NBS, no climate regulation.
Definition	The ROS (Run Off Score) describes the average run-off for a project area.
Strengths and weaknesses	+ worldwide standardized key performance score regarding run-off and water management + easy for communication, understanding and decision-making + useful for design optimization + as a base for regulative definitions (legal prohibition of climate deterioration)
Measurement procedure and tool	- area analysis (eg with GREENPASS® system and tools) - numerical index value (0-1)
Scale of measurement	Object, neighbourhood and city scale
Data source	

Required data	- project area analysis and typology related run-off coefficients - NBS typology
Data input type	- area with surface and vegetation types incl. characteristics - run-off coefficients for urban typologies (NBS, surface, ...)
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy to calculate and understand – for planners and decision makers
Synergies with other indicators	Link to 'Surface runoff in relation to precipitation quantity', 'Water retention capacity of green areas (m3/y)', 'Volume of water removed from wastewater treatment system (m3)'
Connection with SDGs	SDG 11 Sustainable Cities and Communities, SDG 13 Climate action
Opportunities for participatory data collection	-
Additional information	
References	Kraus, F. (2017): The GREENPASS® Methodology. Pan European Network – Government 23 publication. October 2017. Scharf, B.; Schnepf, D. (2017): H2020: Special Report: Greenpass – unleash the power of green. Scharf, B. (2018): Coole Städte planen – Mit der „Greenpass-Methode". Neue Landschaft 01/2018. ISSN 0548-2836. Patzer Verlag. Berlin-Hannover. 2018. Scharf, B.; Kraus, F. (2019): Green Roofs and Greenpass. Buildings 2019, 9, 205. Elagiry, M.; Kraus, F.; Scharf B., Costa, A.; De 2019 Lotto, R. (2019): Nature4Cities: Nature-Based Solutions and Climate Resilient Urban Planning and Modelling with GREENPASS® - A Case Study in Segrate/Milano/IT. 16th IBPSA - International Building Performance Simulation Association Conference. Kraus, F.; Scharf, B. (2020): IT-gesteuerte Natur in der dichten Stadt. Neue Landschaft 01/2020. Kraus, F.; Scharf, B. (2019): Management of urban climate adaptation with NBS and GREENPASS®. Geophysical Research Abstracts. Vol. 21, EGU2019-16221-1, 2019 EGU General Assembly 2019. Kraus, F.; Scharf, B. (2019): Climate-resilient urban planning and architecture with GREENPASS illustrated by the case study 'FLAIR in the City' in Vienna. OP Conf. Ser.: Earth Environ. Sci. 323 012087.

	Kainz, A.; Hollosi, B.; Zuvela-Aloise, M.; Kraus, F.; Scharf, B.; Tötzer, T.; Züger, J.; Reinwald, F. (2019): Modelling the effects of implementing green infrastructure to support urban climate change adaptation and resilient urban planning. EMS Annual Meeting Abstracts Vol. 16, EMS2019-341, 2019. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

4.23 Rainfall storage capacity of NBS

Project Name: CONNECTING Nature (Grant Agreement no. 730222) and PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: S. Connop[1], D. Dushkova[2], D. Haase[2], C. Nash[1], Gerardo Caroppi[3,4], Carlo Gerundo[4], Francesco Pugliese[4], Maurizio Giugni[4], Marialuce Stanganelli[4], Farrokh Nadim[5], Amy Oen[5]

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[2] *Geography Department, Humboldt University of Berlin, Berlin, Germany*

[3] *Aalto University, Department of Built Environment, Espoo, Finland (gerardo.caroppi@aalto.fi)*

[4] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[5] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Rainfall storage (water absorption capacity of NBS) (Applied and EO/RS combined)	**Water Management**
Description and justification	Indicators of Effects on Water Quantity sub-criterion will assess the effects of project scenarios on water quantity: Cities typically place water resources under stress and increase pressure on the quality and quantity of water resources. Changing precipitation patterns due to climate change are expected to exacerbate problems, for instance more intense rainfall events that exceed existing sewage system capacity. NBS can help tackle flood risk, and water quality and scarcity for instance by increasing infiltration

	and evapotranspiration and/or through phytoremediation. Applied approaches can provide a coarse measure of the performance of nature-based solutions, such as Sustainable Drainage System (SuDS) basins, under storm conditions. Remote sensing and GIS technologies coupled with computer modelling are useful tools in providing a solution for future water resources planning and management, especially in formulating policy related to water quality. Data on the stormwater performance of nature-based solutions collected in these ways can be used to: • provide approximated values for total rainfall diverted from storm drains; • monitor performance of SuDS systems in relation to original designed-for capacity; • assess the potential for any additional capacity in SuDS features and therefore potential for additional catchment areas to be diverted into existing SuDS systems; • assess long-term performance and inform management requirements; • provide proof-of-concept for testing new/novel systems; • assess infiltration rates in soils beneath SuDS features; • provide easily accessible data/demonstrations to communities and decision-makers to change perceptions of SuDS.
Definition	The Indicator describes the water storage capacity in terms of volume of NBS and Green Solutions: Calculating/predicting stormwater performance of NBS, for example run-off coefficients in relation to precipitation quantities measured in mm/% from NBS (e.g., green roofs, tree pits, grass etc).
Strengths and weaknesses	**Applied methods:** Strong evidence in terms of local performance but tends to be of a more binary nature (i.e., enough capacity to cope with storm event or not) compared to quantification of peak flows and delays (Env 09). A good simple basis for production of infographics and figures to influence opinion. They are less valuable as methods for generating precise flowrate measurements to be embedded into flood management models. **EO/RS methods:** it is relatively easy to delineate inundation areas using optical remote sensing data, but it is difficult to characterise the water storage of natural lakes or man-made reservoirs using traditional field surveys or remote sensing methods. Water levels can be assessed using gauged hydrological stations, but this is difficult at

	large scales and in less developed regions where hydrological stations are not available. Satellite radar altimetry provides a complementary means of obtaining water surface elevations. However, the sparsely distributed data constrain the large-scale application of this technique. With synoptic and frequent observations, optical remotely sensed images are able to delineate water/land the boundaries, where the water surface elevations can be determined based on their overlap with boundaries and the bottom typography. Conversely, determining the bathymetry of a lake or reservoir tends to be more challenging, requiring special equipment and considerable labour and money. Thus, the bottom topographical measurements of hundreds of large water bodies in the YRB appear to be practically unfeasible.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. *Applied/Participatory methods*: Basic measures of stormwater storage volume can be calculated without detailed analysis of flowrates. Such metrics can provide a coarse measure of the performance of nature-based solutions, such as Sustainable Drainage System (SuDS) basins, under storm conditions. Typically, a weather station or weather radar data are used to calculate total rainfall during a rain event. Data on the stormwater performance of the nature-based solution during the event is then generated using cameras (Connop et al. 2018; Connop and Clough 2016; Clough and Newport 2017), soil moisture sensors (Alves et al. 2014), and/or pressure sensors (Connop et al. 2018; Connop and Clough 2016; Clough and Newport 2017). This data is then analysed to monitor how long after the initiation of the rain event the nature-based solution began to fill, whether the capacity was ever exceeded resulting in the release of stormwater to storm drains, and how long it took to empty following the cessation of the rain event. If duration of monitoring is a limitation (i.e., waiting for a 1 in 100 year storm can, by definition, take a long time), simulation of storm events can also be carried out (Alves et al. 2014; Connop et al. 2018; Connop and Clough 2016; Clough and Newport 2017). By doing so, it is possible to assess the performance of the nature-based solution during rain events of known magnitude without having to wait for such events to occur naturally. Such a method is not only a

	useful tool for testing the SuDS performance of nature-based solutions, it can also be an effective tool for engagement and understanding of SuDS for communities not familiar with the practice. **Earth Observation/Remote Sensing methods**: The use of remote sensing and GIS in water monitoring and management has been long recognized. Potential application and management is identified in promoting the concept of sustainable water resource management. In conclusion remote sensing and GIS technologies coupled with computer modelling are useful tools in providing a solution for future water resources planning and management to government, especially in formulating policy related to water quality. Different studies have extracted flood extent from satellite images available for flood events that occurred in a specific period. That can then be compared with the flood extent derived from the flood extent obtained for the annual rainfall using HEC-HMS and HEC-RAS. Based on the flood extent, it is possible to develop, demonstrate and validate an information system for flood forecasting, planning and management using remote sensing data with the help of Flood Hazard Maps for different return periods (10, 20, 50 and 100 years). This supports the assessment of the population vulnerability and physical vulnerability of the lowest administrative division prone to floods.
Scale of measurement	**Applied methods:** Typically on a component or site level. It can be scaled-up to much larger scales through replication **EO/RS methods:** Possible at various geographical scales, but tends to be better suited to larger scales than micro-scales
Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report
Data input type	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Environmental Indicator Metrics Review Report
Data collection frequency	Data collection frequency will be depend on selected methods, for further details on applied or earth

	observation/remote sensing metrics refer to [Connecting Nature Environmental Indicator Metrics Review Report]
Level of expertise required	**Applied methods:** Some expertise required for instrument installation. Data analysis/interpretation can be very basic once systems are in place. **EO/RS methods:** Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.
Synergies with other indicators	**Applied methods:** Very inexpensive and effective approach to provide long-term monitoring to inform management requirements. Aspects of the method could also form the foundation of evaporative cooling monitoring. **EO/RS methods:** Data generated in this way have synergies with other mapping indicators, most specifically flood risk indicators.
Connection with SDGs	SDG1, SDG2, SDG3, SDG4, SDG6, SDG8 through to SDG17: Reduced impact of flooding; Better irrigation for food production; Reduction of health impacts of flooding; Links to environmental education; Clean water and sanitation co-benefit; Job creation; More sustainable infrastructure; Social equality in relation to water management; Sustainable urban development; More sustainable water management; Climate change adaptation; Improvements in water management and quality; Habitat enhancement/creation; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	Model/Survey: **Applied methods:** Community/stakeholder participation in terms of data downloading, stewardship of equipment or nature-based solution, appointment of SuDS champions to monitor and report on any evidence of basins being overloaded. Storm simulation on SuDS features can also be an excellent mechanism to demonstrate performance to local communities and decision-makers. In so doing, it represents a mechanism for breakdown barriers to delivery and upscaling. **EO/RS methods:** A methodology for identifying the suitability for different rainwater harvesting interventions using a participatory GIS approach and field survey was proposed by Ziadat et al. (2012). Options for implementing different rainwater harvesting interventions can be identified with the participation of local communities. Field investigations indicated that the applied approach helped to select the most promising fields. The approach showed that participatory GIS approaches may be used to integrate

	socio-economic and biophysical criteria and facilitate the participation of farmers to introduce rainwater harvesting interventions in dry rangeland systems to mitigate land degradation.
Additional information	
References	**Applied methods:** Alves, L., Lundy, L., Ellis, J.B., Wilson, S. and Walters, D. The Design and Hydraulic Performance of a Raingarden for Control of Stormwater Runoff in a Highly Urbanised Area. In: ICUD (International Conference on Urban Drainage), 13th International Conference on Urban Drainage, Urban Drainage in the Context of Integrated Urban Water Management: A Bridge between Developed and Developing Countries, Sarawak, Malyasia, 7-12 September 2014. London, Middlesex University. Clough, J and Newport, D. (2017) Renfrew Close Rain Gardens – Year two monitoring and project evaluation report, May 2017. London: University of East London. Connop, S. and Clough, J. (2016) LIFE+ Climate Proofing Housing Landscapes: Interim Monitoring Report. London: University of East London. Connop, S., Clough, J., Alam, R. and Nash, C. (2018) LBHF Climate Proofing Housing Landscapes: Monitoring Report 3 - October 2016 to September 2017. London: University of East London. Connop, S., Nash, C., Gedge, D. Kadas, G, Owczarek, K and Newport, D. (2013) TURAS green roof design guidelines: Maximising ecosystem service provision through regional design for biodiversity. TURAS FP7 Milestone document for DG Research & Innovation. **EO/RS methods:** Gabella, M.; Morin, E.; Notarpietro, R.; Michaelides S. (2013) Precipitation field in the Southeastern Mediterranean area as seen by the Ku-band spaceborne weather radar and two C-band ground-based radars. Atmos. Res., 119, 120–130. Katsanos, D.; Retalis, A.; Tymvios, F.; Michaelides, S. (2016) Analysis of precipitation extremes based on satellite (CHIRPS) and in situ dataset over Cyprus. Natural Hazard., doi:10.1007/s11069-016-2335-8. Lane, J.; Kasparis, T.; Michaelides, S.; Metzger, P. (2017) A phenomenological relationship between vertical air motion and disdrometer derived A-b coefficients. Atmos. Res., doi:10.1016/j.atmosres.2017.07.011. Michaelides, S.; Levizzani, V.; Anagnostou, E.; Bauer, P.; Kasparis, T.; Lane, J.E. (2009) Precipitation: Measurement, remote sensing, climatology and modeling. Atmos. Res., 94, 512–533. Retalis, A.; Tymvios, T.; Katsanos D.; Michaelides S. (2017) Downscaling CHIRPS precipitation data: An artificial neural

	network modelling approach. J. Remote Sens., doi:10.1080/01431161.2017.1312031. Schultz G A (1997) Use of remote sensing data in a GIS environment for water resources management. In: Remote sensing and geographic Information Systems for Design and Operation of Water Resources Systems (Proceedings of Rabat Symposium S3, April 1997). IAHS Publ. no. 242, 1997 Ziadat, F., Bruggeman, A., Oweis, T., Haddad, N., Mazahreh, S., Sartawi, W. and Syuof, M. (2012). A participatory GIS approach for assessing land suitability for rainwater harvesting in an arid rangeland environment. *Arid Land Research and Management*, *26*(4): 297-311.

4.24 Quantitative status of groundwater

Project Name: UNaLab (Grant Agreement no. 730052)

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Quantitative status of groundwater	Water management
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.
Definition	The degree to which a body of groundwater is affected by direct and indirect abstractions (good, poor)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level
Measurement procedure and tool	The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC): 1. Define groundwater bodies within a river basin area

<table>
<tr><td></td><td>
2. Establish type-specific reference conditions per Annex V
3. Identify significant anthropogenic pressures
4. Identify and estimate significant water abstractions for urban, agricultural, industrial and other uses, including seasonal variations and total annual demand
5. Identify and estimate loss of water in the distribution systems
6. Estimate recharge and artificial recharge of groundwater bodies
7. Estimate the effects caused by water regulation, flood protection and land drainage
8. Establish monitoring of quantitative status for groundwater:
    a. Groundwater level monitoring network
    b. Density of monitoring sites
    c. Frequency of monitoring
    d. Additional monitoring requirements for protected areas as listed under Annex IV
9. Present monitoring results as maps in accordance with Annex V
10. Interpret groundwater quantitative status per Annex V
</td></tr>
<tr><td>Scale of measurement</td><td>River basin; Member State</td></tr>
<tr><td>Data source</td><td></td></tr>
<tr><td>Required data</td><td>Anthropogenic pressures on groundwater reserves; Water abstraction rates; Land-use; Water regulation activities; Water losses</td></tr>
<tr><td>Data input type</td><td>Quantitative and qualitative</td></tr>
<tr><td>Data collection frequency</td><td>Frequency of monitoring for drinking water abstraction points:
<table>
<tr><th>Community served</th><th>Frequency</th></tr>
<tr><td>< 10 000</td><td>4 per year</td></tr>
<tr><td>10 000 – 30 000</td><td>8 per year</td></tr>
<tr><td>> 30 000</td><td>12 per year</td></tr>
</table>
</td></tr>
<tr><td>Level of expertise required</td><td>Moderate to High</td></tr>
<tr><td>Synergies with other indicators</td><td>Indicators forming parts of the Member States’ River Basin Management Plans: Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of</td></tr>
</table>

	surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters and *Ecological potential for heavily modified or artificial water bodies*
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. http://data.europa.eu/eli/dir/2000/60/oj European Parliament. (2006). Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. http://data.europa.eu/eli/dir/2006/118/2014-07-11 European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*.

4.25 Depth to groundwater

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Depth to groundwater	**Water Management**
Description and justification	Measurement of depth to groundwater in a well is frequently performed to examine changes in the level of the water table.
Definition	Depth from land surface reference point to top of groundwater table (m)

Strengths and weaknesses	+ Straightforward and easy assessment of water table change over time - Important to take repeated measurements over a long period of time to accurately evaluate changes in groundwater resource volume
Measurement procedure and tool	One of the simplest ways to assess the depth from land surface to groundwater is to measure the water level in a shallow well using a chalked steel measuring tape. Blue carpenter's chalk is commonly used to mark the steel tape, which is lowered into the well until the end of the tape is wet. The level of the water will be indicated by the depth to which the chalk is wet and the colour changes from light blue to dark blue. There are a number of different electronic water level metres marketed by different companies, any of which are suitable for routine monitoring of groundwater level in shallow wells or boreholes. These electronic instruments typically consist of a spool of dual conductor wire with a probe attached to the end and an indicator. As the probe is lowered into the well or borehole, a light or sound will indicate when the indicator comes into contact with water and the circuit is closed. Regardless of the measurement technique employed, when measuring depth to groundwater the depth measurement should be made relative to an established reference point. This reference point is typically denoted by a permanent mark or notch on the well casing and is associated with a geodetic vertical datum established for surveying, e.g., the European Vertical Reference System or applicable local height datum.
Scale of measurement	Plot scale to street scale or greater, depending on surface topography and extent/connectivity of underlying aquifer(s)
Data source	
Required data	Depth to the water table
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Direct relation to *Daily temperature range* indicator
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities

Opportunities for participatory data collection	Participatory data collection is feasible through participation in the measurement procedure
Additional information	
References	Hopkins, J. & Anderson, B. (2016). *A Field manual for Groundwater-level Monitoring at the Texas Water Development Board*. User Manual 52. Retrieved from http://www.twdb.texas.gov/groundwater/docs/UMs/UM-52.pdf Snyder, D.T. (2008). *Estimated depth to Ground Water and Configuration of the Water Table in the Portland, Oregon Area*. Scientific Investigations Report 2008-5059. Reston, Virginia: United States Geological Survey. Retrieved from https://pubs.usgs.gov/sir/2008/5059/pdf/sir20085059.pdf

4.26 Groundwater chemical status

Project Name: UNaLab (Grant Agreement no. 730052)

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Water Quality: Chemical status of groundwater	**Water management**
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans. The Groundwater Directive (2006/118/EC) complements the Water Framework Directive and sets the groundwater quality standards.
Definition	Chemical status of groundwater bodies (good, poor)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level

Measurement procedure and tool	The following procedure is based off requirements set by the Water Framework Directive (2000/60/EC) and Groundwater Directive (2006/118/EC): 1. Define groundwater bodies within a river basin area 2. Establish type-specific reference conditions per Annex V (Directive 2000/60/EC) 3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII (Directive 2000/60/EC): a. Organohalogen compounds and substances which may form such compounds in the aquatic environment b. Organophosphorous compounds c. Organotin compounds d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances f. Cyanides g. Metals and their compounds h. Arsenic and its compounds i. Biocides and plant protection products j. Materials in suspension k. Substances which contribute to eutrophication (in particular, nitrates and phosphates) l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.) 4. Establish relevant threshold values in accordance to Article 3 and Annex II (Directive 2006/118/EC) minimum for: a. Substances or ions or indicators which may occur both naturally and/or as a result of human activities i. Arsenic

	ii. Cadmium iii. Lead iv. Mercury v. Ammonium vi. Chloride vii. Sulphate viii. Nitrites ix. Phosphorus (total)/Phosphates b. Man-made synthetic substances i. Trichloroethylene ii. Tetrachloroethylene c. Parameters indicative of saline or other intrusions i. Conductivity 5. Establish monitoring of chemical status for groundwater: a. Groundwater monitoring network b. Establish surveillance and operational monitoring per Annex V (Directive 2000/60/EC) c. Set of core monitoring parameters: i. Oxygen content ii. pH value iii. Conductivity iv. Nitrate v. Ammonium d. Frequency of monitoring e. Additional monitoring requirements for protected areas as listed under Annex IV (Directive 2000/60/EC) 6. Present monitoring results as maps in accordance with Annex V (Directive 2000/60/EC) 7. Interpret chemical status of groundwater per Annex V (Directive 2000/60/EC)
Scale of measurement	River basin; Member State
Data source	
Required data	Reference conditions; Point and diffuse pollution sources
Data input type	Quantitative
Data collection frequency	Frequency of monitoring for drinking water abstraction points: **Community served** **Frequency**

<table>
<tr><td></td><td><table><tr><td>< 10 000</td><td>4 per year</td></tr><tr><td>10 000 – 30 000</td><td>8 per year</td></tr><tr><td>> 30 000</td><td>12 per year</td></tr></table></td></tr>
<tr><td>Level of expertise required</td><td>Moderate to High</td></tr>
<tr><td>Synergies with other indicators</td><td>Indicators forming parts of the Member States' River Basin Management Plans: Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters and Ecological potential for heavily modified or artificial water bodies</td></tr>
<tr><td>Connection with SDGs</td><td>SDG 3 Good health and well-being, SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action</td></tr>
<tr><td>Opportunities for participatory data collection</td><td>No opportunities identified</td></tr>
<tr><td colspan="2">Additional information</td></tr>
<tr><td>References</td><td>European Parliament. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. http://data.europa.eu/eli/dir/2000/60/oj

European Parliament. (2006). Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. http://data.europa.eu/eli/dir/2006/118/2014-07-11

European Commission. (2012). Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans.</td></tr>
</table>

4.27 Trend in piezometric levels (TPL)

Project Name: NAIAD (Grant Agreement no. 730497)

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Trend in piezometric levels (TPL)	**Water management Natural and Climate Hazards**
Description and justification	Provides an indication of the capacity of available surface water resources to meet the water demands.
Definition	Difference between surface water supply and demand (m^3/year)
Strengths and weaknesses	
Measurement procedure and tool	Modelling through Medina del Campo surface water allocation model.
Scale of measurement	Groundwater Body scale (Medina del Campo Groundwater Body)
Data source: climatic data from local meteorological stations.	
Required data	Climatic data including rainfall, runoff, evapotranspiration, infiltration.
Data input type	Historical data series
Data collection frequency	Annual
Level of expertise required	
Synergies with other indicators	Groundwater availability due to the surface-groundwater connections
Connection with SDGs	SDG 6

Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain– Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

4.28 Groundwater exploitation index (GEI)

Project Name: NAIAD (Grant Agreement no. 730497)

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Groundwater Exploitation Index (GEI)	**Water management** **Natural and Climate Hazards**
Description and justification	Provides an indication of the pressure of water demand on groundwater availability and the sustainability of the abstractions regime.The GEI addresses directly the good quantity mandate of the European Water Framework Directive. The GEI can be used as a tool to support water management with different purposes both within a particular GB or AV or at River basin scale: to achieve sustainable/desirable exploitation rates; to monitor the expected evolution of available groundwater resources; to monitor the temporal and space changes of both groundwater input and groundwater abstraction; to compare the situation in a set of GB/AV; to provide knowledge to understand socio-economic changes linked to agrarian activities; to support environmental policies related to groundwater ecosystems and to surficial

	groundwater dependent ecosystems, and their respective services; etc.
Definition	Ratio between total groundwater input to a particular groundwater body (GB) or aquifer volume (AV) and groundwater abstraction from the same GB or AV in a given lapse of time (usually one year). Usually given as ratio, but can also be given as %.
Strengths and weaknesses	+ It is a simple and easy to understand indicator of groundwater use sustainability. - Usually, the best figures that can be obtained for both groundwater input to and abstraction from a particular BG or AV have significant uncertainties. For this reason, the index should better be used accompanied by its estimated combined uncertainty (Example:1.4 +- 0.7).
Measurement procedure and tool	Groundwater input is usually quantified by a combination of empirical and numerical hydrological methods (estimation or modelling of groundwater recharge from rainfall, of groundwater lateral transfer from nearby geological formations, of excess irrigation water infiltration, and of surface water infiltration through river beds). Groundwater abstractions are quantified by empirical methods (pumping measurement through meters; accounting irrigation surfaces with particular crops and assigning irrigation provisions; deduction from accurate aquifer water balances). Both terms of GEI can also be estimated from the calibration of accurate groundwater flow models (i.e., the Medina del Campo Groundwater Body iMOD groundwater model, in NAIAD). Tools: simple spreadsheets and specific modelling software.
Scale of measurement	Groundwater-body/aquifer scale. It can also be applied to a particular aquifer volume, whose limits must be accurately defined.
Data source	
Required data	To estimate groundwater input: climatic data (rainfall, air temperature); edaphic data (field capacity, wilting point, evapotranspiration); hydrologic and hydrogeologic data (runoff, porosity, specific yield, infiltration, recharge; piezometry; hydraulic gradients). To quantify groundwater abstraction: groundwater pumped (per well and year); surface irrigated with particular crops, type of crops, water provision per crop. Data can be retrieved from public institutions (national/regional meteorological surveys; water management authorities); groundwater users; public and private research institutions.

Data input type	Total water input and total groundwater abstraction (hm^3/yr).
Data collection frequency	Though the GEI is used on a yearly base, it should be calculated with monthly data.
Level of expertise required	To calculate the indicator: expert level on hydrogeology. To understand the rationale behind it: low to medium expert level on hydrogeology.
Synergies with other indicators	With Surface Water Availability (SWA), due to the surface-groundwater relationships in areas where there are water-table aquifers and rivers, lagoons, and/or wetlands. With Trend of Piezometric Levels (TPL).
Connection with SDGs	With SDG 6
Opportunities for participatory data collection	Many types of people can participate in collecting data needed to calculate and/or monitor the GEI. Precipitation and air temperature data can be collected by students of different age and by employees from public and private institutions; groundwater abstraction can be measured by wells' owners. PIEZOMETRIC RECOVERING.
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain–Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

4.29 Aquifer surface ratio with excessive nitrate

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: *Beatriz Mayor[1], Laura Vay[1], Marisol Manzano[2], Virginia Robles[2], Mar García-Alcaraz[2], Javier Calatrava[3], Raffaele Giordano[4], Miguel Llorente[5], Africa de la Hera[5], Javier Heredida[5], Laura Basco[6], Marta Faneca[6], and Tiaravanni Hermawan[6], Elena Lopez-Gunn[1]*

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Aquifer Surface Ratio with Excessive Nitrate (ASRENi)	**Water Management**
Description and justification	Provides an indication of groundwater quality referred to excessive nitrate concentration. The ASRENi addresses directly the good quality status mandate of the European Groundwater Directive. Tool: The ASRENi can be used to control the spatial (X, Y, and Z) evolution of groundwater pollution by nitrate, and it is especially useful to monitor the impact of remediation measures. It is also a powerful tool to report the general status of groundwater quality at River basin and Nationwide scales.
Definition	Ratio of aquifer/groundwater body surface with nitrate concentrations not complying with water quality standards (NO_3 above 50 mg/L) with respect to total aquifer/groundwater body surface.
Strengths and weaknesses	+ It is a simple and easy to understand indicator of groundwater pollution by agricultural activities. - Quite frequently, databases have poor quality with respect to two main aspects: depth representativity within the aquifer/groundwater body, and low spatial density data.
Measurement procedure and tool	Measurement: Water sampling in specifically designed/selected boreholes and wells at different depths and analysis of NO_3 content in accredited laboratories; quantification of groundwater body/aquifer surface with nitrate concentration above 50 mg/L at different depths and estimation of ASRENi with the support of GIS.

	Tools: simple spreadsheets and GIS.
Scale of measurement	Groundwater body/aquifer scale.
Data source	
Required data	Nitrate concentration in groundwater samples taken and analysed after standard international methodologies and in adequately designed/selected observation points. Data can be retrieved from the official databases from water quality monitoring networks of water management authorities; trained groundwater users; public and private research institutions.
Data input type	Nitrate (NO_3 in mg/L) data with indication of X,Y (georeferenced), depth of sampling and depth of screened stretch in the borehole/well, and date of sampling.
Data collection frequency	Usually biannual, based either on a seasonal or a crop-management scale.
Level of expertise required	To calculate the indicator: expert level on GIS. To understand the rationale behind and use the indicator it: low to medium expert level on hydrogeology.
Synergies with other indicators	With Correction Cost of Groundwater Quality.
Connection with SDGs	With SDG 6
Opportunities for participatory data collection	Groundwater sampling for nitrate analysis must be performed following specific methods of international standards, which advises to be collected only by adequately trained personnel.
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain– Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

4.30 Aquifer surface ratio with excessive arsenic

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: *Beatriz Mayor[1], Laura Vay[1], Marisol Manzano[2], Virginia Robles[2], Mar García-Alcaraz[2], Javier Calatrava[3], Raffaele Giordano[4], Miguel Llorente[5], Africa de la Hera[5], Javier Heredida[5], Laura Basco[6], Marta Faneca[6], and Tiaravanni Hermawan[6], Elena Lopez-Gunn[1]*

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[4] *CNR-IRSA, National Research Council – Water Research Institute, Bari, Italy*

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Aquifer Surface Ratio with Excessive Arsenic (ASREAs)	**Water management**
Description and justification	Provides an indication of groundwater quality referred to excessive arsenic concentration. The ASREAs addresses directly the good quality status mandate of the European Groundwater Directive. The ASREAs can be used to control the spatial (X, Y, and Z) evolution of groundwater inadequate quality due to As. It is also a powerful tool to report the general status of groundwater quality at River basin and Nationwide scales.
Definition	Ratio of aquifer/groundwater body surface with arsenic concentrations not complying with water quality standards (As above 0.010 mg/L) with respect to total aquifer/groundwater body surface.
Strengths and weaknesses	+ It is a simple and easy to understand indicator of groundwater inadequate quality for domestic uses. - Quite frequently, data bases have poor quality with respect to three main aspects: depth representativity of data within the aquifer/groundwater body; low spatial density of data; inadequate analytical resolution to monitor possible temporal changes (sometimes the labs use as detection limit just 0.010 mg/L, which difficult to observe increasing/decreasing trends below this value).
Measurement procedure and tool	Measurement: Water sampling in specifically designed/selected boreholes and wells at different depths and analysis of As content in accredited laboratories; quantification of groundwater body/aquifer surface with As concentration above 0.010 mg/L at different depths and estimation of ASREAs with the support of GIS.

	Tools: simple spreadsheets and GIS
Scale of measurement	Groundwater body/aquifer scale, with emphasis on domestic supply wells.
Data source	
Required data	Arsenic concentration in groundwater samples taken and analysed after standard international methodologies and in adequately designed/selected observation points. Data can be retrieved from the official databases from water quality monitoring networks of water management authorities; trained groundwater users; public and private research institutions.
Data input type	Arsenic (As in mg/L or microg/L) data with indication of X,Y (georeferenced), depth of sampling and depth of screened stretch in the borehole/well, and date of sampling.
Data collection frequency	In urban-supply wells, the collection frequency is usually biweekly to monthly. In non-supply monitoring points, the frequency is usually biannual.
Level of expertise required	To calculate the indicator: expert level on GIS. To understand the rationale behind and use the indicator it: low to medium expert level on hydrogeology.
Synergies with other indicators	With Correction Cost of Groundwater Quality.
Connection with SDGs	With SDG 6
Opportunities for participatory data collection	Groundwater sampling for arsenic analysis must be performed following specific methods of international standards, which advises to be collected only by adequately trained personnel.
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain– Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

4.31 Water availability for irrigation purposes

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Rainwater or greywater use for irrigation purposes	**Water Management Natural and Climate Hazards**
Description and justification	Rainwater and greywater have a potential to be reused for irrigation purposes if collected to a storage unit. This is especially prominent for areas exposed to drought. Domestic wastewater consists of greywater, the wastewater discharged from hand basins, showers and baths, dishwashers, and laundry machines, and blackwater from toilets. Depending on local regulations, water from the kitchen sink be regarded as greywater or blackwater. One person generates 90–120 L greywater each day depending on lifestyle, living standard, age, gender, and other factors. Greywater comprises 50-80% of all domestic wastewater but contains a relatively small fraction of the total pollutant load (Antonopoulou, Kirkou, & Stasinakis, 2013; Donner et al., 2010; Li, Wichmann, & Otterpohl, 2009). Separation of domestic greywater from blackwater and on site re-use for toilet flushing or irrigation of non-edible vegetation provides an alternative water source in areas facing water shortage. On-site greywater re-use can reduce potable water use by as much as 50% (Gross, Shmueli, Ronen, & Raveh, 2007).
Definition	Volume of rainwater or greywater used for irrigation purposes (m^3/y or similar unit)
Strengths and weaknesses	+ Secure reserve of water for irrigation at times of drought + Use of automatic meter reading could be a good choice to communicate with stakeholders regarding the benefits of rainwater capture and use for irrigation - Rainwater storage requires a substantial amount of external storage units - There are concerns about the potential for bacterial growth when nutrient-rich waste/greywater remains untreated for a period of time

Measurement procedure and tool	Accurate accounting of rainfall capture and use for irrigation requires use of a water level sensor to measure the volume of water contained within a given rainwater storage unit at any time. If the storage unit is completely sealed and the water level can be easily recorded each time it is opened (and again after water is discharged for use), it may be possible to manually record and calculate the volume of water captured and used for irrigation purposes. An alternate solution is to equip the discharge point of the rainwater storage unit/tank with a water meter, and record the volume of water used over a specific period of time. This is well suited to applications with multiple water storage tanks and/or in situations where it may be challenging to accurately quantify water use manually. The water meter(s) may be connected to an automatic meter reading (AMR) device that enables remote communication of water usage between the water meter and a central point. It is recommended that domestic greywater is filtered (e.g., sand and/or granular activated carbon filter and/or treatment in vertical subsurface-flow wetland or reed bed, etc.) prior to use for irrigation of non-edible vegetation such as landscaping.
Scale of measurement	Plot scale to street scale
Data source	
Required data	Volume of rainwater and greywater used for irrigation purposes
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Low to Moderate
Synergies with other indicators	Related to *Monthly maximum value of daily maximum temperature, Quantitative status of groundwater* and *Depth to groundwater* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Antonopoulou, G., Kirkou, A. & Stasinakis, A.S. (2013). Quantitative and qualitative greywater characterization in

	Greek households and investigation of their treatment using physicochemical methods. *Science of the Total Environment*, 454-455, 426-432. Donner, E., Eriksson, E., Revitt, D.M., Scholes, L., Holten Lützhøft, H.-C. & Ledin, A. (2010). Presence and fate of priority substances in domestic greywater treatment and reuse systems. *Science of the Total Environment*, *408*(12), 2444-2451. Gross, A., Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW)-a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere*, *66*(5), 916-623. Li, Y., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment*, *407*(11), 3439-3449.

4.32 Water Exploitation Index

Project Name: UNaLab (Grant Agreement no. 730052)

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Water Exploitation Index	**Water Management** **Climate and Natural Hazards**
Description and justification	The Water Exploitation Index (WEI) compares the volume of water consumed each year to the available freshwater resources. More specifically, the WEI presents total annual freshwater extraction as a proportion (%) of the long-term annual average freshwater available from renewable resources. The WEI warning threshold of 20% distinguishes a water-stressed area from one not suffering water scarcity. Severe scarcity is defined as WEI >40%.
Definition	Annual total water abstraction as a proportion (%) of available long-term freshwater resources in the geographically relevant area (basin) from which the municipality obtains its water
Strengths and weaknesses	+ European Environment Agency (EEA) uses the WEI to evaluate water scarcity across major river basins in Europe with time

	- Requires substantial amount of external information and data sources
Measurement procedure and tool	The WEI is calculated as follows (European Environment Agency [EEA], 2018): $$WEI = \left(\frac{Volume\ of\ water\ abstraction}{Volume\ of\ renewable\ freshwater\ resources}\right) \times 100$$ An advanced version of the WEI, called the WEI+, accounts for recharge of available freshwater supplies, or water return (EEA, 2018a): $$WEI + = \left(\frac{Volume\ of\ water\ abstraction - Volume\ of\ water\ returns}{Volume\ of\ renewable\ freshwter\ resources}\right) \times 100$$ The volume of long-term renewable freshwater resources in a natural or semi-natural geographically relevant area (e.g., basin or sub-basin) is calculated as (EEA, 2018): $$Long\ term\ renewable\ freshwater\ resources = E_{xIn} + P - ET_a - \Delta S$$ where E_{xIn} = external inflow, P = precipitation, ET_a = actual evapotranspiration and ΔS = change in storage (lakes and reservoirs). The equation for renewable freshwater resources can be simplified as follows for highly-modified (i.e., not natural or semi-natural) river basins or sub-basins (EEA, 2018): $$Long\ term\ renewable\ freshwater\ resources = outflow + (abstraction - return) - \Delta S$$ where outflow = downstream flow or discharge to sea and ΔS = change in storage (lakes and reservoirs).
Scale of measurement	Basin scale
Data source	
Required data	Necessary information about annual volumes of water abstraction (groundwater, surface water) from a given basin or sub-basin can be obtained from records of water supply companies and city documents relating to water abstraction permits. Wastewater treatment companies, water supply companies and municipal environment/environmental management departments are sources of information related to annual volumes of water returns. Information about long-term renewable water resources can be obtained from local water boards, municipal departments and/or national environment agencies.
Data input type	Quantitative

Data collection frequency	Annually
Level of expertise required	Moderate – for data acquisition and processing
Synergies with other indicators	Related to *Depth to groundwater* and *Qunatitative status of groundwater* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Environment Agency (EEA). (2018). *Use of freshwater resources*. Copenhagen: European Environment Agency. Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3

4.33 Water dependency for food production

Project Name: proGIreg (Grant Agreement no. 776528)

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Water dependency for food production	Water Management
Description and justification	Water is a primarily resource, and the water dependencies of food production is a key indicator of efficiency in the use of water and thus environmental footprint. The implementation nature based solution rested on aquaponics systems in urban areas is hypothesized to produce vegetables with a lower water consumption compared with soil based agriculture. The loss of water in these systems is only due to evapotranspiration, without percolation and runoff.
Definition	Amount of water used to produce food in aquaponics systems (m^3)
Strengths and weaknesses	+ Simple calculation - The results will be dependent to which soil based agricultural system is compared

Measurement procedure and tool	The indicator is obtained by a ratio between the food production and the water consumption within the aquaponics systems. The indicator will be calculated at the end of the implementation
Scale of measurement	NBS level
Data source	
Required data	Amount of water used and food produced by the system
Data input type	Continuous variables
Data collection frequency	Continuously collected
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators of environmental footprint
Connection with SDGs	Sustainable consumption and production: The implementation of nature-based solutions contributes to “doing more and better with less,” net welfare gains from economic activities can increase by reducing resource use, degradation and pollution along the whole life cycle.
Opportunities for participatory data collection	
Additional information	
References	Somerville C., Cohen M., Pantanella E., Stankus A., Lovatelli A. (2014). *Small scale aquaponics food production. Integrated fish and plant farming*. FAO fisheries and aquaculture technical paper.

4.34 Calculated drinking water provision

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Calculated drinking water provision	**Water Management** **Natural and Climate Hazards**
Description and cation	Drinking water is commonly stored in dams and water wells, and distributed from them to the consumers. This KPI evaluates the available drinking water in damps or other fonts, and the water which is actually distributed to the consumers in a city or in defined area of a city.
Definition	Measurement method for the drinking water supplied to the consumers, or/and available water provision.
Strengths and weaknesses	+ Each consumer has their own meters, so it is possible to measure the provision in terms of amount of water per flat, building and/or any other facilities - This KPI may require permission to access data
Measurement procedure and tool	Domestic consumption of water is measured by water flow meters, so it can be monitor by the water company/service. With this detailed monitoring consumption of the water can be calculated as $m^3 * ha^{-1} * year^{-1}$. Apart from supplied water, volume of available drinking water is calculated with the measurement of height of water in dams and water wells. Dimensions of the dams and wells are known and the height of water gives the current volume and occupancy rate of dams.
Scale of measurement	City
Data source	
Required data	Water flows and water levels
Data input type	Numeric data and geographic data
Data collection frequency	Yearly
Level of expertise required	Technical
Synergies with other indicators	Abortion capacity of green surfaces, bioretention structures and single trees, run-off coefficient in relation to precipitation quantities.

Connection with SDGs	This KPI is directly related with SDG 6 and SDG 11 and indirectly is related with SDG 3 (access to drinking water is a key part of the health and wellbeing).
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-

4.35 Net surface water availability

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: *Beatriz Mayor[1], Laura Vay[1], Marisol Manzano[2], Virginia Robles[2], Mar García-Alcaraz[2], Javier Calatrava[3], Raffaele Giordano[4], Miguel Llorente[5], Africa de la Hera[5], Javier Heredida[5], Laura Basco[6], Marta Faneca[6], and Tiaravanni Hermawan[6], Elena Lopez-Gunn[1]*

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Net surface water availability	**Water Management Natural and Climate Hazards**
Description and cation	Provides an indication of the capacity of available surface water resources to meet the water demands.
Definition	Difference between surface water supply and demand (m^3/year)
Strengths and weaknesses	

Measurement procedure and tool	Modelling through Medina del Campo surface water allocation model.
Scale of measurement	Groundwater Body scale (Medina del Campo Groundwater Body)
Data source.	
Required data	Climatic data from local meteorological stations including rainfall, runoff, evapotranspiration, infiltration.
Data input type	Historical data series
Data collection frequency	Annual
Level of expertise required	
Synergies with other indicators	Groundwater availability due to the surface-groundwater connections
Connection with SDGs	SDG 6
Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain– Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

4.36 Volume of water removed from water treatment system

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Jose Fermoso[1], Silvia Gómez[1], María González[1], Esther San José[1] and Raúl Sánchez[1]

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Volume of water removed from water treatment system	Water Management
Description and cation	Green infrastructure can prevent rainfall from entering the water treatment system by allowing it to soak into the soil or to evaporate back into the air.

Definition	This KPI evaluates the volume removed from the water treatment services (e.g., in m^3/y)that can also be translated into monetary values.
Strengths and weaknesses	+ This KPI calculation is simple if public data are available - A specific software can be required to calculate the monetary values
Measurement procedure and tool	This KPI requires the measure of water flow pre and post intervention, and discharge data for storm water. With this data, it can be created a local urban catchment hydrograph. A specific software can be used (GI-Val tool 2.1) to model the savings into monetary values. Create local urban catchment hydrograph for demonstration site. Model projected savings (Euro) using GI-Val. Discharge data for storm water (m^3) from United Utilities.
Scale of measurement	City
Data source	
Required data	Volume of water treated in the city, and volume from stormwater.
Data input type	Quantitative: Numeric data (tables).
Data collection frequency	Pre and post intervention.
Level of expertise required	Technical/basic
Synergies with other indicators	The volume of water retained by the NBS can be estimated through KPI Run-off coefficient in relation to precipitation quantities, and KPI Absorption capacity of green surfaces, bioretention structures and single trees.
Connection with SDGs	This KPI is directly related with SDG 6 and SDG 11 and indirectly is related with SDG 13 (promotes a more efficient use of water resources).
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl

	URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring- program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl The Mersey Forest & The University of Manchester (2011). STAR tools: surface temperature and runoff tools for assessing the potential of green infrastructure in adapting urban areas to climate change. Part of the EU Interreg IVC GRaBS project. www.ginw.co.uk/climatechange.

4.37 Volume of water slowed down entering sewer system

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Volume of water slowed down entering sewer system	**Water Management**
Description and cation	The parameters under principle investigation are discharge (m^3 sec^{-1}) and flow velocity (m sec-1), which when plotted on a storm-hydrograph, ought to demonstrate the following changes between the baseline and post GI scenario: • An increased lag-time (L), the time of peak rainfall to peak discharge and, • Reduced peak discharge (Qp)
Definition	Rate change in runoff production at field or plot scale.
Strengths and weaknesses	+ ET represents system losses of groundwater, potentially lowering wetted fringe and water table that is hypothesized to reduce soil moisture and increase infiltration – a useful GI service if permeable paving is installed. - Evapotranspiration (ET) (mm sec-1) and interception rates will not be directly observed under this KPI, through various processes, both are implicit in reducing inflow rates into sewers.
Measurement procedure and tool	Precipitation data will be collected, and water inputs and outputs will be monitored at a number of points of interest throughout the NBS interventions. These data are mapped and evaluated to obtain flow patterns by creating a model. The

	percentage of absorption or retained water will also be taken into account. Some data can be obtained from rainfall stations and gauging stations along the NBS influence area. It will necessary to create a longitudinal chain of continuous discharge observation. Conduct continuous discharge monitoring through the baseline and post-intervention scenario to tests the effects of GI on increased lag-time and reduced Qp
Scale of measurement	Area
Data source	
Required data	Open Pipe • V-notch gauging station weir with stilling well and spot discharge measurement to establish stage-discharge relationship, and therefore continuous discharge, extrapolated from 5 minute water-level (stage). • Non-contact flow measurement – Particle Image Velocity and infa-red height sensors to continually monitor height and velocity, over a known cross sectional area. Together these observations can combine to create a continuous discharge data-series. Closed Pipe • Ultrasonic Flow Meters, see example here: http://www.rshydro.co.uk/liquid-pipe-flowmeters/
Data input type	Numeric data (tables).
Data collection frequency	Pre and post intervention.
Level of expertise required	Technical/expert
Synergies with other indicators	Highly related with KPI Run-off coefficient in relation to precipitation quantities, and KPI Absorption capacity of green surfaces, bioretention structures and single trees.
Connection with SDGs	This KPI is directly related with SDG 6 and SDG 11 and indirectly is related with SDG 13 (promotes a more efficient use of water resources).
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	

References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Hankin B, Craigen I, Chappell NA et al. (2016) Strategic Investigation of Natural Flood Management in Cumbria. Jeremy Benn Associates, Skipton, UK. See http://naturalcourse.co.uk/uploads/2017/04/2016s4667-Rivers-Trust-Life-IP-NFM-Opportunities-Technical-Report-v8.0.pdf (accessed 02/02/2018). https://www.gov.uk/government/publications/flood-risk-maps-for-surface-water-how-to-use-the-map http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/stream-order.htm http://meetingorganizer.copernicus.org/EGU2015/EGU2015-8582.pdf

4.38 Total surface area of wetlands within a defined area

Project Name: UNaLab (Grant Agreement no. 730052)

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Total surface area of wetlands within a defined area	Climate resilience Water Management
Description and justification	Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as "… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide." Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate

	adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.
Definition	Total surface area covered with wetlands within a defined area (ha)
Strengths and weaknesses	+ Straightforward assessment of the surface area occupied by wetlands - Requires access to local records or international/local spatial datasets
Measurement procedure and tool	The extent of the surface area covered by wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual surface area calculation.
Scale of measurement	City; municipality
Data source	
Required data	Land-use raster of the area of interest; local records; satellite imagery
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Moderate – requires knowledge of GIS software Low – when assessing visually using satellite images
Synergies with other indicators	Direct relation to *Water management* and *Biodiversity* challenge categories
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management
Additional information	
References	Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017. Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of

	wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010. Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010. Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013. Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds.). *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

4.39 Total surface area of restored and/or created wetlands

Project Name: UNaLab (Grant Agreement no. 730052)

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Total surface area of constructed and/or restored wetlands within a defined area	Climate resilience Water Management
Description and justification	Wetlands are unique ecosystems that occur in places where the water table is close to the ground level, or where land is covered by water, either seasonally or permanently. Convention on Wetlands (Ramsar, Iran, 1971), or Ramsar Convention, defines wetlands as "… a wide variety of inland habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no deeper than six metres at low tide." Conservation and restoration of wetlands is regarded as one of the critical factors for establishing climate adaptation as part of the disaster risk reduction. Wetlands provide resilience against water-related hazards such as floods, storm surges and droughts by capturing and holding water and gradually releasing it. Peatlands enhance climate resilience by storing carbon.
Definition	Surface area of constructed and/or restored wetlands within a defined area (ha)

Strengths and weaknesses	+ Straightforward assessment of the surface area occupied by constructed and/or restored wetlands - Requires access to local records or international/local spatial datasets
Measurement procedure and tool	The extent of the surface area covered by constructed and/or restored wetlands can be assessed using the land-use raster data (local or EU-wide, e.g., Corine Land Cover) in GIS software that allows to examine the total area. Satellite imagery may be used for visual assessment and manual area calculation.
Scale of measurement	City; municipality
Data source	
Required data	Land-use raster of the area of interest; local records; satellite imagery
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Moderate – requires knowledge of GIS software Low – when assessing visually using satellite images
Synergies with other indicators	Direct relation to *Water management* and *Biodiversity* challenge categories
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection can be implemented among local people; another opportunity is community involvement in wetland management
Additional information	
References	Kumar, R., Tol, S., McInnes, R.J., Everard, M. and Kulindwa, A.A.. *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief, (1). Gland, Switzerland: Ramsar Convention Secretariat, 2017. Ramsar Convention Secretariat. *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 18. Ramsar Convention Secretariat, Gland, Switzerland, 2010. Ramsar Convention Secretariat. *Participatory skills: Establishing and strengthening local communities' and indigenous people's participation in the management of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 7. Ramsar Convention Secretariat, Gland, Switzerland, 2010.

	Renaud, F.G., Sudmeier-Rieux, K. and Estrella, M. (eds.). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: United Nations University Press, 2013. Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (eds.). *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. In Advances in natural and technological hazards research. Switzerland: Springer International Publishing, 2016, pp.598

4.40 Soil water flux

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Soil water flux and degree of saturation	**Water Management**
Description and justification	Soil water flux – is the transport of water into the soil from the atmosphere, into the atmosphere from the soil and within the soil, establishing the soil water mass balance. It is intrinsically related to the stress state of the soil and to ecohydrological processes occurring at the plant-soil-atmosphere continuum (e.g., plant uptake and evapotranspiration). Degree of saturation is a measure of the soil water mass balance. It is directly related to soil strength, matric suction, and soil water flux. Vegetation plays a key role in ecosystems by linking biophysical processes—such as absorption of solar radiation, rainfall interception, and evapotranspiration—to biogeochemical processes—such as photosynthesis and volatile organic compound emission. Moreover, vegetation links the terrestrial carbon cycle to hydrology through stomatal aperture (Jarvis and McNaughton, 1986), and through other processes such as soil-water extraction by roots (de Jong van Lier et al., 2006). Terrestrial water fluxes are controlled to a large extent by above-ground and below-ground biological processes where vegetation plays a major role.

Definition	The degree of saturation is the ratio of the volume of water to the volume of voids, usually represented as percentage, it can vary from 0 (totally dry soil) to 100 (completely saturated soil). The gradient of the total potential of soil water in both, the soil fully saturated by water (saturated flow) as well as in soil not fully saturated by water (unsaturated flow) creates a flow (flux) in the soil.
Strengths and weaknesses	+ A number of models exist for monitoring and prediction of fluxes, albeit usually at a larger scale + Degree of saturation: easy to measure with gravimetric methods in the lab and in situ with reflectometers; intrinsically related to matric suction through soil water retention function; related to meteorological variables rainfall and temperature - Some phenomena associated with vegetation, and this NBS, have not been modelled through the soil water flux
Measurement procedure and tool	Soil water flux is calculated using the hydraulic gradient measured with a tensiometer at two depths and the hydraulic ·conductivity corresponding to the average soil water content between the two depths determined with a neutron probe or by direct sampling and lab testing (moisture content determination). The degree of saturation is calculated as a ratio of the moisture content and specific gravity on one side and the void ratio on the other. Time domain reflectometry sensors
Scale of measurement	Point, micro
Data source	
Required data	For the flux: hydraulic gradient between two points; soil water content For the saturation degree: soil water content, specific gravity of the soil particles, void ratio of the soil
Data input type	Quantitative, numerical
Data collection frequency	Continuous
Level of expertise required	Intermediate to high
Synergies with other indicators	Digital terrain model; soil moisture content, groundwater table level, soil strength
Connection with SDGs	11,13,15,17

Opportunities for participatory data collection	Yes, through citizen science
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Hydrological effect of vegetation against rainfall-induced landslides. Journal of Hydrology, 549 (374–387) Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Plant-Best: A novel plant selection tool for slope protection. Ecological Engineering 106 (2017) 154–173.

4.41 Soil water retention capacity

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

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Soil water retention capacity	Water Management
Description and justification	Soils can store water in their matrix and skeleton depending on their structure, texture and mineral composition. There is an intrinsic relationship between the amount of water stored in the soil and the matric suction, which is established through the soil water retention function. This function defines field capacity and wilting point, which difference establishes the water available to plants in the soil. Soil water retention is also related to soil strength and bridges soil hydrology with mechanics. Soils that can hold a lot of water support more plant growth and are less susceptible to leaching losses of nutrients and pesticides. All of the water held by soil is not available for plant growth. Soil water retention capacity is mainly determined by the soil texture (sand, silt, clay contents), structure (bulk density and porosity), and organic matter content. It can influence the choice of NBS as well as the stability/effectiveness of the NBS put in place to mitigate against natural hazards. In general, the higher the percentage of silt and clay sized particles, the higher the water holding capacity. The small particles (clay and silt) have a much larger surface area than the

	larger sand particles. This large surface area allows the soil to hold a greater quantity of water.
Definition	It is the ability of the soil to store water under changing hydrological regimes -i.e., residual, transition and saturation. Soil water retention (or holding) capacity is the amount of water that a given soil can hold for an intended use.
Strengths and weaknesses	+ Standardised procedure for determination exists; it can be estimated based on soil type; bridges soil hydrology and mechanics; established the boundaries for the water available to plants in the soil. - Direct measurement requires significant time and effort from suitably qualified personnel; difficult to measure on site; requires measurement of matric suction; requires numerical modelling; limited availability of sensors measuring high soil suctions; difficult to establish under vegetated soil
Measurement procedure and tool	Determine water content at field capacity Determine water content at wilting point Plant available water = field capacity – wilting point moisture content Create a soil water retention curve
Scale of measurement	Micro, point but the results can be extrapolated to meso (field) scale
Data source	
Required data	Moisture contents at different air pressures
Data input type	Quantitative: Numerical
Data collection frequency	Periodic
Level of expertise required	Intermediate to high
Synergies with other indicators	Soil type, degree of saturation, moisture content, soil stability (FoS), organic matter content; soil field capacity, wilting point
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	Yes, especially for sampling
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S. B., 2017. Plant-soil reinforcement response under different soil hydrological regimes. *Geoderma*, *285*, 141-150.

	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Hydrological effect of vegetation against rainfall-induced landslides. *Journal of Hydrology, 549*, 374–387.

4.42 Stemflow rate

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Stemflow rate	**Water Management**
Description and justification	Aboveground vegetation parts funnel rainfall around the plant stem and promote its infiltration preferentially into the soil. The volume of water funnelled around the stem is substantial and its infiltration into the soil may promote changes in the stress state of the soil. Also, when rainfall interacts with the canopy it becomes richer with nutrients and organic matter that will then be transported into the soil.
Definition	Proportion of rainfall that is funnelled around the plant stem and then into the soil. Funnelling ratio > 1 implies substantial concentration of rainfall around the plant stem.
Strengths and weaknesses	+: well established procedures exist for NBS that include trees; it can be related to tree architectural traits; easy-to-establish empirical models with incident rainfall; related to soil biogeochemical processes; opportunities to use soil temperature as an indicator of stemflow funnelling belowground -: requires significant effort and suitably qualified workforce for measurement/monitoring; difficult to measure effect in the soil
Measurement procedure and tool	Installation of small diameter gutters spiralling along the tree stem and collection of the volume of water flowing through the gutters. Measurement of rainfall volume beyond the canopy's influence. Linear regression between stemflow and gross rainfall. Data collection of tree architectural traits and implementation of multivariate statistics to relate both tree architecture and stemflow
Scale of measurement	Point (micro, individual) to field (meso)

Data source	
Required data	Water volume; tree architectural traits (canopy cover fraction, leaf area index, number of leaves, number of branches, branches inclination, tree basal area)
Data input type	Numerical, quantitative
Data collection frequency	During every rainfall event
Level of expertise required	Intermediate to high
Synergies with other indicators	Moisture content, soil temperature, matric suction, interception, throughflow, vegetation type, vegetation cover, precipitation
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	Yes
Additional information	
References	Gonzalez-Ollauri. A., Stokes, A., Mickovski, S.B., 2020. A novel framework to study the effect of tree architectural traits on stemflow yield and its consequences for soil-water dynamics. Journal of Hydrology, 582 (124448). Gonzalez Ollauri, A & Mickovski, SB 2017, 'Hydrological effect of vegetation against rainfall-induced landslides', Journal of Hydrology, vol. 549, pp. 374–387

4.43 Percolation rate under different rainfall events

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Percolation rate for different rainfall events	Water Management
Description and justification	After the precipitation reaches the soil (through throughflow, stemflow or directly on the soil surface), some of it will move through the soil and can create instability and erosion within the soil. Percolation may

	also lead to the formation of perched water tables in the soil, which may have a negative effect on soil strength
Definition	The speed at which water (usually from precipitation) moves through soil.
Strengths and weaknesses	+ certain amount of mobile water is needed for supporting the growth of the vegetative part of the NBS; large body of well-established, physically-based models exist for its estimation; well-established field and lab protocols exist for its measurement of flood peak flow reduction and delay. - higher velocities of percolation can increase the risk of internal erosion of finer particles; difficult to quantify the effect of percolation on soil strength.
Measurement procedure and tool	A percolation test consists of digging one or more holes in the soil of the proposed leach field to a specified depth, pre-soaking the holes by maintaining a high water level in the holes, then running the test by filling the holes to a specific level and timing the drop of the water level as the water percolates into the surrounding soil.
Scale of measurement	Micro (individual excavation), to meso (field testing, sometimes a line of excavations)
Data source	
Required data	Water quantity, time for the water quantity to percolate through the soil
Data input type	Numerical, quantitative
Data collection frequency	Once as a baseline reading; sporadically thereafter throughout the NBS life cycle
Level of expertise required	Low
Synergies with other indicators	Moisture content, interception, throughflow, stemflow, vegetation type, vegetation cover, precipitation, erosion rate, soil type, ground water table, water flux
Connection with SDGs	11,13,15,1,7
Opportunities for participatory data collection	Yes
Additional information	
References	Gonzalez Ollauri, A & Mickovski, SB 2017, 'Hydrological effect of vegetation against rainfall-induced landslides', Journal of Hydrology, vol. 549, pp. 374–387

4.44 Dissolved oxygen (DO) content of NBS effluents

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Dissolved oxygen of NBS effluents	Water Management
Description and justification	Water quality can profoundly impact both aquatic and terrestrial ecosystems. Changes to the quality of water may occur due to many different factors, including human activities. It is therefore important to monitor water quality in environments likely to be affected by anthropogenic activity, or in particularly sensitive aquatic ecosystems. Basic water quality parameters include pH, temperature, electrical conductivity (EC), dissolved oxygen (DO) content and flow rate.
Definition	Concentration of oxygen dissolved in water (mg/L or % O_2 saturation). The significance of DO content of natural waters is the requirement for sufficient oxygen to support aquatic life.
Strengths and weaknesses	+ An easy and straightforward assessment + Can be automated to ensure continuous data collection - Potential difficulties with maintenance and calibration of the automated equipment
Measurement procedure and tool	a. Dissolved oxygen content (DO) is traditionally measured in the laboratory using a Winkler method. For the Winkler method, water samples are collected overflowing in the sample bottles to minimize the air interference, and then using a set of reagents the oxygen is "fixed". The reagents include: • 2 ml Manganese sulfate • 2 ml alkali-iodide-azide • 2 ml concentrated sulfuric acid • 2 ml starch solution • Sodium thiosulfate

	After that, the sample is titrated until reaching the endpoint (i.e., colour change). The endpoint determines the concentration of the DO in the water sample, which is equivalent to the number of millilitres of titrant used. b. An alternative and less chemical-intensive method is measuring the DO content using a DO meter and a probe that require calibration according to the manufacturer's instructions. The DO content of water is inversely related to temperature, with decreasing O_2 solubility in water as temperature increases. DO and temperature should always be measured together to ensure accuracy. Many DO meters have an in-built temperature probe and will display DO content in mg/L as well as the per cent (%) O_2 saturation, along with the measured water temperature (in °C). Excessive nutrient (N and P) load to the water bodies results in depleted DO concentrations and degradation of watercourses.
Scale of measurement	Plot scale
Data source	
Required data	Dissolved oxygen and temperature measurement data
Data input type	Quantitative
Data collection frequency	Daily (using automated measurements) or weekly
Level of expertise required	Low
Synergies with other indicators	Synergies with the indicator group *Water quality* indicators
Connection with SDGs	SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection is possible under supervision
Additional information	
References	A number of standard methodologies for water testing are available from, e.g., the International Organization for Standardization (ISO), American Public Health Association (APHA), the European Environment Agency (EEA), and others.

4.45 Eutrophication

Project Name: proGIreg (Grant Agreement no. 776528)

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Eutrophication	**Water Management**
Description and justification	Eutrophication is probably the most serious environmental problem affecting water reservoirs. Excessive nutrient input (mainly nitrogen and phosphorus) lead to an overgrowth of biomass that affect water dissolved oxygen, water transparency with a negative impact on human and animal health.
Definition	The water eutrophication level will be evaluated by a Set Pair Analysis of 5 indices
Strengths and weaknesses	A strength of this indicator is that reduce uncertainties for eutrophication level.
Measurement procedure and tool	Total nitrogen, total phosphorus, chlorophyll concentration, dissolved oxygen, will be used in a Set Pair Analysis to detect a eutrophication level
Scale of measurement	NBS Level
Data source	
Required data	concentration of total nitrogen, total phosphorus, chlorophyll concentration, dissolved oxygen
Data input type	Discrete variables
Data collection frequency	Pre and post implementation data collection
Level of expertise required	High
Synergies with other indicators	This indicator is related to other indicators of environmental benefit
Connection with SDGs	Sustainable consumption and production: The implementation of nature-based solutions contributes to “doing more and better with less,” net welfare gains from

	economic activities can increase by reducing resource use, degradation and pollution along the whole life cycle.
Opportunities for participatory data collection	
Additional information	
References	Wu, F. F., and Xu Wang. "Eutrophication evaluation based on set pair analysis of Baiyangdian Lake, North China." Procedia Environmental Sciences 13 (2012): 1030-1036.

4.46 pH of NBS effluents

Project Name: UNaLab (Grant Agreement no. 730052) and PHUSICOS (Grant Agreement no. 776681)

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pH of the NBS effluents	**Water Management**
Description and justification	Water quality can profoundly impact both aquatic and terrestrial ecosystems. Changes to the quality of water may occur due to many different factors, including human activities. It is therefore important to monitor water quality in environments likely to be affected by anthropogenic activity, or in particularly sensitive aquatic ecosystems. Basic water quality parameters include pH, temperature, electrical conductivity (EC), dissolved oxygen (DO) content and flow rate.
Definition	A measure of the relative acidity or alkalinity of a solution (0-14 pH units). The pH of a sample of water is a measure of the concentration of hydrogen ions (-log[H+]).
Strengths and weaknesses	+ An easy and straightforward assessment + Can be automated to ensure continuous data collection

	+ The measuring equipment is inexpensive - Determination using colorimetric approach may be hindered for the individuals suffering from colour blindness
Measurement procedure and tool	The pH of a sample of water is a measure of the concentration of hydrogen ions. If free H^+ are more it is expressed acidic (i.e., pH < 7), while more OH^- ions is expressed as alkaline (i.e., pH > 7). At higher pH, there are fewer free hydrogen ions, and a change of one pH unit reflects a tenfold change in the concentrations of the hydrogen ion. A pH of 7 is considered to be neutral. Substances with pH of less than 7 are acidic; substances with pH greater than 7 are basic. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH may also determine whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble. The pH is considered a 'master variable' as the pH, together with oxidative-reductive potential, determines the chemical speciation, behaviour and fate of (bio)chemical compounds in the environment. The pH range of natural waters varies from ca. 4.5 in peat-influenced waters to as high as 10.0 in systems influenced by intense algal photosynthetic activity. The typical pH range of natural waters is 6.5-8.0. Measuring of the pH is simple and is usually done using either a colorimetric method (visual or electronic) or electronic meters. Steps in the determination of pH include: • Checking the equipment. Some of the following equipment should be used: o pH colorimeter field kit o pH meter with built-in temperature sensor, or o colorimeter with reagents • Measuring the pH values o In the colorimetric method (both visual and electronic), indicators that change colour according to the pH of the solution are used. With colorimetric kits, chemical or two (reagents) are added to the water sample, and the resulting colour is

	compared to the colour standards of known pH values o With the calibrated pH meter, the electrode is placed in the water and the pH is recorded The recommended method of pH measurement is electrometry/use of a pH electrode.
Scale of measurement	Plot scale
Data source	
Required data	pH measurement data
Data input type	Quantitative
Data collection frequency	Daily (using automated measurements) or weekly
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection is possible under supervision
Additional information	
References	A number of standard methodologies for water testing are available from, e.g., the International Organization for Standardization (ISO; ISO 10523:2008 Water quality — Determination of pH), American Public Health Association (APHA), the European Environment Agency (EEA), and others.

4.47 Electrical conductivity of NBS effluents

Project Name: UNaLab (Grant Agreement no. 730052) and PHUSICOS (Grant Agreement no. 776681)

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Electrical conductivity of the NBS effluents	Water Management
Description and justification	Water quality can profoundly impact both aquatic and terrestrial ecosystems. Changes to the quality of water may occur due to many different factors, including human activities. It is therefore important to monitor water quality in environments likely to be affected by anthropogenic activity, or in particularly sensitive aquatic ecosystems. Basic water quality parameters include pH, temperature, electrical conductivity (EC), dissolved oxygen (DO) content and flow rate.
Definition	Electrical conductivity (EC) is a measure of a solution to conduct electricity (µS/cm or S/m). EC reflects a dissolved (ionisable) mineral salt content in water.
Strengths and weaknesses	+ An easy and straightforward assessment + Can be automated to ensure continuous data collection - Potential difficulties with maintenance and calibration of the automated equipment
Measurement procedure and tool	The conductivity (specific conductance) depends on the total concentration, mobility, valence and the temperature of the solution of ions. Electrolytes in a solution disassociate into positive (cations) and negative (anions) ions and impart conductivity. Most dissolved inorganic substances are in the ionised form in water and contribute to conductance. The conductance of the samples gives rapid and practical estimate of the variation in dissolved mineral content of the water supply. Conductance is defined as the reciprocal of the resistance involved and expressed as mho or Siemens. Conductivity is

	reported at 25 °C as temperature is proportional to the conductivity levels. In the aqueous solutions, the electrical conductivity is influenced by the presence of inorganic dissolved solids, each ion carrying an electrical charge. Typically, the distilled water has very low conductivity (ca. 0.05 µS/cm), whereas seawater has considerably higher values (ca. 50 000 µS/cm). Pollutants from urban, agricultural and industrial sources usually increase the electrical conductivity of water and make it unsuitable for usage. Generally, natural waters have stable conductivity levels, and the increase in electrical conductivity usually implies the disturbance associated, for example, with the urban runoff, which can contain elevated concentration of salts and other ions. The EC (in µS/cm) provides a rough approximation of the total dissolved solids (TDS, in mg/L) content, via the equation: $$Conductivity \times \frac{2}{3} = Total\ disolved\ solids$$
Scale of measurement	Plot scale
Data source	
Required data	Electrical conductivity measurement data
Data input type	Quantitative
Data collection frequency	Daily (using automated measurements) or weekly
Level of expertise required	Low
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection is possible under supervision
Additional information	
References	A number of standard methodologies for water testing are available from, e.g., the International Organization for Standardization (ISO), American Public Health Association (APHA), the European Environment Agency (EEA), and others.

ASTM. (2014). *ASTM D1125-14 Standard Test Methods for Electrical Conductivity and Resistivity of Water*. ASTM International, West Conshohocken, PA.

4.48 Water Framework Directive: Physico-chemical quality of surface waters

Project Name: UNaLab (Grant Agreement no. 730052), NAIAD (Grant Agreement no. 730497), PHUSICOS (Grant Agreement no. 776681)

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Water Framework Directive: Physicochemical status of surface waters	Water Management
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. Good ecological status of water bodies aggregates a number of indicators into an integrated indicator and it has been developed to determine and monitor the ecological

	status of water bodies in Europe through the EU Water Framework Directive (WFD). The EU WFD (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.
Definition	Physico-chemical quality of surface waters - rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level
Measurement procedure and tool	The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC): 1. Characterise water bodies within a river basin area per Annex II: a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies 2. Establish type-specific physicochemical reference conditions per Annex V 3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII: a. Organohalogen compounds and substances which may form such compounds in the aquatic environment b. Organophosphorous compounds c. Organotin compounds d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances f. Cyanides g. Metals and their compounds h. Arsenic and its compounds i. Biocides and plant protection products j. Materials in suspension k. Substances which contribute to eutrophication (in particular, nitrates and phosphates)

	l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.) 4. Establish monitoring of physicochemical status for surface waters: a. Design of surveillance, operational and/or investigative monitoring per Annex V b. Frequency of monitoring c. Additional monitoring requirements for protected areas as listed under Annex IV 5. Present monitoring results as maps in accordance with Annex V 6. Classify physicochemical status of surface waters per Annex V:
Scale of measurement	River basin; Member State
Data source	
Required data	Reference conditions; Anthropogenic pressures, Point and diffuse pollution sources
Data input type	Quantitative
Data collection frequency	Frequency for surveillance monitoring period:

Quality element	Rivers	Lakes	Transitional	Coastal
Thermal conditions	3 months	3 months	3 months	3 months
Oxygenation	3 months	3 months	3 months	3 months
Salinity	3 months	3 months	3 months	
Nutrient status	3 months	3 months	3 months	3 months
Acidification status	3 months	3 months		
Other pollutants	3 months	3 months	3 months	3 months
Priority substances	1 month	1 month	1 month	1 month

For operational monitoring, the frequency of monitoring required for any parameter shall be determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element. As

	a guideline, monitoring should take place at intervals not exceeding those indicated for surveillance monitoring.
Level of expertise required	Moderate to High
Synergies with other indicators	Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters* and *Ecological potential for heavily modified or artificial water bodies*
Connection with SDGs	SDG 3 Good health and well-being, SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy* http://data.europa.eu/eli/dir/2000/60/oj European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans.*

4.49 Total pollutant discharge to local waterbodies

Project Name: UNaLab (Grant Agreement no. 730052)

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Total pollutant discharge to local waterbodies	**Water Management**
Description and justification	In the EU, all waterbodies are classified by quality status based on guidelines set in the Water Framework Directive (WFD), Directive 2000/60/EC (European Parliament, Council of the European Union, 2000). The WFD outlines biological, physico-chemical and hydromorphological quality elements. Comparison of measured water quality parameters for a given waterbody with standard values outlined in the WFD allows classification of the status of a waterbody from high to bad. Parameters taken into account include a large number of variables including, e.g., plankton counts, aquatic flora, invertebrates, hydrological continuity and conditions, thermal conditions, oxygen conditions, salinity, nutrient conditions and prevalence of priority pollutants and other specific pollutants. Many of these parameters are waterbody specific and the determination of stress caused by a pollution source depends on the type and size of the waterbody (European Parliament, Council of the European Union, 2000).
Definition	Water quality status according to WFD as determined by pollutant discharge monitoring
Strengths and weaknesses	+ Persistent quality monitoring of the receiving waterbody is a good way of following the environmental impacts of the pollutant discharges of urban communities, but they depend heavily on the condition and size of the receiving waterbody and the whole catchment area - Selecting proper sampling procedures as well as measured variables to capture a representative figure of the pollution discharge loading is challenging
Measurement procedure and tool	Pollutant discharge is estimated by taking samples from urban runoff from the target area and comparing the time series of the selected parameters. First, sampling sites are selected to represent the catchment urban area in question as comprehensively as possible. Ideally, sampling sites can be streams, ditches or runoff sewers collecting from a large catchment area in the urban area of interest, but not yet

	mixing with a larger waterbody. A sampling schedule is determined and followed. Ideally, continuous automatic aggregate samplers are used with flowmeters, providing the most reliable estimates of parameter yearly aggregates. Alternate sampling method is systematic sampling in which samples are taken with identical time steps (e.g., every 2 months) regardless of conditions, like rainfall, traffic or temperature. All non-continuous sampling procedures inflict bias into results, and will only capture a fraction of the actual runoff quality, which makes results invariably noisy. On-site measurements, sampling and laboratory analysis are to be performed by personnel and in premises with experience in water sampling and analysis using standardized methods, chemicals and equipment. For technical details, please refer to standard methods or equivalent methods available at the laboratory performing the analysis. As the details of each urban environment and NBS can differ substantially, and as parameters described here are often only indicative of water quality, potential change in pollution discharge is presented in a Likert-type scale:

1	Several of the parameters indicate significantly worse water quality, or more than half of the parameters indicate somewhat worse water quality
2	One of the parameters indicate significantly worse water quality, or some of the parameters indicate somewhat worse water quality
3	The parameters indicate no change in the water quality
4	One of the parameters indicate significantly better water quality, or some of the parameters indicate somewhat better water quality
5	Several of the parameters indicate significantly better water quality, or more than half of the parameters indicate somewhat better water quality

Scale of measurement	District scale
Data source	
Required data	Measurement data of the parameters
Data input type	Qualitative and quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Low to high
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group

Connection with SDGs	SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection possible under supervision
Additional information	
References	Allen Burton, G., Jr., & Pitt, R.E. (2010). *Stormwater Effects Handbook. A Toolbox for watershed Managers, Scientists, and Engineers*. Boca Raton, FL: Lewis Publishers, CRC Press. European Parliament, Council of the European Union. (2000). *EU Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02000L0060-20140101 United States Environmental Protection Agency (US EPA). (2017). *Water Quality Standards Handbook: Chapter 3: Water Quality Criteria*. EPA-823-B-17-001. Washington, D.C.: EPA Office of Water, Office of Science and Technology. Retrieved from https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf Zumdahl, S.S., & DeCoste, D.J. (2012). *Chemical Principles*. Seventh Edition. Boston, MA: Cengage Learning.

4.50 Water Quality: basic physical parameters

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

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Water Quality: Basic physical parameters	**Water Management**
Description and justification	Indicators of Effects on Water Quality sub-criterion will assess the effects of project scenarios on water quality, in terms of physical, microbiological, biological and chemical parameters.
Definition	Physical parameters of water, together with chemical and microbiological properties, determine the water quality. Main quality characteristics of natural waters include

	temperature; colour; taste and odour; turbidity; total solids; conductivity; pH, and dissolved oxygen. All of these must be evaluated to obtain a comprehensive assessment of the water quality of the waterbodies. **TEMPERATURE**. Responds to inflows, water releases and industrial discharge pressures, and is of crucial importance for the assessment of biocenoses. Temperature is influenced by daily changes due to respiration (with lower variation in fast flowing rivers). Monitoring should consider seasonal stratification and mixing (in deep water) and cold water releases. Sampling should be performed in-situ using submersible probe, fortnightly/monthly during all seasons, by a single measurement or water column profile. **COLOUR. C**olour in water is primarily a concern of water quality for aesthetic reason. Coloured water gives the appearance of being unfit to drink, even though the water may be perfectly safe for public use. On the other hand, colour can indicate the presence of organic substances, such as algae or humic compounds. More recently, colour has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in water. **TASTE AND ODOUR.** Taste and odour are human perceptions of water quality. Human perception of taste includes sour (hydrochloric acid), salty (sodium chloride), sweet (sucrose) and bitter (caffeine). Relatively simple compounds produce sour and salty tastes. However sweet and bitter tastes are produced by more complex organic compounds. Human detect many more tips of odour than tastes. Organic materials discharged directly to water, such as falling leaves, runoff, etc., are sources of tastes and odour-producing compounds released during biodegradation. **TURBIDITY.** Turbidity is a measure of the light-transmitting properties of water and is comprised of suspended and colloidal material. It is important for health and aesthetic reasons. **TOTAL SOLIDS.** The Total Solids content of water is defined as the residue remaining after evaporation of the water and drying the residue to a constant weight at 103 °C to 105 °C. Total solids include Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)
Strengths and weaknesses	+ These are basic measures of river condition and important influences on natural river systems. It - Some of these parameters may vary locally

Measurement procedure and tool	Model/Survey. In situ sampling.
Scale of measurement	Various
Data source	
Required data	Various
Data input type	Quantitative and semi-quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	6
Opportunities for participatory data collection	
Additional information	
References	http://echo2.epfl.ch/VICAIRE/mod_2/chapt_2/main.htm http://wgbis.ces.iisc.ernet.in/energy/monograph1/Methpage1.html

4.51 Total polycyclic hydrocarbon (PAH) content of NBS effluents

Project Name: Connecting Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop[1]

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Total polycyclic aromatic hydrocarbon (PAH) content of NBS effluents	**Water Management**
Description and justification	Polycyclic aromatic hydrocarbons (PAHs) are a group of more than 100 chemicals that are persistently toxic in the environment. In areas of contamination, PAHs can be found in water, soils, sediments and plants. Bioremediation is one of the mechanisms that has been identified as a potential method for reducing/removing

	PAHs in natural systems (Samanta et al. 2002). As such, nature-based solutions represent a mechanism for intercepting PAHs from source, or remediating PAHs in-situ. Assessing the level of PAHs in water released from nature-based solutions represents a mechanism for evaluating the perfomance of the nature-based solution in terms of increase/decrease in PAHs.
Definition	Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental pollutants that possess carcinogenic and mutagenic properties (Menzie and Potokib1992). Whilst PAHs can come from natural sources, they are also formed during incomplete combustion, pyrosynthesis, or pyrolysis of hydrocarbons (petrogenesis) (Li et al. 2010). As such, PAH release into the environment is associated with anthropogenic sources and urbanisation (Menzie and Potokib1992).
Strengths and weaknesses	+ Well established protocols exist for analysing PAHs in water - Results can be heavily influenced by sampling frequency. - Depending on sampling methodology, regular sampling visit might be required
Measurement procedure and tool	Typically, PAH analysis is carried out through laboratory analysis of water samples. For information on general water sampling procedures, see indicator 1.2 Water Quality General and the Connecting Nature Environmental Indicator Metrics Review Report. However, in-situ methods are emerging (Felemban 2019). Once water samples have been collected, laboratory analysis typically comprises the use of analytical methods such as gas chromatography/mass spectrometry (GC/MS), including chemical ionization MS, ion trap MS, TOF/MS, and isotope-ratio MS (IRMS), and high-performance liquid chromatography (HPLC) with fluorescence detection or ultraviolet detection (HPLC/UV) (Molaei et al. 2016; Felemban 2019). In addition to PAH concentrations, it can be advisable to calculate change in flow rates due to NBS also. By doing so, it may be possible to calculate PAH loading in addition to pollutant level. This is a worthwhile consideration as, it is possible that concentrations in water could increase whilst overall pollutant load can decrease (due to a significant reduction in water flow over time).

Scale of measurement	Typically carried out on a site scale, but could be combined with city-wide water quality monitoring if NBS is sufficiently scaled-up.
Data source	
Required data	Spatial data in relation to water flows and sampling methodologies
Data input type	Quantitative and spatial
Data collection frequency	Regular sampling/continuous sampling is recommended to avoid missing pollution spikes/first flush events. However, if background levels are the target for evaluation, less frequent sampling may be adequate.
Level of expertise required	Water sampling does not necessarily require a high degree of expertise. Laboratory analysis does however require technical expertise.
Synergies with other indicators	Improved water quality can have correlations with nature, health and social value of a waterways, particularly in relation to biodiversity indicators.
Connection with SDGs	SDG3, SDG4, SDG6, SDG8-SDG12; SDG14-SDG17: Clean water supply; Links to environmental education; Clean water; Job creation; Cleaner water supply; Social equality in relation to water quality; Sustainable urban development; More sustainable water management; Improved water quality (for life below water); Improved water quality (for life on land); Environmental Justice; Opportunities for collaborative working
Opportunities for participatory data collection	Opportunities are available for participatory processes, particularly in relation to taking water samples for subsequent analysis. Automated dataloggers offer less opportunity for such participation with participation limited to observing and processing the data produced. There are also opportunities for stewardship of equipment or nature-based solution, etc.
Additional information	
References	Felemban, S, Vazquez, P and Moore, E (2019) Future Trends for In Situ Monitoring of Polycyclic Aromatic Hydrocarbons in Water Sources: The Role of Immunosensing Techniques. *Biosensors 2019, 9*, 142. Li, J., Shang, X., Zhao, Z., Tanguay, R. L., Dong, Q., & Huang, C. (2010). Polycyclic aromatic hydrocarbons in water, sediment, soil, and plants of the Aojiang River waterway in Wenzhou, China. *Journal of hazardous materials, 173*(1-3), 75–81. Menzie CA, Potokib B. (1992) Exposure to carcinogenic PAHs in the environment. *Environ. Sci. Technol. 26*,1278–1284. Molaei, S, Saleh, A. and Ghoulipour VSeidi, S (2016) Centrifuge-less Emulsification Microextraction Using Effervescent CO2

	Tablet for On-site Extraction of PAHs in Water Samples Prior to GC–MS Detection. *Chromatographia 79*, 629–640. Samanta, S, Singh, OV and Jain, RK (2002) Polycyclic aromatic hydrocarbons: environmental pollution and bioremediation. *Trends in Biotechnology 20*(6), 243-248.

4.52 Total organic carbon (TOC) content of NBS effluents

Project Name: Connecting Nature (Grant Agreement no. 730222)
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Total organic carbon (TOC) content of NBS effluents	Water Management
Description and justification	Total Organic Carbon (TOC) is a measure of the total amount of carbon in organic compounds and is a key parameter for accessing the organic load of water. Organic carbon occurs as the result of decomposition of plant or animal material in both surface and groundwater. It is an extremely important part of the carbon cycle (and hence carbon calculation of nature-based solutions) and a food source in aquatic ecosystems. Total organic carbon (including dissolved organic carbon - organic matter that can pass through a filter no larger than 0.45 µm) can also contribute to the acidity water bodies and can increase the turbidity of aquatic systems, impacting phototrophic organisms. Nature-based solutions can play a key role in the carbon cycle and in relation to the total organic carbon balance. As such, understanding their role in relation to total organic carbon in water released from the nature-based solution is a key part of understanding their wider benefits, co-benefits and dis-benefits.
Definition	Total organic carbon in a water sample (mg/L C). Carbon load (mg/L over time) is also a critical part of the understanding of this indicator (mean concentration of carbon mg/L)
Strengths and weaknesses	+ Well established protocols exist for analysing Total Organic Carbon in water - Results can be heavily influenced by sampling frequency.

	- Depending on sampling methodology, regular sampling visits might be required
Measurement procedure and tool	Organic carbon content analysis in effluent from nature-based solutions can be carried out through laboratory analysis of extracted water samples. For information on general water sampling procedures, see indicator 1.2 Water Quality General and the Connecting Nature Environmental Indicator Metrics Review Report. However, in-situ methods are also available (e.g., Proteus Multiparameter Water Quality Meter) and have the advantage of more regular/frequent sampling intensities. If water sampling for subsequent analysis is carried out, once water samples have been collected, they are sent off for laboratory analysis. Total organic carbon (TOC) is a non-specific test. Rather than determining which particular compounds are present, the test quantifies the sum of all organic carbon within those compounds. A number of established and emerging methods exist for quantifying TOC, typically depending on expected concentration thresholds. An established methodology is thermal combustion ion chromatography using a tube furnace and readily accessible HPLC (Fung et al. 1996). In addition to a Total Organic Carbon concentration, it can also be advisable to calculate change in flow rates due to the nature-based solution. By so doing, it may be possible to calculate PAH loading in addition to pollutant level. This is a worthwhile consideration as, it is possible that concentrations in water could increase whilst overall pollutant load can decrease (due to a significant reduction in water flow over time).
Scale of measurement	Typically carried out on a site scale, but could be combined with city-wide water quality monitoring if NBS is sufficiently scaled-up.
Data source	
Required data	Spatial data in relation to water flows and sampling methodologies
Data input type	Quantitative and spatial
Data collection frequency	Regular sampling/continuous sampling is recommended to avoid missing pollution spikes/first flush events. However, if background levels are the target for evaluation, less frequent sampling may be adequate.
Level of expertise required	Water sampling does not necessarily require a high degree of expertise. Laboratory analysis does however require

	technical expertise. In-situ analysis only requires technical expertise in relation to installation of equipment.
Synergies with other indicators	Improved water quality can have correlations with nature, health and social value of a waterways, particularly in relation to biodiversity indicators. There are also links to climate change mitigation due to the links to the carbon cycle story.
Connection with SDGs	SDG3, SDG4, SDG6, SDG8-SDG12; SDG14-SDG17: Clean water supply; Links to environmental education; Clean water; Job creation; Cleaner water supply; Social equality in relation to water quality; Sustainable urban development; More sustainable water management; Improved water quality (for life below water); Improved water quality (for life on land); Environmental Justice; Opportunities for collaborative working
Opportunities for participatory data collection	Opportunities are available for participatory processes, particularly in relation to taking water samples for subsequent analysis. Automated dataloggers offer less opportunity for such participation with participation limited to observing and processing the data produced. There are also opportunities for stewardship of equipment or nature-based solution, etc.
Additional information	
References	Fung, YS, Wu, Z and Dao, KL (1996) Determination of Total Organic Carbon in Water by Thermal Combustion-Ion Chromatography. *Analytical Chemistry 68*(13), 2186-2190.

4.53 General ecological status of surface waters

Project Name: UNaLab (Grant Agreement no. 730052)

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Ecological status of surface waters	Water management
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential

	for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.
Definition	General ecological status of surface waters applicable to rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level
Measurement procedure and tool	The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC): 1. Characterise water bodies within a river basin area per Annex II: a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies 2. Establish type-specific ecological reference conditions per Annex V 3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII: a. Organohalogen compounds and substances which may form such compounds in the aquatic environment b. Organophosphorous compounds c. Organotin compounds d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances f. Cyanides g. Metals and their compounds h. Arsenic and its compounds i. Biocides and plant protection products j. Materials in suspension k. Substances which contribute to eutrophication (in particular, nitrates and phosphates)

	l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.) 4. Establish monitoring of ecological status for surface waters (The monitoring network shall be designed so as to provide a coherent and comprehensive overview of ecological and chemical status within each river basin and shall permit classification of water bodies into five classes consistent with the normative definitions): a. Design of surveillance, operational and/or investigative monitoring per Annex V b. Frequency of monitoring c. Additional monitoring requirements for protected areas as listed under Annex IV 5. Present monitoring results as maps in accordance with Annex V 6. Consider quality elements for classifying the ecological status per Annex V: a. Biological elements b. Chemical and physicochemical elements c. Hydromorphological elements d. Specific pollutants 7. Classify ecological status of surface waters (separate for rivers, lakes, transitional waters and coastal waters) per Annex V
Scale of measurement	River basin; Member State
Data source	
Required data	Biological, physicochemical, hydromorphological quality of surface waters
Data input type	Quantitative and qualitative
Data collection frequency	Different frequencies for biological, physicochemical, hydromorphological and other quality elements determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element.
Level of expertise required	Moderate to High
Synergies with other indicators	Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters,*

	Hydromorphological status of surface waters, Physicochemical status of surface waters and *Ecological potential for heavily modified or artificial water bodies*
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. http://data.europa.eu/eli/dir/2000/60/oj European Parliament. (2006). *Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration*. http://data.europa.eu/eli/dir/2006/118/2014-07-11 European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*.

4.54 Ecological potential for heavily modified or artificial water bodies

Project Name: UNaLab (Grant Agreement no. 730052)

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Ecological potential for heavily modified or artificial water bodies	**Water management**
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework

	Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.
Definition	Ecological potential for heavily modified or artificial water bodies (maximum, good, moderate, poor, bad)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level
Measurement procedure and tool	The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC): 1. Characterise water bodies within a river basin area per Annex II: a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies 2. Establish type-specific reference conditions per Annex V 3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII: a. Organohalogen compounds and substances which may form such compounds in the aquatic environment b. Organophosphorous compounds c. Organotin compounds d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances f. Cyanides g. Metals and their compounds h. Arsenic and its compounds i. Biocides and plant protection products j. Materials in suspension k. Substances which contribute to eutrophication (in particular, nitrates and phosphates) l. Substances which have an unfavourable influence on the oxygen balance (and can

	be measured using parameters such as BOD, COD, etc.) 4. Establish monitoring of ecological potential for heavily modified or artificial water bodies: a. Design of surveillance, operational and/or investigative monitoring per Annex V b. Frequency of monitoring 5. Consider quality elements for classifying the ecological potential for heavily modified or artificial water bodies per Annex V: a. General conditions b. Biological quality elements c. Chemical and physicochemical elements d. Hydromorphological elements e. Specific synthetic pollutants f. Specific non-synthetic pollutants The quality elements applicable to artificial and heavily modified surface water bodies shall be those applicable to whichever of the four natural surface water categories (rivers, lakes, transitional waters or coastal waters) most closely resembles the heavily modified or artificial water body concerned. 6. Present monitoring results as maps in accordance with Annex V 7. Classify ecological potential for heavily modified or artificial water bodies per Annex V
Scale of measurement	River basin; Member State
Data source	
Required data	Reference conditions; Anthropogenic pressures; General, biological, physicochemical, hydromorphological quality of heavily modified or artificial water bodies
Data input type	Qualitative and quantitative
Data collection frequency	Different frequencies for biological, physicochemical, hydromorphological and other quality elements determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element.
Level of expertise required	Moderate to High
Synergies with other indicators	Indicators forming parts of the Member States' River Basin Management Plans: *Quantitative status of groundwater, Chemical status of groundwater, Ecological status of*

	surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters and Ecological potential for heavily modified or artificial water bodies
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. http://data.europa.eu/eli/dir/2000/60/oj European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*.

4.55 Biological quality of surface waters

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik, Laura Wendling, Ville Rinta-Hiiro, Arto Laikari, Malin zu-Castell Rüdenhausen

VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland

Water Quality: Biological status of surface waters	**Water Management**
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.

Definition	Biological quality of surface waters - rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level
Measurement procedure and tool	The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC): 1. Characterise water bodies within a river basin area per Annex II: a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies 2. Establish type-specific biological reference conditions per Annex V 3. Identify significant anthropogenic pressures, and estimate point and diffuse source pollution in particular by substances listed under Annex VIII: a. Organohalogen compounds and substances which may form such compounds in the aquatic environment b. Organophosphorous compounds c. Organotin compounds d. Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine related functions in or via the aquatic environment e. Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances f. Cyanides g. Metals and their compounds h. Arsenic and its compounds i. Biocides and plant protection products j. Materials in suspension k. Substances which contribute to eutrophication (in particular, nitrates and phosphates) l. Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.) 4. Establish monitoring of biological status for surface waters:

<table>
<tr><td></td><td>
a. Design of surveillance, operational and/or investigative monitoring per Annex V
b. Frequency of monitoring
c. Additional monitoring requirements for protected areas as listed under Annex IV
5. Present monitoring results as maps in accordance with Annex V
6. Classify biological status of surface waters per Annex V
</td></tr>
<tr><td>Scale of measurement</td><td>River basin; Member State</td></tr>
<tr><td colspan="2">Data source</td></tr>
<tr><td>Required data</td><td>Biological reference conditions; Anthropogenic pressures</td></tr>
<tr><td>Data input type</td><td>Qualitative, quantitative</td></tr>
<tr><td>Data collection frequency</td><td>For surveillance monitoring period:
<table>
<tr><th>Quality element</th><th>Rivers</th><th>Lakes</th><th>Transitional</th><th>Coastal</th></tr>
<tr><td>Phytoplankton</td><td>6 months</td><td>6 months</td><td>6 months</td><td>6 months</td></tr>
<tr><td>Other aquatic flora</td><td>3 years</td><td>3 years</td><td>3 years</td><td>3 years</td></tr>
<tr><td>Macroinvertebrates</td><td>3 years</td><td>3 years</td><td>3 years</td><td>3 years</td></tr>
<tr><td>Fish</td><td>3 years</td><td>3 years</td><td>3 years</td><td></td></tr>
</table>
For operational monitoring, the frequency of monitoring required for any parameter shall be determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element. As a guideline, monitoring should take place at intervals not exceeding those indicated for surveillance monitoring.</td></tr>
<tr><td>Level of expertise required</td><td>Moderate to High</td></tr>
<tr><td>Synergies with other indicators</td><td>Indicators forming parts of the Member States’ River Basin Management Plans: Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters and Ecological potential for heavily modified or artificial water bodies</td></tr>
<tr><td>Connection with SDGs</td><td>SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action, SDG 14 Life below water</td></tr>
</table>

Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. http://data.europa.eu/eli/dir/2000/60/oj European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans*.

4.56 Total number and species richness of aquatic macroinvertebrates

Project Name: UNaLab (Grant Agreement no. 730052) and PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Gerardo Caroppi[3,4], Carlo Gerundo[4], Francesco Pugliese[4], Maurizio Giugni[4], Marialuce Stanganelli[4], Vittoria Capobianco[5], Farrokh Nadim[5], Amy Oen[5]

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Total number and species richness of aquatic macroinvertebrates	Water Management
Description and justification	The Extended Biotic Index (EBI) is based on the analysis of macroinvertebrate communities that colonize river ecosystems. Aquatic macroinvertebrates are animals that do not have a backbone, can be observed without magnification and spend at least part of their life in water. Most macroinvertebrates spend part of all of their life attached to submerged rocks, logs and vegetation. They are good indicators of the health of aquatic ecosystems because: • Macroinvertebrates are affected by physical, chemical and biological conditions of the stream

	• Macroinvertebrates are relatively long-lived and cannot escape pollution, so can therefore reflect changes to stream conditions across space and time • Macroinvertebrates are ubiquitous in perennial aquatic systems • Macroinvertebrates are a critical part of the food web in streams • Macroinvertebrates have a range of different life history strategies (e.g., mode of respiration, feeding strategy, reproduction) that can be used to evaluate causes of aquatic ecosystem impairment • Macroinvertebrates can easily be sampled and identified in a cost-effective manner These communities live in the substrate and are composed of populations characterized by different levels of sensitivity to environmental modifications and with different ecological roles. Since macroinvertebrates have relatively long life cycles, the index provides integrated information over time on the effects caused by different causes of disruption (physical, chemical and biological). In monitoring the quality of running waters it must therefore be considered a complementary method to the chemical and physical control of water.
Definition	Total number and species richness of aquatic macroinvertebrates (unitless)
Strengths and weaknesses	+ Most commonly used element for biological classification of the European rivers + Yields an opportunity for community members to engage in environmental monitoring +/- Macroinvertebrate monitoring can not only provide information about how changes to the landscape or stream characteristics affect the health of the biological community - Low effectiveness in deep rivers, where the invertebrates may be difficult to sample. - May not yield accurate results
Measurement procedure and tool	It is recommended that an aquatic biologist assist in the design of a biosurvey programme and provide a locally-adapted macroinvertebrate identification key. Monitoring approaches typically involve the establishment of a transect-type study area or sampling ‘reach’ and macroinvertebrate sample collection along with habitat assessment. The relative intensity of the biosurvey and level of supervision by professional aquatic biologists depends upon the programme objective. It is generally

	recommended that macroinvertebrate sampling programmes start with the simplest, least resource-intensive approach and work towards increasing complexity depending on the available resources, expertise and volunteer interest. An example of a macroinvertebrate sampling programme is: • Establish sample location (sample station) • Estimate habitat proportions • Collect macroinvertebrate samples • Clean and preserve the sample • Habitat assessment and estimation of flow • Generate a site sketch The gathering of invertebrates typically occurs through a net with a handle and is performed by sampling at different points within the water course so that all the different habitats are examined; the collected sample is preserved by addition of formalin and analyzed in the laboratory using a stereomicroscope. Each collected specimen is identified at the systematic level (genus or family) requested by the method. The determination of the EBI value is based on a double entry table: the rows have as headings the different groups of macroinvertebrates listed in order of decreasing sensitivity to environmental changes; the columns have as headings the ranges of the total number of systematic units than can be found in the samples. The EBI score is obtained by crossing the line corresponding to the most sensible systematic group with the column of the number of systematic units found. The score corresponds to a water quality class and represents a synthetic valuation.
Scale of measurement	Plot to neighbourhood/district scale or river basin scale
Data source	
Required data	Sampling distances from the stream, types of habitats, relative proportion of each habitat, stream bed composition, stream flow.
Data input type	Qualitative and quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	For sampling, low to moderate. For identification of samples, some degree of expertise is required.

Synergies with other indicators	Synergies with the indicator group *Water quality* indicators
Connection with SDGs	SDGs 6 Sustainable water management, 13 Climate action, and 14 Life below water
Opportunities for participatory data collection	Opportunities for community members to engage in the data collection with assistance
Additional information	
References	European Parliament, Council of the European Union. (2000). *EU Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02000L0060-20140101 http://www.isprambiente.gov.it/

4.57 Morphological Quality Index (MQI)

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: Guillaume Piton[1], Jean-Marc Tacnet[1]

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Morphological Quality Index (MQI)	**Water Management**
Description and justification	The Morphological Quality Index was developed to assess the hydromorphology quality of rivers as introduced in the EU Water Framework Directive (WFD). An extensive review of existing methods to assess the hydromorphology of rivers demonstrated that most methods insufficiently account for physical processes (Belletti et al. 2015). Based on a weighted aggregation of 28 subindicators, the MQI is aimed at an assessment, classification and monitoring of the current morphological state of rivers (Rinaldi et al. 2017). First developed in Italy (Rinaldi et al. 2013), the index was tested and expended on rivers of all Europe (Rinaldi et al. 2015b) during the REFORM EU Project (https://www.reformrivers.eu).
Definition	The MQI is computed by a weighted sum of alteration scores on sub-indicators. The list of sub-indicators is context specific (confined versus partially confined and unconfined reaches). The full mathematical equations are provided in Rinaldi et al. (2015a, p. 99-102). Forms are provided in the appendix of Rinaldi et al. (2015a) as well as in Microsoft Excel spreadsheets that performs the computation automatically

	once filled (available from https://reformrivers.eu/guidebook-evaluation-stream-morphological-conditions-morphological-quality-index-mqi).
Strengths and weaknesses	+ Provide rapidly an aggregated indicator accounting for the state of the art on geomorphology. + Detailed and tried and tested forms and guidelines in the implementation of the method enables quite good robustness considering the complexity of the question. + Very useful indicator to perform a first appraisal of the river reaches' degree of alteration that may guide later on the prioritising of restoration measures, as well as, on which component and process the restoration effort should likely focus (e.g., hydrology, sediment continuity, bank protection, riparian forest) - Relevant at scale of about one kilometre, thus irrelevant for very small measures. In this case, see Rinaldi et al. (2017) for alternative indexes as MQIm or GUS. - Provide one single estimation aggregating numerous different alterations, so it necessarily simplifies the complexity of nature.
Measurement procedure and tool	The whole measurement procedure is described in Rinaldi (2015a). Detailed appendix with helpful advises and precisions are provided. The procedure follows three steps: (i) Segmentation of the river in several homogeneous reaches, one MQI value will be evaluated for each reach. The segmentation procedure should cautiously follow the guidelines. (ii) Estimation of the 28 sub-indicators for each river reach by GIS analysis and field visit; (iii) Computation of the MQI (using the forms provided by the authors or by using the equations) for each river reach. According to the authors and to our experience, a MQI assessment typically takes a couple of days per river reaches.
Scale of measurement	The sub-indicators and the aggregated MQI are computed for river reaches, i.e., homogeneous sections of river that are typically 0.1-10 km long and usually longer than one km. If the relevant scale of analysis would be reaches significantly shorter than one kilometre, the MQIm ("MQI for monitoring" may be more relevant, see Rinaldi et al. (2015a & 2017). MQI (or MQIm) is dimensionless. Comprised between 0 (river totally altered in every component and process) and 1 (wild natural river without alteration).
Data source	
Required data	Estimations of scores of each sub-indicator rely on:

	(i) GIS analysis of aerial photographs and maps (current and a few decade old). Data on reach slope is also required and land use maps (river channel, riparian forest) helps performing the assessment faster. (ii) Field survey to get data on grain size, presence of large wood, vegetation state, evidences of bank erosion, incision, variability of the cross section and inventory of structures (e.g., bank protections, weirs, check dams). (iii) Archives, reports or testimony are required to appraise past and current management practices and alterations (e.g., dredging, vegetation maintenance, large wood removal).
Data input type	GIS data (photographs, maps, land use maps) and field visit to fill the forms.
Data collection frequency	A MQI assessment should first be performed to assess the current status of the river. Prospective applications assuming various strategies to be implemented were tested by Piton et al. (2018) and Gnonlonfin et al. (2019) and proved feasible although more uncertain than for assessment of current status. The MQI forms propose a way to take uncertainty into account which should be used for instance in the case of prospective assessment. After works, e.g., that a NBS strategy be implemented, Rinaldi et al. (2015a, p. 31) recommend waiting at least 5 years before performing a new MQI assessment to enable the river to adjust to the works. After high magnitude flood events (e.g., time return higher than 10-20 years), they also advice waiting a couple of years to let the river recover to its long term geomorphic trajectory.
Level of expertise required	Intermediate: The MQI assessment was tailored to be applicable by river managers, thus it requires a classical background in geomorphology, basic knowledge in GIS software and field visits.
Synergies with other indicators	Complementary with all other indicators on Water Quality
Connection with SDGs	6, 14, 15
Opportunities for participatory data collection	Low: the indicators are quite technical and data collection requires a background in geomorphology.
Additional information	
References	<u>Guidelines for the application:</u> Rinaldi M, N. Surian, F. Comiti M. Bussettini B B. 2015a. Guidebook for the evaluation of stream morphological conditions by the morphological quality index (MQI) - D6.2,

Part 3, . Deliverable 6.2 of REFORM (REstoring rivers FOR effective catchment Management), a Collaborative project (large-scale integrating project) funded by the European Commission within the 7th Framework Programme under Grant Agreement 282656. [online] Available from: http://www.reformrivers.eu/system/files/6.2%20Methods%20to%20assess%20hydromorphology%20of%20rivers%20part%20III%20revised_0.pdf (accessed on May, 19, 2020)

Scientific papers:

Belletti B, Rinaldi M, Buijse A D, Gurnell A M, Mosselman E. 2015. A review of assessment methods for river hydromorphology. Environmental Earth Sciences 73:2079–2100. DOI: 10.1007/s12665-014-3558-1

Rinaldi M, Surian N, Comiti F, Bussettini M. 2013. A method for the assessment and analysis of the hydromorphological condition of Italian streams: The Morphological Quality Index (MQI). Geomorphology 180-181:96–108. DOI: 10.1016/j.geomorph.2012.09.009

Rinaldi M, Belletti B, Bussettini M, Comiti F, Golfieri B, Lastoria B, Marchese E, Nardi L, Surian N. 2017. New tools for the hydromorphological assessment and monitoring of European streams. Journal of Environmental Management 202:363–378. DOI: 10.1016/j.jenvman.2016.11.036

Examples of use:

Rinaldi, M., L. Nardi, B. Belletti, S. Bizzi, K. Brabec, F. Comiti, L. Demarchi, M. Giełczewski, B. Golfieri, H. Habersack, S. Hellsten, S. Kaufman, M. Klösch, E. Marchese, P. Marcinkowski, S. Muhar, T. Okruszko, A. Paillex, M. Poppe, J. Rääpysjärvi, H. Seppo, M. Schirmer, M. Stelmaszczyk, N. Surian, W. Van de Bund (2015b) Final report on methods, models, tools to assess the hydromorphology of rivers, Deliverable 6.2, Part 5, of REFORM (REstoring rivers FOR effective catchment Management), a Collaborative project (large-scale integrating project) funded by the European Commission within the 7th Framework Programme under Grant Agreement 282656. [online] Available from http://www.reformrivers.eu/methods-models-tools-assess-hydromorphology-rivers-part-5-applications (Accessed on May 19, 2020)

Gnonlonfin A., Piton G., Marchal R., Munir M. B., Wang Z.X., Moncoulon D., Mas A., Arnaud P., Tacnet JM., Douai A. 2019. DELIVERABLE 6.3 DEMO Insurance Value Assessment - Part 7: France: Brague . NAIAD H2020 project (Grant Agreement nº 730497)

Piton G, Philippe F, Tacnet J-m, Gourhand A. 2018. Focus - Caractérisation des altérations de la géomorphologie naturelle d'un cours d'eau Application du Morphological Quality Index (MQI) aux projets d'aménagement du Grand

	Buëch à La Faurie. Science Eaux & Territoires 26:58–61. DOI: 10.14758/set-revue.2018.26.11

4.58 Hydromorphological quality of surface waters

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik, Laura Wendling, Ville Rinta-Hiiro, Arto Laikari, Malin zu-Castell Rüdenhausen

VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland

Hydromorphological status of surface waters	Water Management
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.
Definition	Hydromorphological quality of surface waters - rivers, lakes, transitional waters and coastal waters (rated high, good, moderate, poor, bad)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level
Measurement procedure and tool	The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC): 1. Characterise water bodies within a river basin area per Annex II: a. Rivers, lakes, transitional waters or coastal waters — or artificial surface water bodies or heavily modified surface water bodies 2. Establish type-specific hydromorphological reference conditions per Annex V 3. Identify and estimate the impacts of significant water flow regulation 4. Identify and estimate significant morphological alterations to water bodies

<table>
<tr><td></td><td>
5. Establish monitoring of hydromorphological status for surface waters:
    a. Design of surveillance, operational and/or investigative monitoring per Annex V
    b. Frequency of monitoring
    c. Additional monitoring requirements for protected areas as listed under Annex IV
6. Present monitoring results as maps in accordance with Annex V
8. Classify hydromorphological status of surface waters per Annex V
</td></tr>
<tr><td>Scale of measurement</td><td>River basin; Member State</td></tr>
<tr><td colspan="2">Data source</td></tr>
<tr><td>Required data</td><td>Reference conditions; Anthropogenic impacts; Water regulation activities</td></tr>
<tr><td>Data input type</td><td>Quantitative and qualitative</td></tr>
<tr><td>Data collection frequency</td><td>
Frequency for surveillance monitoring period:
<table>
<tr><th>Quality element</th><th>Rivers</th><th>Lakes</th><th>Transitional</th><th>Coastal</th></tr>
<tr><td>Continuity</td><td>6 years</td><td></td><td></td><td></td></tr>
<tr><td>Hydrology</td><td>Continuous</td><td>1 month</td><td></td><td></td></tr>
<tr><td>Morphology</td><td>6 years</td><td>6 years</td><td>6 years</td><td>6 years</td></tr>
</table>
For operational monitoring, the frequency of monitoring required for any parameter shall be determined by Member States so as to provide sufficient data for a reliable assessment of the status of the relevant quality element. As a guideline, monitoring should take place at intervals not exceeding those indicated for surveillance monitoring.
</td></tr>
<tr><td>Level of expertise required</td><td>Moderate to High</td></tr>
<tr><td>Synergies with other indicators</td><td>Indicators forming parts of the Member States’ River Basin Management Plans: Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters and Ecological potential for heavily modified or artificial water bodies</td></tr>
<tr><td>Connection with SDGs</td><td>SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption</td></tr>
</table>

	and production, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Parliament. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. http://data.europa.eu/eli/dir/2000/60/oj European Commission. (2012). *Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans.*

4.59 Fluvial Functionality Index

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Fluvial Functionality Index	Water Management
Description and justification	Indicators of Effects on Water Quality sub-criterion will assess the effects of project scenarios on water quality, in terms of physical, microbiological, biological and chemical parameters.
Definition	The main objective of the FFI (APAT, 2007) consists of the overview of the comprehensive state of the river environment and in the evaluation of its functionality, understood to be the result of synergy and integration of an important series of biotic and abiotic factors present in the water ecosystem and in the connected terrestrial one. Through the analysis of morphological, structural and biotic parameters of the ecosystem, interpreted following the principles of river ecology, the functions associated with it as well as the distances from the condition of greatest functionality, identified following a reference model, can be highlighted. The understanding of the environmental features allows the definition of a global index of functionality in terms of retention and cycling capacity of

	the fine and coarse particulate organic matter (short FPOM and CPOM) (Elwood et al., 1983), of buffer potential of the riparian ecotones as well as of morphological structure. It is important to define what is considered as reference conditions or which the objectives of the evaluation are in order to specify which landscape changes merit a second evaluation.
Strengths and weaknesses	+ The FFI provides a rigorous but easy to use tool, to read and understand the functional relationships affecting river ecology, with the aim of recovering, as much as possible, that ratio of positive functionality between rivers, man and territory. -The FFI is an adaptation for Italian waters of the RCE index (Petersen, 1992). Although it is very well adapted for European water bodies, using the most reliable adaptation to specific regional water bodies is highly recommended.
Measurement procedure and tool	The degree of naturalness is determined through a card with 14 questions related to the same number of environmental parameters: 1) state of surroundings, 2) vegetation belt, 3) size and, 4) continuity of functional structures, 5) hydric conditions, 6) flooding efficiency, 7) riverbed substrate, 8) erosion, 9) transversal section, 10) fish fitness, 11) hydro-morphology, 12) riverbed vegetation, 13) detritus, and 14) microbenthic community. In order to apply the method, the operator should undertake an experimental campaign on the stream to be investigated, and must assign the scores on the basis of the observations required by the survey. Then the sum of these scores is carried out and a final result can be converted into a corresponding class quality and in the respective quality assessment. Some parameters must be evaluated separately for the two shores of the stream, and thus they may provide two different final judgments. It is recommended to perform the evaluation along a reach of 150 m per watercourse.
Scale of measurement	River basin. The FFI is translated in class quality.
Data source	
Required data	Information about morphological, structural and biotic parameters of the ecosystem.
Data input type	Semi-quantitative
Data collection frequency	As many of the characteristics of the FFI are landscape dependent, there is no need to repeat the methodology

	with a constant frequency. However, it is important to specify both the reference conditions and the objectives of the evaluation in order to detect which landscape changes merit a second evaluation.
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	6
Opportunities for participatory data collection	
Additional information	
References	APAT. (2007). IFF Indice di funzionalità fluviale 2007. Agenzia Nazionale per la Protezione dell'Ambiente e per i Servzi Tecnici. Roma. ISBN 978-88-448-0318-6. Elwood J.W., Newbold J.D., O'Neil R.V., Van Winkle W. (1980). *Resource spiralling: an operational paradingm for analysing lotic ecosystem*. In: Dynamics of lotic ecosystems, Fontaine T.D., S.M. Bartell eds., Ann Arbor, Michigan, USA, 3-27. Petersen, R.C. Jr. (1992). The RCE: A Riparian, Channel, and Environmental Inventory for small streams in the agricultural landscape. *Freshwater Biology, 27*, 295-306.

NATURAL AND CLIMATE HAZARDS

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5 Recommended Indicators of Natural and Climate Hazards

5.13 Disaster Resilience

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Silvia Vela and Margherita Cioffi

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Disaster resilience scorecard for cities	**Natural and Climate Hazards**
Description and justification	The Disaster resilience scorecard provides a set of assessment criteria for the local governments that allow assessing their disaster resilience, structuring around UNDRR's Ten Essentials for Making Cities Resilient. It also helps to monitor and review progress and challenges in the implementation of the Sendai Framework for Disaster Risk Reduction: 2015-2030 and supports the baseline analysis for preparation of the disaster risk reduction and resilience strategies.
Definition	The Scorecard prompts to identify "most probable" and "most severe" risk scenarios for each of the identified city hazards, or for a potential multi-hazard event
Strengths and weaknesses	+ Promote resilience awareness + Establishing a baseline status of disaster resilience

	+ Enabling planning towards DRR - Need for a facilitator to interpret the results - The assessment is not immediate and requires time (e.g., month(s))
Measurement procedure and tool	First, the actors are identified, which should include local authorities, private businesses, research centres, academia, community groups, etc. Via interviews and workshops, external and internal parties provide their scores and comments to the ten categories (i.e., Essentials) and their sub-categories that are evaluated in the MS Excel spreadsheet. The overall score of the assessment provides information on the city's overall relative disaster resilience whilst individual sub-categories support identification of specific vulnerabilities to different hazards and risks. Two options and their respective Excel spreadsheets exist for the DRR evaluation: - Preliminary level: responding to key Sendai Framework targets and indicators, and with some critical sub-questions. In total there are 47 questions indicators, each with a 0 – 3 score - Detailed assessment: a multi-stakeholder exercise that can be a basis for a detailed city resilience action plan. The detailed assessment includes 117 indicator criteria, each with a score of 0 – 5.
Scale of measurement	City
Data source	
Required data	Information on the city pressures and hazards
Data input type	Quantitative and qualitative
Data collection frequency	Additional data collection is needed only if the assessment is repeated to monitor progress in DRR. Short-term: within 1 year since the compilation Mid-term: from 1 to 5 years since the compilation Long-term: 5 years since the compilation
Level of expertise required	High – requires the ability to use the scorecard template and the ability to interpret the outcomes
Synergies with other indicators	The evaluation of each Essential may rely on multiple indicators for the respective topic
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land

Opportunities for participatory data collection	Yes, with data available to Cities' departments
Additional information	
References	United Nations Office for Disaster Risk Reduction, *Disaster Resilience Scorecard for Cities – Preliminary Level Assessment*, May 2017 https://www.unisdr.org/campaign/resilientcities/toolkit/article/disaster-resilience-scorecard-for-cities

5.14 Disaster-risk informed development

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik, Laura Wendling, Ville Rinta-Hiiro, Arto Laikari, Malin zu-Castell Rüdenhausen

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Disaster-risk informed development	Natural and Climate Hazards
Description and justification	Natural and climate hazards such as floods or earthquakes cannot be prevented. However, it is possible to anticipate the consequences and take preventive measures. Including disaster risk planning into national and/or municipal urban development plans enhances the resilience against natural hazards that reduces the economic losses and damages to property.
Definition	The extent to which disaster risk has been taken into account when planning national-level or municipal-level economic or urban development (0-2)
Strengths and weaknesses	+ Ensures robust action planning for urban disaster resilience - Requires prior risk assessment on national/municipal level
Measurement procedure and tool	The inclusion of disaster-risk informed urban development to local development plans can be assessed using the scale: 0 – No inclusion: Disaster risk has not been accounted in either national economic development plans, or in city-level urban planning; 1 – Partial inclusion: Present only in the active national development plan/strategy; 2 – Full inclusion: Accounted for in both the active national development plan/strategy and in city-level urban planning

	(e.g., through policies, directives, urban development plans or strategies).
Scale of measurement	Municipality; country
Data source	
Required data	Local risk assessment for natural and climate hazards; local development plans
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	Moderate
Synergies with other indicators	The indicator can be assessed in conjunction with *Disaster resilience* indicator. It is directly related to all indicators the *Natural and Climate Hazards* indicator group and encompasses them and their impacts for a holistic urban development.
Connection with SDGs	SDG 9 Industry, innovation and infrastructure, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Tyszka, T. and Zielonka, P. *Large risks with low probabilities: Perceptions and willingness to take preventive measures against flooding*. IWA Publishing, 2017, pp. 105-118.

5.15 Mean annual direct and indirect losses due to natural and climate hazards

Project Name: RECONECT (Grant Agreement no. 776866)

Author/s and affiliations: Karsten Arnbjerg-Nielsen[1]

[1]*Department of Environmental Engineering, Technical University of Denmark, Denmark*

Mean annual direct and indirect losses due to natural and climate hazards	Natural and Climate Hazards
Description and justification	The losses due to natural and climate hazards can be calculated for any area. The calculation is usually based on models in order to account for natural variation of the hazards. The mean annual losses are often referred to as

	the risk of the hazard and the indicator is within hydrometeorological risks most often denoted *Expected Annual Damage*. The indicator is a key input into any economic assessment of the feasibility of a project aimed at hydro-meteorological risk reduction because the project costs should be balanced against the calculated reduction of *EAD* in e.g., a cost-benefit analysis.
Definition	The definition of EAD is given as (e.g., (Zhou et al., 2012)): $$EAD = \int_A \int_p D(p) dp dA$$ where *D(p)* denotes the damage that occurs at an annual frequency *p* and *A* denotes the area in question. The equation assumes that there is no damage for events occurring more often than once per year.
Strengths and weaknesses	While in principle it is a simple metric it is in reality difficult to assess because of relatively high inherent uncertainties. The uncertainties are mainly related to calculation of how the hazard is exposing assets in the area and how much value the assets have to humans before and after being exposed to the hazard.
Measurement procedure and tool	There is typically a distinction between direct and indirect costs and tangible and intangible costs (Merz et al., 2010). Direct costs are costs related to the direct impact of the hazard, e.g., destruction of buildings and infrastructure, while the indirect costs are a consequence of the hazard, but not directly e.g., disruption of public services, relocation of citizens etc. Tangible costs can be assessed based on an economic market while intangible costs are all other costs, e.g., loss of life, psychological distress, damage of cultural heritage, and loss of trust in authorities. Using the definition above it is assumed that also intangible costs are assigned an economic value, but in some cases key intangible costs are reported as numbers of humans affected (Kreibich et al., 2017). Use of this approach should be aligned with the indicator *Number of people adversely affected by natural disasters each year*.
Scale of measurement	Typically the area is considered without consideration of the economic activity in the surrounding area and only considering costs during and shortly after the hazard occured. However, there are exceptions where larger scale (often positive) impacts as well as improved economic productivity post-event are included in the analysis, e.g., Hallegatte et al., 2011.
Data source	

Required data	Hazard maps as a function of the frequency of the hazard(s). Typically this will be in the form of raster og shape files in a GIS environment. Value maps covering the area showing what assets can be exposed and what cost is associated with exposure, typically as a function of key characteristics of the hazard. For water hazards this could be e.g., inundation depth and/or duration of exposure. This data should be available in the same format as the hazard maps
Data input type	Quantitative
Data collection frequency	The data should in principle be collected every time there is a) a change in the land use that affects the value maps, and b) new information about the hazards become available.
Level of expertise required	Medium to high.
Synergies with other indicators	This indicator is related to several other indicators, in particular to *Number of people adversely affected by natural disasters each year* and to the indicator group on Health and Wellbeing.
Connection with SDGs	The connection is closest to SDG 1 (target 1.5) and SDG 11 (several targets) (Sørup et al, 2019).
Opportunities for participatory data collection	A participatory approach to establishing the value maps will both increase the awareness of the indicator and improve the accuracy of the assessment.
Additional information	
References	Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C., Wood, R.M., 2011. Assessing climate change impacts, sea level rise and storm surge risk in port cities: A case study on Copenhagen, Climatic Change. https://doi.org/10.1007/s10584-010-9978-3 Hammond, M.J., Chen, A.S., Djordjević, S., Butler, D., Mark, O., 2015. Urban flood impact assessment: A state-of-the-art review. Urban Water J. 12, 14–29. https://doi.org/10.1080/1573062X.2013.857421 Kreibich, H., Baldassarre, G. Di, Vorogushyn, S., Aerts, J.C.J.H., Apel, H., Aronica, G.T., Arnbjerg-nielsen, K., Bouwer, L.M., Bubeck, P., Caloiero, T., Chinh, D.T., Cortès, M., Gain, A.K., Giampá, V., Kuhlicke, C., Kundzewicz, Z.W., Llasat, M.C., Mård, J., Matczak, P., Mazzoleni, M., Molinari, D., Dung, N. V, Petrucci, O., Schröter, K., Slager, K., Thieken, A.H., Ward, P.J., Merz, B., 2017. Adaptation to flood risk : Results of international paired flood event studies. Earth's Futur. 5, 953–965. https://doi.org/10.1002/2017EF000606 Merz, B., Kreibich, H., Schwarze, R., Thieken, a., 2010. Review

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5.16 Risk to critical urban infrastructure

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Reduction of inundation risk for critical urban infrastructures (probability-economic) (Applied and EO/RS combined)	**Natural and Climate Hazards**
Description and justification	Metrics are based on the quantification of infrastructure that has a reduced risk of flooding due to NBS implementation. Ultimately, this relates to a reduced economic cost of flooding, or increased health & wellbeing of communities due to reduced stress levels associated with flooding or risk of flooding. It should be noted that, if NBS is poorly designed or well-designed but poorly constructed, it has the potential to lead to increased local flooding risk for some areas. Advances in remote sensing technology and new satellite platforms such as ALOS sensors have widened the application of satellite data, for instance to validate flood inundation models. Flood modelling based on remote sensing rainfall data will be useful for developing regional flood early-warning and flood mitigation systems in flood hazardous areas. Reduction in flood-risk by nature-based solutions simulation can be used to: • Support the development of strategic plans for NBS implementation to reduce flood risk and comply with Flood Risk Management; • Predict the impact of individual NBS projects;

	• Quantify the predicted impact of implemented NBS; • Promote stakeholder engagement in NBS planning; • Support the leveraging of finances necessary for delivering NBS projects.
Definition	Probability of a reduction of inundation risk for critical urban infrastructures based on more applied and participatory hydraulic modelling and GIS assessment.
Strengths and weaknesses	**Applied methods:** Robustness of evidence depends upon the level of precision of the simulation software and the data analysed. Typically, simulations requiring the most basic data input are associated with the least precise results. This is not always the case, however, and model validation (either through real-world testing or validation against other models) is recommended. **EO/RS methods:** There are some limitations/barriers to the reliability of the evidence generated. This includes the expense associated with the most high-resolution satellite images when financial resources are scarce, or when images are not available on the study area. In addition, some areas can be covered with clouds causing a partial loss of information. The presence of dense urban areas and forests also affect both SAR and multispectral based flood mapping and requires a more-complex data processing which is not straightforward to accomplish with a user-friendly approach. High spatial resolution is a key factor when mapping floods in dense urban areas, and it is one of the limitations of the free of charge satellite data approach. These services provide rapid mapping products that can be affected by uncertainty and are not always validated. Maps of flooded areas produced by official authorities and based on bespoke aerial photos and field surveys are more accurate, although they are time-consuming and require higher costs to be generated. Based on experience, however, on-demand high costs, high resolution data and field surveys are often necessary to ensure reliability of evidence.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects, refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Scale of measurement	**Applied methods:** Simulations are typically carried out on catchment scales identifying flood risk areas under different climate scenarios. Local impacts can also be modelled to

	assess impacts on storm sewer systems and local flood risk areas. **EO/RS methods:** Can be applied at various geographical scales, but is most commonly applied at a catchment scale.
Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Data input type	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Data collection frequency	Data collection frequency will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Level of expertise required	**Applied methods:** Expertise required is very much based on the complexity of the data requirements of the model. Very basic models exist that require very low levels of expertise and are ideal for use as community engagement tools. To maximise the value of participatory approaches, experience of managing such projects is beneficial. **EO/RS methods:** There a semi-automatic method for flood mapping, based only on free satellite images and open-source software. The proposed method is suitable to be applied by the community involved in flood hazard management, not necessarily experts in remote sensing processing. Much of the freely available data is available with the first level of atmospheric or radiometric calibration, allowing their use by different types of users and not only experts in remote sensing processing. In addition, free GIS plugins allow the downloading and processing of free multispectral satellite images. The availability of these resources is useful for the management of natural hazard effects. However, expertise will be needed in order to improve and manually refine the automatic mapping using free ancillary data such as the digital elevation model-based water depth model and available ground truth data.
Synergies with other indicators	**Applied methods:** Simulation software often characterises multiple benefits of NBS implementation, often including impacts on water quality. Flood risk prediction also has synergies with the economic cost of such flooding, particularly in relation to insurance values. Flood risk

	reduction can also be related to health & wellbeing indicators associated with the stress caused by flood risk to properties, business and other infrastructure. **EO/RS methods:** Synergies exist between floods, climate change adaptation and disaster risk reduction. Synergies between managing flood risk, reaching or maintaining a good ecological status, promoting of ecosystem services and safeguarding the nature or ecosystem services in floodplains can be very complex.
Connection with SDGs	All except SDG2, SDG5 and SDG12: Decreasing costs associated with insurance risk; Decreased stress, health risk and physical risk; Links to environmental education; Possible cleaner water co-benefit; Decrease risk to energy infrastructure; Job creation; Reduced infrastructure risk; Green infrastructure development; Social equality in relation to flood risk; Sustainable urban development; Climate change adaptation; More sustainable water management; Habitat enhancement/creation; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods** Opportunities are available for a participatory process, particularly in relation to stakeholder decision-making (Voinov and Gaddis 2008; Voinov et al. 2016; Gray et al. 2018) and or data-gathering through ICT-enabled citizen observatories (When et al. 2015). Involving stakeholders through active participation can increase the legitimacy of risk processes, public acceptance, commitment, and support with respect to decision-making processes (Inam et al. 2017). **EO/RS methods:** To assess flood risk at a neighbourhood level, accurate data on flood extent, exposure and vulnerability is required. One of the possible and useful ways to obtain these data is a combination of remote sensing data and local knowledge through participatory processes. Further detail can be found on participatory processes in Env19_Applied.
Additional information	
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5.17 Mean number of people adversely affected by natural disasters each year

Project Name: RECONECT (Grant Agreement no. 776866)

Author/s and affiliations: Karsten Arnbjerg-Nielsen[1]

[1]*Department of Environmental Engineering, Technical University of Denmark, Denmark*

Mean number of people adversely affected by natural disasters each year	Natural and Climate Hazards
Description and justification	This indicator is closely related to the previous indicator on the costing of natural hazards / disasters, but specifically addresses the problem that while intangible costs are important in relation to assessing impacts of natural disasters they may be difficult to assign an

	economic value to. Hence some studies recommend to assess these costs by counting the number of people affected rather than applying an economic value to these adverse effects.
Definition	The definition of the mean number of people affected each year is given as: $$Mean\ number\ of\ people\ affected = \int_A \int_p I(p)\rho dp dA$$ where $I(p)$ denotes the number of people exposed to the disaster that occurs at an annual frequency p, ρ denotes the proportion of people exposed that are affected, and A denotes the area in question. The equation assumes that there is no damage for events occurring more often than once per year. There may be several sub-indicators distinguishing between different impacts such as loss of life, relocation, and physical or mental health.
Strengths and weaknesses	The weakness of this indicator is that it is sometimes ignored in decision-making because of the difficulty of assigning an actual economic value to the indicator. This is however also the strength since it may spark discussions among the participants on how to use this indicator in an assessment.
Measurement procedure and tool	By definition this indicator comprise an important part of the intangible costs in the preceeding indicator. For health impacts some studies model individual impacts of sub-indicators, while others advocate the use of more generic indicators across health impacts such as Disability Adjusted Life Year (DALY) and the Quality Adjusted Life Year (QALY). A review of the studies can be found in (Hammond et al., 2015).
Scale of measurement	The scale of the measurements is the physical area impacted by the disaster.
Data source	
Required data	Hazard maps as a function of the frequency of the natural disaster. Typically this will be in the form of raster og shape files in a GIS environment. Impact maps covering the area showing the density of $I(p)$ and the value of ρ over the area. This data should be available in the same format as the hazard maps
Data input type	Quantitative
Data collection frequency	The data should in principle be collected every time there is a) a change in the population affecting $I(p)$ and/or ρ, and b) new information about the disaster become available.

Level of expertise required	High.
Synergies with other indicators	This indicator is related to several other indicators, in particular to *Mean annual direct and indirect losses due to natural and climate hazards* and to the indicator group on Health and Wellbeing.
Connection with SDGs	The connection is closest to SDG 1, SDG 3 and SDG 11.
Opportunities for participatory data collection	A participatory approach to defining the sub-indicators to be included in the analysis will both increase the awareness of the indicator and improve the accuracy of the assessment.
Additional information	
References	Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C., Wood, R.M., 2011. Assessing climate change impacts, sea level rise and storm surge risk in port cities: A case study on Copenhagen, Climatic Change. https://doi.org/10.1007/s10584-010-9978-3 Hammond, M.J., Chen, A.S., Djordjević, S., Butler, D., Mark, O., 2015. Urban flood impact assessment: A state-of-the-art review. Urban Water J. 12, 14–29. https://doi.org/10.1080/1573062X.2013.857421 Kreibich, H., Baldassarre, G. Di, Vorogushyn, S., Aerts, J.C.J.H., Apel, H., Aronica, G.T., Arnbjerg-nielsen, K., Bouwer, L.M., Bubeck, P., Caloiero, T., Chinh, D.T., Cortès, M., Gain, A.K., Giampá, V., Kuhlicke, C., Kundzewicz, Z.W., Llasat, M.C., Mård, J., Matczak, P., Mazzoleni, M., Molinari, D., Dung, N. V, Petrucci, O., Schröter, K., Slager, K., Thieken, A.H., Ward, P.J., Merz, B., 2017. Adaptation to flood risk : Results of international paired flood event studies. Earth's Futur. 5, 953–965. https://doi.org/10.1002/2017EF000606 Merz, B., Kreibich, H., Schwarze, R., Thieken, a., 2010. Review article "assessment of economic flood damage." Nat. Hazards Earth Syst. Sci. 10, 1697–1724. https://doi.org/10.5194/nhess-10-1697-2010 Sørup, H.J.D., Fryd, O., Liu, L., Arnbjerg-Nielsen, K., and Jensen, M.B. 2019. An SDG-based framework for assessing urban stormwater management systems. Blue-Green Systems, Blue-Green Systems, 1, 1, 102-118. DOI: 10.2166/bgs.2019.922. Zhou, Q., Mikkelsen, P.S., Halsnæs, K., Arnbjerg-Nielsen, K., 2012. Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits. J. Hydrol. 414–415. https://doi.org/10.1016/j.jhydrol.2011.11.031

5.18 Multi-hazard early warning

Project Name: UNaLab (Grant Agreement no. 730052)

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Multi-hazard early warning system	**Natural and Climate Hazards**
Description and justification	Natural and climate hazards occur worldwide, and they bring casualties, property damages and substantial economic losses. Disaster risk reduction is the backbone to mitigation the destructive consequences. Several parts comprise multi-hazard early warning system: (i) Disaster risk knowledge, (ii) Detection, monitoring, analysis and forecasting of the hazards and possible consequences, (iii) Warning dissemination and communication, and (iv) Preparedness and response capabilities (World Meteorological Organisation, 2018).
Definition	The degree of implementation of multi-hazard early warning system (0-2)
Strengths and weaknesses	+ Straightforward assessment of local disaster risk reduction - Requires municipal- or national-level measures
Measurement procedure and tool	Implementation of multi-hazard early warning system can be assessed using the scale: 0 – No monitoring implemented; 1 – Only a weather monitoring system is present; 2 – Both weather monitoring system and multi-hazard early warning system are present.
Scale of measurement	Municipality
Data source	
Required data	Disaster risk knowledge, hazard monitoring and forecasting, warning communication and preparedness capabilities on the municipal or national level
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	Moderate

Synergies with other indicators	Directly related to *Disaster-risk informed development* indicator
Connection with SDGs	SDG 9 Industry, innovation and infrastructure, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	World Meteorological Organisation. *Detection, Monitoring, Analysis & Forecasting of Hazards and Possible Consequences*. Retrieved from: https://public.wmo.int/en/resources/world-meteorological-day/wmd-2018/multi-hazard/detection-monitoring World Meteorological Organisation. Multi-hazard Early Warning Systems: A Checklist: Outcome of the first Multi-hazard Early Warning Conference. 1st Multi-hazard Early Warning Conference (Cancún, Mexico), 2018.

6 Additional Indicators of Natural and Climate Hazards

6.13 Potential areas exposed to risks

6.13.1 Urban/residential areas

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Urban/Residential Areas	Natural and Climate Hazards
Description and justification	Indicators of Potential Areas Exposed to Risks sub-criterion will assess the potential areas exposed to risk.
Definition	An urban area or urban agglomeration is a human settlement with high population density and infrastructure of built environment.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from maps and land-use maps.
Scale of measurement	ha
Data source	
Required data	Geographical and topographical data (GIS)
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	

References	

6.13.2 Productive areas

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Productive Areas	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Areas Exposed to Risks sub-criterion will assess the potential areas exposed to risk.
Definition	The areas utilized for the agricultural, grazing and industrial productions. Agricultural production data refers to vegetable and fruit production that is made available for human consumption. Grazing and pasture production are meat, milk and other products available for the human consumption obtained by the method of feeding in which a herbivore feeds on plants such as grasses, or other multicellular organisms such as algae. Industrial production is a measure of output of the industrial sector of the economy. The industrial sector includes manufacturing, mining, and utilities.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from maps and land-use maps.
Scale of measurement	ha
Data source	
Required data	Geographical and topographical data (GIS)
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium

Synergies with other indicators	
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	
References	

6.14 Natural areas, sites of community importance and special protection areas

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Natural Areas, Site of Community Importance (SCI), Special Protection Areas (SPA)	Natural and Climate Hazards
Description and justification	Indicators of Potential Areas Exposed to Risks sub-criterion will assess the potential areas exposed to risk.
Definition	The Indicator describes the extension, measured in hectares, of Site of Community Importance (SCI) and Special Protection Areas (SPA) in the study area. The Indicator will hardly change in the Design and longterm scenario, even if it could be assessed if the NBS implementation have produced such a beneficial impact on biodiversity to activate EU procedures in order to enlarge SCI and/or SPA perimeter.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from maps and land-use maps.
Scale of measurement	ha

Data source	
Required data	Geographical and topographical data (Model/Survey).
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	15
Opportunities for participatory data collection	
Additional information	
References	

6.15 Potential population exposed to risks

6.15.1 Inhabitants

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Inhabitants	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Population Exposed to Risks sub-criterion will assess the potential population exposed to risk.
Definition	Number of people that inhabits a place, especially as permanent residents.
Strengths and weaknesses	

Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr/ha
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

6.15.2 Area and population exposed to flooding

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Raúl Sánchez, Jose Fermoso, Silvia Gómez, María González, Jose María Sanz, Esther San José

CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain

Area (Ha) and population (number of inhabitants) exposed to flood risk	**Natural and Climate Hazards**
Description and justification	The areas and population exposed to flooding will be compared before and after the installation of the NBS to know if the intervention has influence in mitigating effects from flood risks. Flood hazard maps cover the geographical areas which could be flooded according different scenarios in terms of the return period. For each scenario studied the following

	elements shall be taken into account: the flood extent, water depths or water level, flow velocity. On the other hand, flood risk maps show the potential adverse consequences associated with flood scenarios referred to potential significant flood risks areas and expressed in terms of: number of inhabitants potentially affected; type of economic activity of the area potentially affected; and special installations (Annex I to Council Directive 96/61/EC of 24 September 1996, concerning integrated pollution prevention and control (1) which might cause accidental pollution in case of flooding and potentially affected protected areas identified in Annex IV(1)(i), (iii) and (v) to Directive 2000/60/EC) Other information which the Member State considers useful such as the indication of areas where floods with a high content of transported sediments and debris floods can occur and information on other significant sources of pollution.
Definition	This KPI can evaluate the increasing on green areas and its relation with the flooding risks. This indicator has been mainly defined for a floodable park but it could also be applied to scale the impact of other types of NBS on areas and population exposed to flooding.
Strengths and weaknesses	The calculation of this KPI is complex and requires specific knowledge and/or the use of a specific tool. However, the output of this KPI is valuable information regarding people's security.
Measurement procedure and tool	No sensor devices are required; however, GIS software or other specific software (i.e., Iber software) is required. A numerical model for hydraulic simulations will be applied to assess this KPI for the situation after the implementation of the NBS that is pretended to be studied. Main steps to build and run a hydraulic simulation in Iber software is shown below (extracted from Iber user´s manual) and Bladé et al. (2014): Create or import a geometry of the study Area; Assign a series of input parameters (bed roughness, turbulence model and other hydraulic parameters); Build a numerical mesh; Run the computation and Results visualization. The procedure may be different depending on the software used. For the evaluation of this KPI after the implementation of the NBS´s, different maps, tables and graphs extracted from the post-process interface of Iber software as well as demographic data from studied area will be the base to develop flood hazard maps and flood risk maps and thus, obtain the following data:

	• Area (ha) exposed to flooding: This value represents the surface of land expressed in hectares (ha) that is flooded for the different scenarios considered (10, 100 and 500 years return period). • Population (inhab) exposed to flooding: This value represents the number of citizens living in parts of land that are flooded for the different scenarios considered (10, 100 and 500 years return period). Finally, the higher decrease in both area (ha) and population (inhab) exposed to flooding when comparing the values prior and after to the implementation of the NBS considered, the greater potential benefits in mitigating flood risks will be achieved.
Scale of measurement	City
Data source	
Required data	Digital land cover maps from CORINE land cover project; demographic data from the studied area; and size and topography from digital elevation models (DEM) of each intervention.
Data input type	GIS data
Data collection frequency	Yearly
Level of expertise required	Expert
Synergies with other indicators	Abortion capacity of green surfaces, bioretention structures and single trees, run-off coefficient in relation to precipitation quantities.
Connection with SDGs	This KPI is directly related with SDG 16 and SDG 11 and indirectly is related with SDG 15 (soil loss processes contributes to desertification).
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl

URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl
URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl
Iber software. http://iberaula.es/space/54/downloads
Bladé, E., Cea, L., Corestein, G., Escolano, E., Puertas, J., Vázquez-Cendón, E., Dolz, J., Coll, A., 2014.
Iber: herramienta de simulación numérica del flujo en ríos. Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería, Volume 30, Issue 1, 2014, Pages 1-10, ISSN 0213-1315, DOI: 10.1016/j.rimni.2012.07.004

Flood hazard map and flood risk map, respectively, of Pisuerga and Esgueva rivers as they flow through the city of Valladolid for a 100 years return period flood.

6.15.3 Other people (workers, tourists, homeless)

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Other People (Workers, Tourists, Homeless)	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Population Exposed to Risks sub-criterion will assess the potential population exposed to risk.
Definition	Number of workers, tourists, homeless etc.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr/ha
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

6.15.4 Elderly, children, disabled

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Elderly, Children, Disabled	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Population Exposed to Risks sub-criterion will assess the potential population exposed to risk.
Definition	Number of people old or aging, young human people being below either the age of puberty or the legal age of majority, people with an impairment that may be cognitive, developmental, intellectual, mental, physical, sensory, or some combination of these.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr/ha
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

6.16 Potential Population Vulnerable to Risks

6.16.1 Population

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Population	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Population Vulnerable to Risks sub-criterion will assess the potential population vulnerable to risk.
Definition	Vulnerability of population (inhabitants of a particular place). For instance, the vulnerability of people is strictly connected to the vulnerability of buildings where they live.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3

Opportunities for participatory data collection	
Additional information	
References	

6.17 Potential buildings exposed to risks

6.17.1 Housing

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Housing	Natural and Climate Hazards
Description and justification	Indicators of Potential Buildings Exposed to Risks sub-criterion will assess the potential buildings exposed to risk.
Definition	Density of buildings where people live in, or the providing of places for people to live.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low

Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	
References	

6.17.2 Agricultural and industrial buildings

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Agricultural and Industrial Buildings	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Buildings Exposed to Risks sub-criterion will assess the potential buildings exposed to risk.
Definition	Density of factories and other premises used for manufacturing, altering, repairing, cleaning, washing, breaking-up, adapting or processing any article, generating power or slaughtering livestock.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	

Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	
References	

6.17.3 Strategic Buildings (Hospitals, schools, etc.)

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Strategic Buildings (Hospitals, schools, etc.)	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Buildings Exposed to Risks sub-criterion will assess the potential buildings exposed to risk.
Definition	Density of buildings allocated to civil protection activities of local authorities, public and private sanitary facilities equipped with first aid, Regional, Provincial, Municipal and Mountain Communities administrative offices.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr
Data source	
Required data	Model/Statistical Data

Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	9
Opportunities for participatory data collection	
Additional information	
References	

6.18 Potential infrastructures exposed to risks

6.18.1 Roads

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Roads	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Infrastructures Exposed to Risks sub-criterion will assess the potential infrastructures exposed to risk.
Definition	Length per km^2 of a wide way leading from one place to another, especially one with a specially prepared surface which vehicles can use.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.

Scale of measurement	m/km^2
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	9
Opportunities for participatory data collection	
Additional information	
References	

6.18.2 Railways

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Railways	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Infrastructures Exposed to Risks sub-criterion will assess the potential infrastructures exposed to risk.
Definition	Length per km^2 of a track made of steel rails along which trains run.
Strengths and weaknesses	

Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	m/km^2
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	9
Opportunities for participatory data collection	
Additional information	
References	

6.18.3 Lifelines

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Lifelines	Natural and Climate Hazards
Description and justification	Indicators of Potential Infrastructures Exposed to Risks sub-criterion will assess the potential infrastructures exposed to risk.

Definition	Distributive systems and related facilities necessary to provide electric power, oil and natural gas, water and wastewater, and communications.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	m/km^2
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	9
Opportunities for participatory data collection	
Additional information	
References	

6.19 Potential infrastructures vulnerable to risks

6.19.1 Buildings

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Buildings	Natural and Climate Hazards
Description and justification	Indicators of Potential Infrastructures Vulnerable to Risks sub-criterion will assess the potential infrastructures and buildings vulnerable to risks.
Definition	Vulnerability of housing, industrial buildings and strategic buildings. For instance, a wooden house is sometimes less likely to collapse in an earthquake, but it may be more vulnerable in the event of a fire or a hurricane.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	nr/km^2
Data source	
Required data	Model/Statistical Data/GIS
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	

References	

6.19.2 Transportation infrastructures and lifelines

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Transportation Infrastructures and Lifelines	**Natural and Climate Hazards**
Description and justification	Indicators of Potential Infrastructures Vulnerable to Risks sub-criterion will assess the potential infrastructures and buildings vulnerable to risks.
Definition	Vulnerability of transportation infrastructures like roads and railways, and vulnerability of lifelines (water distribution systems, sewerage, pipelines, energy lifelines,...).
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	m/km^2
Data source	
Required data	Model/Statistical Data/GIS
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	9

Opportunities for participatory data collection	
Additional information	
References	

6.20 Insurance against catastrophic events

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik, Laura Wendling, Ville Rinta-Hiiro, Arto Laikari, Malin zu-Castell Rüdenhausen

VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland

Catastrophe insurance	**Natural and Climate Hazards**
Description and justification	Catastrophes originating from natural and/or climate hazards are low-probability high-impact and high-cost events, and they are usually not included in the general insurance policies. Catastrophe insurances are widely used to enhance the resilience of businesses, individuals and public amenities from external pressures and aid them in restoring any financial losses.
Definition	Share of population holding insurance against catastrophic consequences of natural and climate hazards (%)
Strengths and weaknesses	+ Simple assessment that indicates the disaster preparedness - Requires access to policy holder databases
Measurement procedure and tool	The indicator is assessed as: $\frac{Population\ holding\ catastrophe\ insurance\ policies}{Total\ popultation} \times 100\%$
Scale of measurement	Municipality; country
Data source	
Required data	National records on proportion of population holding insurance policies against catastrophic events
Data input type	Quantitative
Data collection frequency	Annually

Level of expertise required	Low to Moderate
Synergies with other indicators	Directly related to all indicators the *Natural and Climate Hazards* indicator group
Connection with SDGs	SDG 9 Industry, innovation and infrastructure, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	

6.21 Flood hazard

Project Name: RECONECT (Grant Agreement no. 776866)

Author/s and affiliations: Laddaporn Ruangpan[1], Zoran Vojinovic[1], Arlex Sanchez Torres[1], Slobodan Djordjevic[2]

[1] *IHE Delft Institute for Water Education, Delft, the Netherlands*

[2] *University of Exeter,UK*

Flood hazard	**Natural and Climate Hazards**
Description and justification	Flood hazard is the condition referring to the potential of the hydro-meteorological phenomena to cause harm to humans and objects.
Definition	The probability that a flood of a particular intensity will occur over an extended period. There are many dimensions (water depth, velocities, durations, debris. etc.) to flood hazard.
Measurement procedure and tool	Flood hazards typically rely upon the results from computational models. The simplest computational flood hazard models are based on hydrological models which represent the processes by which rainfall is converted into run-off. Hazard can be determined from a simulation using combined 1D and 2D hydrodynamic model models. The models that can be used are HEC-RAS 1D-2D, DHI MIKE FLOOD software, SOBEK, Delft 3D and other. 1-Dimensional (1D) models are simplified models that characterize the terrain using the channel data (i.e., a cross-section of both main ricer and tributaries, river

	network, structure and roughness), and observation data (i.e., rainfall, water level and discharge data). At each cross-section, the flow depth and velocity perpendicular to the cross-section is computed. 2 Dimensional (2D) models calculate the flow both parallel and non-parallel to the main flow Component of the model consisted of the topographic data (i.e., digital elevation model (DEM)) of the area. Aerial LiDAR data can also be used as topography data for the 2D modelling by generating DEM of the area. They are useful for modelling areas of complex topography.
Data source	
Required data	List of data that can be used to assess the flood hazard, the following examples of data can be used: • Rainfall time series • Discharge time series • Information on surface properties including roughness, permeability and topography • Data on the layouts and geometry of channel networks including elevations, diameters and the properties of any control structures.

Monitoring technique	List the techniques that can be used to collect these data and expand on the steps needed to obtain these data. In particular, to collect data for flood hazard assessment, these are possible techniques:
	• Ground measurement
	• Geospatial data, for example
	  • Satellite data for flood events
	  • Satellite data
	LiDAR

Data collection frequency	Hourly, daily
Level of expertise required	Good. Permission maybe required if accessing large quantities of data and the duration for which the data will be assessed
Synergies with other indicators	Flood vulnerability Reduction of damage costs
Connection with SDGs	SDG 11
Additional information	
References	

6.22 Flooded area

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Flooded Area	Natural and Climate Hazards
Description and justification	Indicators of Flooding Risk Resilience sub-criterion will assess the site response to Flooding phenomena based on susceptibility indicators: land use cover, run-off coefficient, rainfall intensity and duration.
Definition	Area submerged by discharge during the flooding event.
Strengths and weaknesses	
Measurement procedure and tool	Susceptible flooding area maps are available, using different colours to mark out zones exposed to different level of risk from fluvial and tidal flooding. Alternative approaches are based on the implementation of numerical simulations, which combining GIS-based software and hydraulic solvers, are able to detected the flooding areas, as a function of the set forcing, through one-dimensional (e.g., HECRAS of the US Army Corps of Engineers), two-dimensional (e.g., FLO-2D of the FLO-2D software Inc.) or tri-dimensional (e.g., ANUGA Hydro developed by the Australian National University).
Scale of measurement	ha
Data source	
Required data	Floodable area maps, rainfall data, hydraulic, geological and geotechnical information, topography (Model/GIS).
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	

Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	

6.23 Height of flood peak and time to flood peak

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Height of flood peak **Time to flood peak**		**Water Management** **Natural and Climate Hazards**
Description and justification	Rapid urbanisation and industrialisation have led to reduced vegetative cover and decreased water storage in the subsurface, as well as the concentration and accumulation of surface runoff in sewage systems due to reduced infiltration into the soil. As a result, the volume of surface runoff as well as the velocity and time to peak storm runoff and baseflow are all increased. Urbanisation also reduces the land coverage of forests and vegetation that help to dissipate the flow energy (Devi, Ganasri & Dwarakish, 2015; Liu, Gebremeskel, De Smedt, Hoffman & Pfister, 2004). The detrimental effects of urbanisation on hydrologic systems are expected to increase in the future due to both increasing urbanisation as well as changes to the global climate, including rising sea levels, glacial retreat, changing precipitation patterns and an increasing frequency of extreme events (Kiehl, 2011).	
Definition	Flood peak height is the highest point of the rising limb of a flood hydrograph (describing discharge over time) (m^3/s, cfs, L/s or similar units) Time to flood peak (h)	

Strengths and weaknesses	+ Straightforward assessment of degree to which the changes in the local land-use (i.e., change in imperviousness) had an effect on reducing/promoting runoff - Requires *in situ* measurements
Measurement procedure and tool	Assessment of the effectiveness of flood management methods can be performed by different methods. For example, the assessment of runoff can be performed by in situ measurements before and after construction of a flood management structure. In the studies reviewed by Iacob et al. (2014), the assessment of natural management methods was performed either by hydrologic and hydraulic modelling or by direct monitoring. Parameters used for the assessment of the performance of natural flood management measures were: (a) flood peak reduction for different flood event return periods (e.g., 1, 2, 25, 50, or 100 years); (b) increase in time to flood peak; (c) decrease in annual probability of flood risk for the selected area.
Scale of measurement	Site to catchment scale
Data source	
Required data	*In situ* runoff measurements
Data input type	Quantitative
Data collection frequency	At the time of precipitation events and/or daily, monthly and yearly continuous monitoring before and after construction of the area and/or installation of NBS
Level of expertise required	Low
Synergies with other indicators	Direct relationship to *Surface runoff in relation to precipitation quantity* indicator, and partial relationship to *Measured infiltration rate and capacity* and *Evapotranspiration rate* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Iacob, O., Rowan, J.S., Brown, I.M., & Ellis, C. (2014). Evaluating wider benefits of natural flood management strategies: An

	ecosystem-based adaptation perspective. *Hydrology Research*, *45*(6), 774-787.

6.24 Peak flow rate

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Peak Flow Rate	Natural and Climate Hazards
Description and justification	Indicators of Flooding Risk Resilience sub-criterion will assess the site response to Flooding phenomena based on susceptibility indicators: land use cover, run-off coefficient, rainfall intensity and duration.
Definition	Maximum rate of discharge during the period of runoff caused by a rainfall event. For a time period of T years, the T years-recurrence peak flow Q_T is defined as a value of discharge, which occurs statistically each T years. More precisely, Q_T is defined by the fact that probability to have a maximal annual discharge greater than Q_T is equal to $1/T$. It is influenced by both the basin (size, shape, geographical location, topography, geology, type of vegetal cover, extent of surface detention) and the rainfall event characteristics (intensity, duration, spatial and temporal distribution pattern, storm direction).
Strengths and weaknesses	
Measurement procedure and tool	The peak flow can be estimated by applying two main approaches: probabilistic and deterministic models. Probabilistic models are based on statistical inference which essentially estimates the design variables by fitting the observed data. Deterministic models are based upon the peak flow estimation through analytical relationships and provide a point estimate without uncertainty assessment. Rainfall-Runoff models are applicable to estimate the peak flow. These are usually applied when flow observations are not available and, thus, they require the use of rainfall data (more easily available) to quantify the required data.

Scale of measurement	m^3/s
Data source	
Required data	Rainfall data, hydraulic, geological and geotechnical information, topography (Model/Survey).
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	

6.25 Peak flood volume

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*
[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Peak flood volume	**Natural and Climate Hazards**
Description and justification	Indicators of Flooding Risk Resilience sub-criterion will assess the site response to Flooding phenomena based on susceptibility indicators: land use cover, run-off coefficient, rainfall intensity and duration.
Definition	Represents the volume of water corresponding to the peak flow. Flood volumes are related to 1) the time scales of the meteorological inputs (rainfall, snowmelt) and 2) the time

	scales of the storage and delay of this input in the catchment (Gaàl et al., 2015).
Strengths and weaknesses	
Measurement procedure and tool	The flood volume is intended as the total volume between the time of the apparent sudden rise of the hydrograph and the time when the descending limb again reached the initial discharge (Kovàcs, 1978).
Scale of measurement	m3
Data source	
Required data	Rainfall data, hydraulic, geological and geotechnical information, topography (Model).
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	The volumes are strictly related to the peak flow, depending on the catchment properties, the rainfall durations and the catchment processes.
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	Gaàl L., Szolgay J., Kohnovà S., Hlavčovà, Parajka J., Viglione A., Merz R., Blöschl G. (2015). Dependence between flood peaks and volumes: a case study on climate and hydrological controls. Hydrological Sciences Journal, 60(6), 968-984. DOI: 10.1080/02626667.2014.951361 Kovàcs Z.P.S.J. (1978). Documentation of the January, 1978 floods in Pretoria and in the Crocodile River catchment. Technical Report No. TR 88. Department of Water Affairs, Private Bag X313 Pretoria (SA).

6.26 Flood excess volume

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: Guillaume Piton[1], Jean-Marc Tacnet[1]

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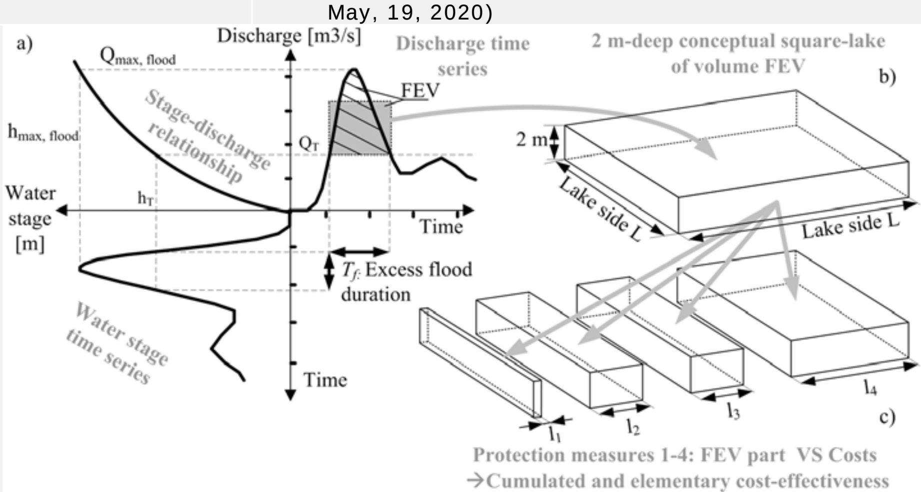
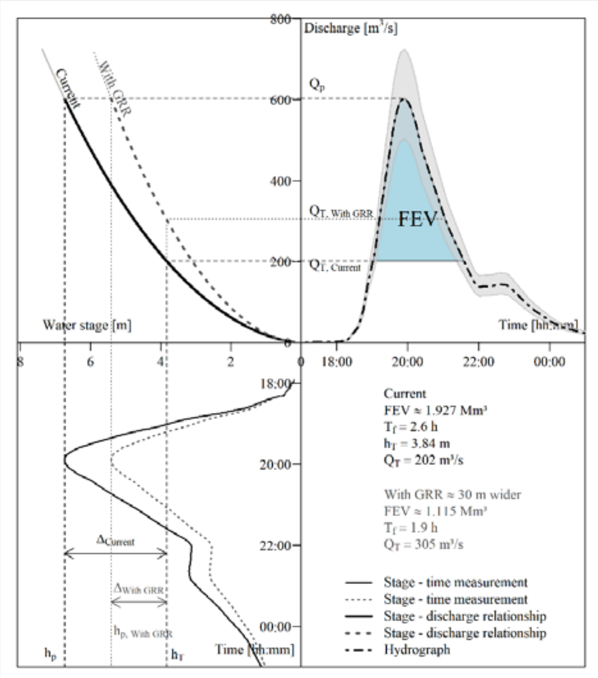
Flood-Excess Volume (FEV)	**Natural and Climate Hazards Water Management**
Description and justification	Flooding adverse consequences occur when flow levels exceed channel banks and reach areas with assets. Knowing the whole volume of the flood hydrograph is interesting but insufficient to determine whether the flood will trigger adverse consequences or not: it is also necessary to know the discharge times series (i.e., the hydrograph), the flow level over which flooding starts and to know the stage – discharge relationship to determine which fraction of the total volume can actually be harmful. The FEV is a computation of this hydrograph fraction: the hydrograph volume in excess compared to the channel capacity. In essence, when implementing water retention measures for flood protection, one does not want to buffer the whole hydrograph volume, just the FEV. The FEV method enables first to compute this water excess volume. In a second step, it is possible to compute how much of the FEV several protection measures can handle. If costs of each measures are available, it is finally possible to compute the cost-efficacy ratio of the whole strategy as well as of each measure (Cost per percentage of FEV). Overall, the FEV framework enables fast and straightforward computation of the amount of water causing problems, the design of the number and size of a panel of measures required to mitigate the associated problems and a fast assessment of the measure and strategy cost-efficacy ratio.
Definition	The FEV of a given flood event at a certain location is defined as (Bokhove et al., 2019): the water volume causing flood damage due to river levels h exceeding a relevant threshold h_T such that, some or major flooding issues occur for $h > h_T$. The data required to compute it are: (i) event hydrograph, i.e., discharge time series Q(t), (ii) water stage – discharge relationship, i.e., channel conveyance capacity h(Q) and (iii) the threshold value for flooding in term of discharge Q_T or of flow level $h_T=h(Q_T)$.
Strengths and weaknesses	+ The FEV framework is fast and simple to implement, has great educational potential and was tried and tested with success on several sites across Europe (Brague River FR, Aire and Calder Rivers UK, Glinščica River SLO). + Flood mitigation strategies usually relies on both water retention measures and works on the channel to increase its conveyance capacity. Usual indicators focus on one aspect or the other while the FEV encapsulates both. The

	example provided as attached figure shows how giving room to the river (GRR) enables changing the channel capacity and then decrease the remaining FEV nearly by half. - Fast and straightforward methods necessarily rely on several simplification hypothesis and thus provide imperfect assessments. Among limitations of FEV discussed by Bokhove et al. (2020) (i) Three-dimensional flood dynamics is reduced to the analysis of FEV at or near the most critical point along a river where flooding starts. Generally, river hydraulics are modelled in a one- or two-dimensional manner: it is therefore best to consider FEV-analysis as a diagnostic at the worst spot. (ii) Only the averaged and cumulative effects of retention measures upstream of the point of FEV-analysis are considered. Spatio-temporal considerations en route to the most critical point of flooding are thus ignored. (iii) Only effectiveness is considered here but not benefits, which would require a full economic analysis of damages saved and/or costs incurred.
Measurement procedure and tool	Given an in situ hydrograph Q(t) explicitly as function of time t, or implicitly as a function Q = Q(h) of the in situ river level h = h(t), discretized in time step of duration Δt, and knowing the threshold discharge for flooding $Q_T=Q(h_T)$, the approximation of FEV is: $$FEV = \sum_{flood} \left(Q(t) - Q(h_T)\right)\Delta t = \sum_{flood} \left(Q(h(t)) - Q(h_T)\right)\Delta t$$ For data-scarce contexts, Bokhove et al. (2020) provides simplified equations.
Scale of measurement	m3
Data source	
Required data	Hydrograph, water stage – discharge curve, threshold depth for flooding.
Data input type	Quantitative
Data collection frequency	Possibly hourly measurement of discharge or flow stage on the duration of the flood event (if possible more frequent for flash floods)
Level of expertise required	Intermediate
Synergies with other indicators	Complementary with Height Of Flood Peak/Time To Flood Peak, Peak Flow, Peak Volume, Flood Peak Reduction, Reduction Of Inundation Risk For Critical Urban Infrastructures.
Connection with SDGs	13
Opportunities for participatory data collection	Fine-tuning of the threshold level for flooding can benefit from local dweller knowledge.

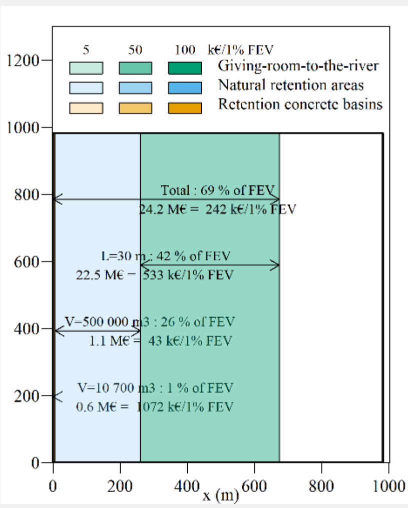
	Proposition and sizing of protection measures can be performed with stakeholder participation (Arfaoui and Gnolonfin, 2020)
Additional information	
References	Arfaoui N, Gnonlonfin A. 2020. Supporting NBS restoration measures: A test of VBN theory in the Brague catchment. Economics Bulletin 40: 1272–1280. [online] Available from: https://ideas.repec.org/a/ebl/ecbull/eb-20-00134.html (accessed on May, 19, 2020) Bokhove O., Kelmanson M.A., Kent T., Piton G., Tacnet JM. 2019. Communicating (nature-based) flood-mitigation schemes using flood-excess volume. River Research and Applications 35: 1402–1414. DOI: 10.1002/rra.3507 Bokhove O., Kelmanson M.A., Kent T., Piton G., Tacnet JM. 2020. A Cost-Effectiveness Protocol for Flood-Mitigation Plans Based on Leeds' Boxing Day 2015 Floods. Water 12: 1–30. DOI: 10.3390/w12030652 Piton G., Dupire S., Arnaud P., Mas A., Marchal R., Moncoulon D., Curt. T., Tacnet J. 2018. DELIVERABLE 6.2 From hazards to risk: models for the DEMOs - Part 3: France: Brague catchment DEMO. NAIAD H2020 project (Grant Agreement nº 730497) [online] Available from: http://naiad2020.eu/wp-content/uploads/2019/02/D6.2_REV_FINAL.pdf (accessed on May, 19, 2020)



Conceptual flood-excess volume (FEV) representations. (a) Three-panel graph highlighting FEV: (bottom-left) view of river-level time series around a flood event; (top-left) stage–discharge relationship arising from (top-right) discharge data, in which FEV is the hatched ''area'' between the discharge curve $Q(t) = Q(\tilde{h}) = Q(h(t))$, displayed vertically as function of time horizontally, and a chosen threshold discharge $Q_T = Q(h_T)$ with exceedance time T_f, involving in situ temporal river levels $h = h(t)$. (b) FEV square-lake representation as a $D = 2$ m-deep square lake, with side-length $L = (FEV/D)^{0.5}$, to facilitate visualisation of FEV ''size.'' (c) FEV-effectiveness assessment computed for each measure as equivalent FEV fraction, represented as side L of the square lake (Bokhove et al., 2019)



Application example of the FEV at the Brague catchment scale on flood disaster of Oct. 2005 (time return of about 500 years). Current stage – discharge capacity (thick line, upper left panel) triggered flooding above discharge Q_T = 202 m^3/s generating 1,900,000 m^3 of FEV. In a NBS strategy giving room the river (30 m widening) this threshold discharge is increased to 305 m^3/s and the FEV became 1,100,000 m^3 that may be partially handled with complementary water retention measures.



Square lake representation at the Brague catchment scale on flood disaster of Oct. 2005: the full FEV of 1.9 Mm^3 is equivalent to a square lake of side nearly 1 km long and 2 m deep. The existing retention concrete basin of 10,700 m3 handle less than 1% of this total volume at high cost. Giving 30 m of width to the river would cope with 42% of the FEV while the natural retention areas would cope with 26% of the FEV at low cost. 31% of FEV remains and require other measures if one want to protect against the full event.

6.27 Moisture index

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Moisture Index	**Green Space Management Natural and Climate Hazards**
Description and justification	Indicators of Moisture sub-criterion will assess the portion of total precipitation used to satisfy plant (vegetation) needs.
Definition	As used by Thornthwaite (1931) in his climatic classification: an overall measure of precipitation effectiveness for plant growth that takes into consideration the weighted influence of water surplus and water deficiency as related to water need and as they vary according to season.
Strengths and weaknesses	
Measurement procedure and tool	Living Labs/Model
Scale of measurement	-
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	

Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	Thornthwaite C.W. (1931). The climates of North America according to a new classification. Geographical Review, 21, 633–655.

6.28 Flammability index

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Flammability Index	**Green Space Management** **Natural and Climate Hazards**
Description and justification	Indicators of Flammability sub-criterion will assess the ability of a landscape to burn or ignite, causing fire or combustion.
Definition	Ability of a landscape to burn or ignite, causing fire or combustion.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Survey
Scale of measurement	-
Data source	
Required data	

Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	

6.29 Soil Type

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

[1] *Built Environment Asset Management Centre, Glasgow Caledonian University, Glasgow, Scotland, UK*

Soil type	**Natural and Climate Hazards**
Description and justification	Different soil types would have different strengths and resistance against erosion or sliding.
Definition	Systematic categorization of soils based on distinguishing attributes as well as criteria that dictate choices in use.
Strengths and weaknesses	Strengths: standard classification and description methods exist; it is possible to generate digital soil maps with a relatively reduced amount of data inputs; it is intrinsically related to soil hydrological properties relevant for landslides and erosion control. Weaknesses: high resolution intrusive investigation is needed
Measurement procedure and tool	Trial pits or boreholes excavated and samples taken. Description and classification done to existing European Standards (e.g., Eurocodes).

Scale of measurement	Micro / point measurement
Data source	
Required data	Laboratory and in situ test results
Data input type	Category/type and value (particle size distribution, soil organic matter, soil pH, and electric conductivity)
Data collection frequency	Once (very low frequency)
Level of expertise required	Low
Synergies with other indicators	Soil temperature, aggregate stability, soil matric suction, soil strength, soil water flux
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Yes.
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S. B., 2017. Plant-best: A novel plant selection tool for slope protection. Ecological Engineering, 106 (154-173) Mickovski, S B and Thomson, C S. 2016. Innovative Approach in the Stabilisation of Coastal Slopes. Engineering Sustainability, 171(1): 15–24

6.30 Soil strength

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

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Soil strength	**Natural and Climate Hazards**
Description and justification	Different soil types would have different strengths and resistance against erosion or sliding. Soil strength is a key variable in slope stability analysis.
Definition	Soil strength depends on the angle of internal shear (mostly granular soils) and cohesion (mostly fine grained soils)

Strengths and weaknesses	Strengths: standard lab and in situ testing methods exist (e.g., BS1377-9); intrinsically related to soil type and soil-water content Weaknesses: high resolution intrusive investigation is needed
Measurement procedure and tool	Trial pits or boreholes excavated and samples taken. Strength tests in situ or in laboratory done to existing European Standards (e.g., Eurocodes). Tools include: shear vane, shearbox, triaxial apparatus, cone penetrometer, static penetration.
Scale of measurement	Micro / point measurement
Data source	
Required data	Laboratory and in situ test results
Data input type	Value (units of pressure for cohesion; decimal degrees for friction)
Data collection frequency	Once for the baseline and sporadic (after a rainfall event or after a landslide) thereafter
Level of expertise required	Medium
Synergies with other indicators	Soil temperature, soil type, aggregate stability, soil matric suction
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Yes.
Additional information	
References	Mickovski, B. S.2018. Risk-based framework accounting for the effects of vegetation in geotechnical engineering. CE / Papers. 2, 2-3, p. 377-382. Gonzalez-Ollauri, A. and Mickovski, S. B., 2017. Plant-soil reinforcement response under different soil hydrological regimes. Geoderma, 285 (141-150)

6.31 Soil temperature

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Soil temperature	Climate Resilience Natural and Climate Hazards Green Space Management
Description and justification	Soil temperature is intrinsically related to soil microbial activity and to biogeochemical and hydrological fluxes in the soil. Different soil temperatures would be preferred by different vegetation whose roots would provide strengths and resistance against erosion or sliding.
Definition	The degree or intensity of heat present in soil, especially as expressed according to a comparative scale and shown by a thermometer or perceived by touch.
Strengths and weaknesses	Strengths: standard measurement methods exist; closely linked to air temperature; linked to complex soil biogeochemical processes; Weaknesses: high resolution intrusive investigation is needed; site-specific investigation needed to establish connections with other environmental variables and processes.
Measurement procedure and tool	Trial pits or boreholes excavated and samples taken or thermometer and/or thermocouples inserted and measurement taken in situ
Scale of measurement	Micro / point measurement
Data source	
Required data	Temperature
Data input type	Value (units of temperature)
Data collection frequency	continuous
Level of expertise required	Low
Synergies with other indicators	Soil strength, soil type, aggregate stability, soil matric suction, plant evapotranspiration, soil water flux, soil carbon flux
Connection with SDGs	11, 13, 15, 17

Opportunities for participatory data collection	Yes.
Additional information	
References	Gonzalez-Ollauri. A., Stokes, A., Mickovski, S.B., 2020. A novel framework to study the effect of tree architectural traits on stemflow yield and its consequences for soil-water dynamics. Journal of Hydrology, 582 (124448)

6.32 Level of Groundwater Table

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Ground water table level	Natural and Climate Hazards
Description and justification	Depth below ground surface at which the ground water exists. Higher levels cause more instability, lower levels increase strength and resistance to erosion and landslides.
Definition	The amount of water in storage in the monitored aquifer. When recharge exceeds natural discharge plus abstraction, groundwater levels rise. When recharge is less than natural discharge plus abstraction, groundwater levels fall.
Strengths and weaknesses	+: standard measurement methods exist; cartographic indices exist to spatially predict depth of water table -: high resolution intrusive investigation is needed
Measurement procedure and tool	Trial pits or boreholes excavated and measurement/monitoring carried out in situ using a dipmeter / piezometer
Scale of measurement	Micro / point measurement
Data source	
Required data	Levels [m] below ground surface
Data input type	Height [m] above datum
Data collection frequency	Periodic, continuous
Level of expertise required	Low

Synergies with other indicators	Soil strength, soil type, aggregate stability, soil matric suction, plant evapotranspiration
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Yes.
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Hydrological effect of vegetation against rainfall-induced landslides. Journal of Hydrology, 549 (374–387) White, B., Ogilvie, J., Campbell, D.M.H., Hiltz, D., Gauthier, B., Chisholm, H.K.H., Wen, H.K., Murphy, N.C., Arp, P.A., 2012. Using the cartographic depth-to-water index to locate small streams and associated wet areas across landscapes. Can. Water Resour. J. 37 (4), 333–347.

6.33 Shallow landslide risk – slope stability factor of safety

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

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Slope instability risk (factor of safety)	**Natural and Climate Hazards**
Description and justification	The engineering stability of slopes is based on calculation of a factor of safety, where FoS=1 denotes a failing slope, FoS<1 unstable slope, while FoS>1 a stable slope. The calculation is based on Limit Equilibrium of forces and overturning moments acting on a limited mass of soil.
Definition	A ratio between the stabilising and destabilising forces/moments acting on a limited mass of soil.
Strengths and weaknesses	+: number of standardised methods and approaces exist; software for calculation exists -: the factor is based on a 2D analysis of a cross-section of a slope and potential local variations in the soil/water properties can affect it.
Measurement procedure and tool	Soil and water parameters need to be derived before entering a closed mathematical solution for computation. Commercial and free software exists for calculation and visualisation of the FoS based on methods and approaches

	standardised, among others, with the European Standards (Eurocodes)
Scale of measurement	Meso-scale (slope scale)
Data source	
Required data	Soil strength/physical parameters, ground water parameters, vegetation parameters
Data input type	Numerical, quantitative data input into a software package
Data collection frequency	Ideally continuous
Level of expertise required	High
Synergies with other indicators	Soil strength, Soil matric suction, water retention, soil type, vegetation coverage, vegetation cover, ground water table level
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	Yes, through continuous sampling and monitoring
Additional information	
References	EN ISO 1997 parts 1 and 2

6.34 Landslide safety factor

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Landslide Safety Factor	Natural and Climate Hazards
Description and justification	Indicators of Landslide Risk Resilience sub-criterion will assess the site response to landslide phenomena based on susceptibility indicators: slope angle, pore water pressure, groundwater depth, soil properties, land use, land cover.

Definition	In the conventional limit equilibrium methods, the Factor of Safety is intended as “the factor by which the shear strength of the soil would have to be divided to bring the slope into a state of barely stability equilibrium” (Duncan, 1996). This definition, called “the strength-reserving” definition, is the most familiar to engineers (Zheng et al., 2005).
Strengths and weaknesses	Safety Factor is widely adopted for slope instability estimation.
Measurement procedure and tool	Limit equilibrium methods are commonly used to evaluate the slope stability from which derive the reliable indication of stability as the Factor of Safety.
Scale of measurement	Dimensionless
Data source	
Required data	Geological and geotechnical information, topography (Model).
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	Duncan J.M. (1996). State of the art: limit equilibrium and finite element analysis of slopes. Journal of Geotechnical and Geoenvironmental Engineering (ASCE), 122(7), 577–596. DOI:10.1061/(ASCE)0733- 9410(1996)122:7(577) Zheng H., Liu D.F., Li C.G. (2005). Slope stability analysis based on elasto-plastic finite element method. International Journal For Numerical Methods In Engineering, 64(14), 1871–1888. DOI: 10.1002/nme.1406

6.35 Landslide risk – History of instability on site

Project Name: OPERANDUM (Grant Agreement no. 776848)

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History of instability on site	Natural and Climate Hazards
Description and justification	Recording the different instability events on/adjacent to a site helps in assessing the possibility of future instability. Slopes that have historically failed are more likely to fail again.
Definition	Failures include erosion, landslides, rockfalls, flooding or any other natural hazard
Strengths and weaknesses	+: provides a timeline and frequency of events that can be mitigated; mapping can be undertaken using historical aerial photographs; new digital mapping approaches can be used to identify zones subjected to past failures; large body of statistical models available to detect past events on the basis of rainfall intensity. -: qualitative measurement which may under/over estimate the true type or frequency of instability events; need for a standardised way of recording.
Measurement procedure and tool	Usually surveys/interviews focus groups with local residents but also review of local press/media articles and historic maps/photos.
Scale of measurement	Local and regional
Data source	
Required data	Dates of events
Data input type	Qualitative
Data collection frequency	Once as a baseline, sporadic afterwards (to record any new instability episode)
Level of expertise required	Intermediate
Synergies with other indicators	Soil strength, Soil stability (factor of safety), Erosion (soil loss), topography, rainfall
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Entirely participatory

Additional information	
References	Mickovski S.B., Santos O., Ingunza P.M.D., Bressani L.2015. Coastal slope instability in contrasting geo-environmental conditions. In: Geotechnical Engineering for Infrastructure and Development - Proc. XVI European Conference for Soil Mechanics and Geotechnical Engineering, Edinburgh, Scotland, September 2015: 1801-1806.

6.36 Occurred landslide area

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Occurred Landslide Area	Natural and Climate Hazards
Description and justification	Indicators of Landslide Risk Resilience sub-criterion will assess the site response to landslide phenomena based on susceptibility indicators: slope angle, pore water pressure, groundwater depth, soil properties, land use, land cover.
Definition	Represents the observed surface which moves downward of a mass of rock, earth, or artificial fill on a slope divided by the surface subjected to the high and medium landslide risk obtained by analytical modelling (in percentage). The main scopes of the index is to assess the effectiveness of the adopted design solution for either the entire or the partial area referred to the total risk area.
Strengths and weaknesses	Relatively easy to estimate.
Measurement procedure and tool	This indicator can be estimated from both analytical and observational considerations.
Scale of measurement	Dimensionless, %
Data source	
Required data	Geological and geotechnical information, topography (Model/Survey).

Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	

6.37 Landslide risk – Digital elevation/terrain modelling

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Topography (digital elevation/ terrain models)	**Natural and Climate Hazards**
Description and justification	Topography and relief of a slope are needed as a basis for the assessment of the stability of the terrain where the NBS will be built or operated in. It is also needed for siting and conceptual design of NBS against any form of natural or climate hazard.
Definition	Digital elevation model (DEM), digital terrain model (DTM) or digital surface model (DSM) is a 3D CG representation of a terrain's surface created from a terrain's elevation data.
Strengths and weaknesses	+: DTMs exist globally (provided by: BGS, USGS, ERSDAC, CGIAR, Spot Image, etc); algorithms to retrieve topographical attributes such as slope gradient, aspect, and curvature exist. DTMs can be used for digital soil mapping. Topographic indices related to landscape ecology and dynamics are available and need DTM-derived information.

	-: the resolution of the DTM needs to be commensurate with the size of the NBS put in place; it needs data processing and knowledge of GIS and spatial analysis
Measurement procedure and tool	Commonly built using data collected using remote sensing techniques, but they may also be built from land surveying (e.g., photogrammetry, lidar, etc)
Scale of measurement	millimetres to kilometres
Data source	
Required data	Point cloud or similar depending on the type of survey.
Data input type	Numerical, quantititative; A DEM can be represented as a raster (a grid of squares, also known as a heightmap when representing elevation) or as a vector-based triangular irregular network (TIN). The TIN DEM dataset is also referred to as a primary (measured) DEM, whereas the Raster DEM is referred to as a secondary (computed) DEM.
Data collection frequency	Periodically
Level of expertise required	Intermediate for surveying, high for data processing
Synergies with other indicators	Soil strength, slope stability (FoS), erosion (soil loss), water table depth, surface water accumulation and flow, plant establishment and growth, soil organic matter, soil nutrients
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Yes, through open source and citizen science data exchange platforms
Additional information	
References	Gonzalez-Ollauri, A., Mickovski, S.B., 2017. Shallow landslides as drivers for slope ecosystem evolution and biophysical diversity. Landslides, 14:1699-1714. Peckham, R.J. and Gyozo, J. (Eds.)(2007): Development and Applications in a Policy Support Environment Series: Lecture Notes in Geoinformation and Cartography. Heidelberg.

6.38 Soil mass movement

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

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Soil mass movement	Natural and Climate Hazards
Description and justification	Soil mass movement indicates instability and existence of a range of natural hazards including landslides, rockfalls, avalanches, debris flows, and similar.
Definition	Soil mass movement, also called soil mass wasting comprises bulk movements of soil and rock debris down slopes in response to the pull of gravity, water or the rapid or gradual sinking of the Earth's ground surface in a predominantly vertical direction.
Strengths and weaknesses	+: mass movement observation methods exist in a more or less standardised form for a very long time -: some movements are too slow to be observed with a naked eye, and some are too fast to allow appropriate reaction.
Measurement procedure and tool	Usually using some form of survey (photogrammetric, lidar, etc) at regular/irregular intervals, but also analysis of history of instability, photographic/media records. Local measurements of soil mass movement can be carried out using inclinometers and/or piezometers installed to a certain depth in the soil suspected of mass movement.
Scale of measurement	Micro to macro
Data source	
Required data	Quantitative, numerical values of velocity of movement, depth of movement, and/or profile of moving mass
Data input type	numerical
Data collection frequency	continuous
Level of expertise required	Medium to high
Synergies with other indicators	Soil type, soil strength, history of instability, moisture content, groundwater level, topography, rainfall, temperature
Connection with SDGs	11, 13, 15, 17

Opportunities for participatory data collection	Yes for data collection and reporting
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Plant-Best: A novel plant selection tool for slope protection. Ecological Engineering 106 (2017) 154–173.

6.39 Velocity of occurred landslide

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Velocity of Occurred Landslide	Natural and Climate Hazards
Description and justification	Indicators of Landslide Risk Resilience sub-criterion will assess the site response to landslide phenomena based on susceptibility indicators: slope angle, pore water pressure, groundwater depth, soil properties, land use, land cover.
Definition	Factor having significant relevance in the landslide classification. A velocity range is connected to the different types of landslides, on the basis of observation of either case histories or site observations (Cruden & Varnes, 1996).
Strengths and weaknesses	
Measurement procedure and tool	Model
Scale of measurement	m/s
Data source	
Required data	Geological and geotechnical information, topography (Model/Survey).
Data input type	Quantitative
Data collection frequency	

Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	Cruden D.M., Varnes D.J. (1996). Landslide Types and Processes. Special Report, transportation Research Board, National Academy of Sciences, 247, 36-75.

6.40 Erosion risk

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

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Erosion risk (soil loss estimate)	Natural and Climate Hazards
Description and justification	Soil erosion is among the most challenging and continuous environmental problems in the world and can take form of erosion by water (usually surface runoff) or wind. The displaced soil travels away from the point of origin and can create additional risks to life and property. Soil erosion is one of the main and original risks the NBS were employed to mitigate against.
Definition	The likelihood of a site/plot of soil to lose the uppermost layer due to the agents of water, wind, etc. Usually measured as the volume of lost soil per unit of time.
Strengths and weaknesses	+: relatively standard methods exist for estimation; databases exist for preliminary assessment. -: lack of data on the erosion risk of man-made or engineered soil surfaces and NBS
Measurement procedure and tool	(Revised) Universal Soil Loss Equation is used to calculate the soil loss per unit of time. The calculation involves consideration of soil type, climatic parameters (rainfall), and methods of soil cultivation (not necessarily NBS).

Scale of measurement	Meso (field) to macro/global (regional, continental)
Data source	
Required data	Soil parameters, vegetation parameters, climatic parameters
Data input type	Numerical, quantitative
Data collection frequency	Once as a baseline, sporadically thereafter throughout the life of the NBS
Level of expertise required	Intermediate to high
Synergies with other indicators	Runoff rate, percolation rate, water flux, slope stability (FoS) , soil type, rainfall (precipitation), throughflow, stemflow
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	yes
Additional information	
References	Wischeimer, W. H. and Smith, D. D.: 1965, Predicting Rainfall Erosion Losses from Cropland East of Rocky Mountains, U.S. Department of Agriculture, Agricultural Handbook, No. 282, Washington, D.C. Panagos, P. Et al. 2015. The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy 54 (438-447).

6.41 Total Predicted Soil Loss (RUSLE)

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Total Predicted Soil Loss (RUSLE)	**Natural and Climate Hazards** **Green Space Management**
Description and justification	Indicators of Soil Physical Resilience sub-criterion will assess if the project scenarios enhance the ability of a soil to resist or recover their healthy state in response to destabilising influences.
Definition	RUSLE is widely applied to estimate the rate of soil loss by water. The landscape profile is defined by a slope length, which is the length from the origin of overland flow to the point where the flow reaches a major flow concentration or a major area of deposition. The soil loss is an average erosion rate for the landscape profile.
Strengths and weaknesses	
Measurement procedure and tool	RUSLE (model/survey)
Scale of measurement	ton/ha/year
Data source	
Required data	Rain data, soil characteristics, land use information.
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	

Additional information	
References	

6.42 Days with temperature >90th percentile (TX90p)

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik[1], Laura Wendling[1], Ville Rinta-Hiiro[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Days with temperature >90th percentile (TX90p)	**Natural and Climate Hazards**
Description and justification	Nature-based solutions can support climate change adaptation by reducing local ambient air temperature. They can also provide insulation from cold and/or shelter from wind. By moderating the urban microclimate, green infrastructure can support reduction in energy use and improved thermal comfort (Demuzere et al., 2014).
Definition	Percentage of days during which the maximum daily temperature (TX) exceeds the 90th percentile (TX90p) threshold of the daily maximum temperature (%)
Strengths and weaknesses	+ Straightforward assessment of heatwaves occurrence - Requires statistical tools and judgement
Measurement procedure and tool	Ambient air temperature can be assessed through continuous monitoring of temperature, near the NBS intervention area, and evaluation of the maximum daily temperature before and after NBS implementation. Evaluating the effect on the heatwave reduction by assessing the daily temperatures produces more accurate results that monthly averages, which tend to “lose” the small changes that are crucial for several domains, such as health and agriculture (Alexander *et al.*, 2006). The TX90p defines the occurrence of the extremely hot days falling above the 90th percentile (1/10th of the sample) allowing the evaluation of the *extent* of the extreme temperatures changes (Alexander *et al.*, 2006). The TX90p is evaluated as $$TX_{ij} > TX_{in}90$$ where

	TX_{ij} – daily maximum temperature on day *i* in period *j* *$TX_{in}90$* – calendar day 90th percentile centred on a five-day window for the base period 1961-1990
Scale of measurement	Plot to district scale
Required data	Automated continuous monitoring of ambient air temperature
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low – for continuous temperature monitoring; Moderate – when using the statistical tools
Synergies with other indicators	Directly contributes to evaluation of the *Warm spell duration index* indicator and is closely related to *Daily temperature range* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through direct temperature measurements if these are not automated
Additional information	
References	Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., ... & Tagipour, A. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, *111*, D05109. Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management, 146*, 107-115. ETCCDI. (2009). *Climate change indices*. Available from: http://etccdi.pacificclimate.org/list_27_indices.shtml

6.43 Warm spell duration index (WSDI)

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Maria Dubovik[1], Laura Wendling[1], Ville Rinta-Hiiro[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Silvia Coelho[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Warm spell duration index (WSDI)	Natural and Climate Hazards
Description and justification	Nature-based solutions can support climate change adaptation by reducing local ambient air temperature. They can also provide insulation from cold and/or shelter from wind. By moderating the urban microclimate, green infrastructure can support reduction in energy use and improved thermal comfort (Demuzere et al., 2014).
Definition	Number of days per annum when the maximum daily temperature TX > 90th percentile threshold (see indicator TX90p) for at least six consecutive days
Strengths and weaknesses	+ Straightforward assessment of heatwaves occurrence - Requires statistical tools and judgement
Measurement procedure and tool	Evaluating the effect on the heatwave reduction by assessing the daily temperatures produces more accurate results that monthly averages, which tend to "lose" the small changes that are crucial for several domains, such as health and agriculture. The WSDI defines the periods of excessive heat during the daytime, and it is evaluated using a percentile-based threshold (Alexander *et al.*, 2006): $$TX_{ij} > TX_{in}90$$ where TX_{ij} – daily maximum temperature on day *i* in period *j* $TX_{in}90$ – calendar day 90th percentile centred on a five-day window for the base period 1961-1990
Scale of measurement	Plot to district scale
Data source	
Required data	Automated continuous monitoring of ambient air temperature
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation

Level of expertise required	Low – for continuous temperature monitoring; Moderate – when using the statistical tools
Synergies with other indicators	Directly evaluated from *Days with temperature > 90th percentile (TX90p)* indicato and closely related to *Daily temperature range* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through direct temperature measurements if these are not automated
Additional information	
References	Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., ... & Tagipour, A. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, *111*, D05109. Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management*, *146*, 107-115. ETCCDI. (2009). *Climate change indices*. Available at: http://etccdi.pacificclimate.org/list_27_indices.shtml

6.44 Heatwave incidence

Project Name: UNaLab (Grant Agreement no. 730052)

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Heatwave incidence expressed as the numbe orf combined tropical nights (>20°C) and hot days (>35°C) per annum	**Climate Resilience** **Natural and Climate Hazards**
Description and justification	Heatwave is a period of prolonged abnormally high surface temperatures relative to those normally expected. Heatwaves can be characterized by low humidity, which may exacerbate drought, or high humidity, which may

	exacerbate the health effects of heat-related stress such as heat exhaustion, dehydration and heatstroke. Heatwaves in Europe are associated with significant morbidity and mortality. Furthermore, climate change is expected to increase average summer temperatures and the frequency and intensity of hot days (Russo et al., 2014). In cities and urban areas, the UHI tends to exacerbate heatwave episodes.
Definition	Number of combined tropical nights (>20°C) and hot days (>35°C)
Strengths and weaknesses	+ Easy and straightforward assessment - Requires substantial amount of external data for modelling
Measurement procedure and tool	This indicator is assessed through continuous monitoring of temperature, and/or estimated by applying meteorological models such as the WRF (NCAR & UCAR, n.d.; NOAA, n.d.)
Scale of measurement	Building/plot to regional scale
Data source	
Required data	Initial and boundary conditions, topography, land use and urban parameters (building height, width, number of road lanes) (Emmons et al., 2010; Pineda, Jorba, Jorge & Baldasano, 2004). These data can be obtained through national statistics, municipal departments, Corine Land Cover, and a mapping application such as OpenStreetMap.
Data input type	
Data collection frequency	Annually, and before and after NBS implementation
Level of expertise required	Low – for continuous temperature monitoring High – for applying meteorological models
Synergies with other indicators	Assessed from *Mean or peak daytime temperature* indicator and connected with *Urban Heat Island* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through sample collection, e.g., air quality measurements if these are not automated
Additional information	
References	Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). *Geoscientific Model Development*, *3*, 43-67.

National Center for Atmospheric Research (NCAR) & University Corporation for Atmospheric Research (UCAR). (n.d.). Weather Research and Forecasting (WRF) Model Users' Page. Retrieved from http://www2.mmm.ucar.edu/wrf/users/

National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/

Pineda, N., Jorba, O., Jorge, J. & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model. *International Journal of Remote Sensing*, *25*(1), 129–143.

Russo, S., Dosio, A., Graversen, R., Sillmann, J., Carrao, H., Dunbar, M.B. …Vogt, J.V. (2014). Magnitude of extreme heat waves in present climate and their projection in a warming world. Journal of Geophysical Research: Atmospheres, 119(22), 12500–12512.

Weather Research and Forecasting Model (WRF): https://www.mmm.ucar.edu/weather-research-and-forecasting-model

6.45 Human comfort: Universal thermal climate index (UTCI)

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Universal Thermal Climate Index (UTCI)	Climate Resilience Natural and Climate Hazards Health and Wellbeing
Description and justification	UTCI index represents air temperature of the reference condition with the same physiological response as the actual condition. The UTCI provides a one-dimensional value that reflects the human physiological reaction to the multi-dimensional outdoor thermal environment (Bröde et al., 2012). It can predict both whole body thermal effects (hypothermia and hyperthermia; heat and cold discomfort), and local effects (facial, hands and feet cooling and frostbite). Applications of the UTCI include weather forecasts, bioclimatological assessments, bioclimatic

	mapping, urban design, engineering of outdoor spaces, outdoor recreation, epidemiology and climate impact research.
Definition	The UTCI is the air temperature that would produce under reference conditions the same thermal strain as the actual thermal environment. In other words, the UTCI is the reference environmental temperature causing strain.
Strengths and weaknesses	+ Mathematical expression of a person's thermal comfort in the outdoors + The output is expressed in easily understandable temperature units, e.g., °C.
Measurement procedure and tool	The human body core temperature must be maintained within a narrow range around 37°C to ensure proper function of the body's inner organs and the brain, thus optimising human comfort, performance and health. In contrast, the temperature of the skin and extremities can vary widely, depending upon environmental conditions. This variation in the temperature of extremities is one of the mechanisms to equilibrate heat production and heat loss. The heat exchange between the human body and environment can be described in the form of the energy balance equation: $\boldsymbol{M + W + C + K + E + Q + Res \pm S = 0}$ where M=heat produced by metabolism; W=heat generated by muscular activity; C=sensible heat flux (heat transferred by convection); K=heat transferred through conduction contact with solid bodies); E=latent heat flux (evaporative heat flux); Q=radiative heat transfer; Res=heat transfer through respiration; and, S=heat content of the body. The UTCI is derived from this mathematical model of thermoregulation with an integrated adaptive clothing model that also accounts for predicted votes of the dynamic thermal sensation based on core and skin temperature (Fiala et al., 1999, 2001, 2003; Havenith et al., 2011). The deviation of UTCI temperature from measured air temperature depends on measured values of air temperature (T_a) and mean radiant temperature (T_{mrt}), wind speed at a height of 10 m (v_a) and humidity expressed as water vapour pressure (p_a) or relative humidity (rH): $\boldsymbol{UTCI(T_a, T_{mrt}, v_a, p_a) = Ta + Offset(T_a, T_{mrt}, v_a, p_a)}$ The model reference condition is walking at 4 km/h (135 W/m^2) with $T_{mrt}=T_a$, v_a=0.5 m/s, rH=50% (T_a >29°C)

<table>
<tr><td></td><td>and p_a=20 hPa (T_a >29°C) (Bröde et al., 2012). The UTCI dynamic model response can be determined using the online calculator available from http://utci.org. The relationship between UTCI temperature (expressed in °C) and physiological stress is shown in the table below (adapted from Błażejczyk et al., 2010).
<table>
<tr><th>UTCI (°C) range</th><th>Stress category</th></tr>
<tr><td>Above +46</td><td>Extreme heat stress</td></tr>
<tr><td>+38 to +46</td><td>Very strong heat stress</td></tr>
<tr><td>+32 to +38</td><td>Strong heat stress</td></tr>
<tr><td>+26 to +32</td><td>Moderate heat stress</td></tr>
<tr><td>+9 to +26</td><td>No thermal stress</td></tr>
<tr><td>0 to +9</td><td>Slight cold stress</td></tr>
<tr><td>-13 to 0</td><td>Moderate cold stress</td></tr>
<tr><td>-27 to -13</td><td>Strong cold stress</td></tr>
<tr><td>-40 to -27</td><td>Very strong cold stress</td></tr>
<tr><td>Below -40</td><td>Extreme cold stress</td></tr>
</table></td></tr>
<tr><td>Scale of measurement</td><td>Plot – street – neighbourhood – district</td></tr>
<tr><td>Data source</td><td></td></tr>
<tr><td>Required data</td><td>Air temperature, T_a (°C)
Mean radiant temperature, T_{mrt} (degrees Kelvin)
Water vapour pressure (hPa)
Relative humidity (%)
Wind speed at a height of 10 m (m/s)</td></tr>
<tr><td>Data input type</td><td>Quantitative</td></tr>
<tr><td>Data collection frequency</td><td>Frequency as desired. UTCI can be calculated frequently with measurement intervals determined by (automated) weather data acquisition.</td></tr>
<tr><td>Level of expertise required</td><td>Low to Moderate</td></tr>
<tr><td>Synergies with other indicators</td><td>Direct relation to Heatwave incidence and Number of combined tropical nights and hot days indicators. Similar to Physiological equivalent temperature (PET)</td></tr>
<tr><td>Connection with SDGs</td><td>SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action</td></tr>
<tr><td>Opportunities for participatory data collection</td><td>Participatory data collection is feasible through direct participation in weather data collection</td></tr>
</table>

Additional information	
References	Błażejczyk, K., Broede, P., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kampmann, B. & Kunert, A. (2010). Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. Miscellanea Geographica, 14, 91-102. Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. & Havenith, G. (2012). International Journal of Biometeorology, 56, 481-494. Fiala, D., Havenith, G., Bröde, P., Kampmann, B & Jendritzky, G. (2011). UTCI-Fiala multi-node model of human temperature regulation and thermal comfort. International Journal of Biometeorology, 56, 429-441. Fiala D, Lomas KJ, Stohrer M (1999) A computer model of human thermoregulation for a wide range of environmental conditions: the passive system. Journal of Applied Physiology, 87, 1957–1972. Fiala D, Lomas KJ, Stohrer M (2001) Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. International Journal of Biometeorology, 45, 143–159. Fiala D, Lomas KJ, Stohrer M (2003) First principles modeling of thermal sensation responses in steady-state and transient conditions. ASHRAE Transactions, 109, 179–186. Havenith G, Fiala D, Błażejczyk K, Richards M, Bröde P, Holmér I, Rintamäki H, Benshabat Y, Jendritzky G (2011) The UTCI-Clothing Model. International Journal of Biometeorology, 56, 461-470.

6.46 Human comfort: Physiological equivalent temperature (PET)

Project Name: UNaLab (Grant Agreement no. 730052)

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Human Comfort: Physiological Equivalent Temperature (PET)	Climate Resilience Natural and Climate Hazards
Description and justification	Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface

	temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006).
Definition	Mean or peak daytime local temperature by PET calculation (°C)
Strengths and weaknesses	+ Compared to PMV, PET has the advantage to use °C, which allows the results to be easily interpreted by urban or regional planners - Requires extensive amount of data for evaluation
Measurement procedure and tool	To calculate PET (Höppe, 1999): 1. Determine the thermal conditions of the body using MEMI (1) for a given set of climatic parameters. The Munich energy-balance model for individuals (MEMI) is based on the energy balance equation of the human body and is related to the Gagge two-node model (Gagge, Stolwijk, & Nishi, 1972). The MEMI equation is as follows: $$M + W + +C + E_D + E_{Re} + E_{Sw} + S = 0 \quad (1)$$ where, M is the metabolic rate (internal energy production by oxidation of food); W is the physical work output; R is the net radiation of the body; C is the convective heat flow; E_D is the latent heat flow to evaporate water into water vapour diffusing through the skin; E_{Re} is the sum of heat flows for heating and humidifying the inspired air; E_{Sw} is the heat flow due to evaporation of sweat; and, S is the storage heat flow for heating or cooling the body mass. As a first step, the mean surface temperature of the clothing (T_{cl}), the mean skin temperature (T_{sk}) and the core temperature (T_c) must be evaluated. These three parameters provide the basis for calculation of E_{Sw}. Two equations are necessary to describe the heat flows from the body core to the skin surface (F_{cs}) as shown in (2), and heat flows from the skin surface through the clothing layer to the clothing surface (F_{sc}) as shown in (3) (Höppe, 1999): $$F_{CS} = v_b \times \rho_b \times c_b \times (T_c - T_{sk}) \quad (2)$$ where, v_b is blood flow from body core to skin (L/s/m^2); ρ_b is blood density (kg/L); and, c_b is the specific heat (W/sK/kg). $$F_{CS} = (1/I_{cl}) \times (T_{sk} - T_{cl}) \quad (3)$$

	where, I_{cl} is the heat resistance of the clothing (K/m^2/W). 2. Insert calculated values for mean skin temperature (T_{sk}) and core temperature (T_c) into the MEMI equation (1) and solve the three equations for air temperature, T_a (v☐= 0.1 m/s; water vapour pressure = 12 hPa; T_{mrt} = T_a). This temperature is equivalent to PET.
Scale of measurement	Building or plot scale
Data source	
Required data	Energy balance of the human body, heat flows though the body and clothing
Data input type	Quantitative
Data collection frequency	Annually, and before and after NBS implementation
Level of expertise required	High – requires ability to follow the calculation procedure and units, and to critically evaluate the results
Synergies with other indicators	Directly related to *Incorporation of environmental design in buildings* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Gagge, A., Stolwijk, J.A., & Nishi, Y. (1971). An effective temperature scale based on a simple model of human physiological regulatory response. ASHRAE Transactions, 77(1), 247-257. Höppe, P. (1999). The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. International Journal of Biometeorology, 2466, 71-75.

6.47 Human comfort Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD)

Project Name: UNaLab (Grant Agreement no. 730052)

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Mean or peak daytime temperature – Predicted Mean Vote-Predicted Percentage Dissatisfied	**Climate Resilience Natural and Climate Hazards**
Description and justification	Green urban infrastructure can significantly affect climate change adaptation by reducing air and surface temperatures with the help of shading and through increased evapotranspiration. Conversely, green urban infrastructure can also provide insulation from cold and/or shelter from wind, thereby reducing heating requirements (Cheng, Cheung, & Chu, 2010). By moderating the urban microclimate, green infrastructure can support a reduction in energy use and improved thermal comfort (Demuzere et al., 2014). The cooling effect of green space results in lower temperatures in the surrounding built environment (Yu & Hien, 2006)
Definition	Mean or peak daytime local temperature by PMV-PPD calculation (unitless value)
Strengths and weaknesses	+ Mathematical expression of a person's thermal comfort under indoor steady-state conditions - Subjective evaluation of thermal sensations - The output is not expressed in any temperature units, e.g., °C.
Measurement procedure and tool	The model aims to estimate the mean thermal sensation of a group of individuals and their respective percentage of dissatisfaction with the thermal environment, expressed in terms of Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD). The practical application of the PMV equation and associated variables has been described by Ekici (2016). PMV provides a score that relates to the Thermal Sensation Scale (Fanger, 1970). If the score is zero, the occupant satisfaction regarding the environment is at the maximum level (Ekici, 2016). Thermal Sensation Scale (Fanger, 1970): **Scale** / **Description** / **How it feels**

	3	Hot	Intolerably warm
	2	Warm	Too warm
	1	Slightly warm	Tolerably uncomfortable, warm
	0	Neutral	Comfortable
	-1	Slightly cool	Tolerably uncomfortable, cool
	-2	Cool	Too cool
	-3	Cold	Intolerably cool
Scale of measurement	Building scale		
Data source			
Required data	Metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity (Rupp, Vásquez, & Lamberts, 2015).		
Data input type	Semi-quantitative		
Data collection frequency	Annually		
Level of expertise required	High – requires the ability to apply the mathematical model and evaluate the results		
Synergies with other indicators	Directly related to *Incorporation of environmental design in buildings* indicator		
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action		
Opportunities for participatory data collection	Participatory data collection is feasible through direct participation in the indicator assessment		
Additional information			
References	Ekici, C. (2016). Measurement uncertainty budget of the PMV thermal comfort equation. International Journal of Thermophysics, 37, 48 Ekici, C. (2013). Review of Thermal Comfort and Method of Using Fanger's PMV Equation. Proceedings of the 5th International Symposium on Measurement, Analysis and Modelling of Human Functions, 27-29 June 2013, Vancouver, Canada. 4 pp. Fanger, P. (1970). Thermal comfort. Analysis and applications in environmental engineering. Copenhagen: Danish Technical Press. Rupp, R. F., Vásquez, N. G., & Lamberts, R. (2015). A review of human thermal comfort in the built environment. Energy and Buildings, 105, 178–205.		

6.48 Urban Heat Island (UHI) incidence

Project Name: UNaLab (Grant Agreement no. 730052)

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Urban Heat Island (UHI) effect	**Climate Resilience** **Natural and Climate Hazards**
Description and justification	The UHI effect is caused by the absorption of sunlight by (stony) materials, reduced evaporation and the emission of heat caused by human activities. The UHI effect is greatest after sunset and reported to reach up to 9°C in some cities, e.g., Rotterdam (Van Hove et al., 2015). Because of the UHI effect, citizens living in urban areas experience more heat stress than those living in the countryside.
Definition	Urban Heat Island (UHI) effect (°C)
Strengths and weaknesses	+ Fairly easy and straightforward assessment of temperature differences - Requires a rather large amount of temperature measurement stations to holistically identify the effect within the urban area
Measurement procedure and tool	1. Identify or install one or more meteorological (temperature) measurement stations within the built environment, and one measurement station outside the city that functions as a reference station. 2. Compare the hourly average air temperature measurements of the urban measurement station(s) with the station outside the city (the reference station). 3. Look for the largest temperature difference (hourly average) between urban and countryside areas during the summer months. This temperature difference is an absolute measure of the UHI effect.
Scale of measurement	Building/plot to regional scale
Data source	
Required data	Hourly temperature measurements
Data input type	Quantitative

Data collection frequency	Annually; at minimum before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Assessed from *Mean or peak daytime temperature* indicator and connected with *Heatwave Risk* indicator
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Van Hove, L.W.A., Jacobs, C.M.J., Heusinkveld, B.G., Elbers, J.A., van Driel, B.L., & Holtslag, A.A.M. (2015). Temporal and spatial variability of urban heat island and thermal comfort within the Rotterdam agglomeration. Building and Environment, 83, 91-103. United States Environmental Protection Agency. (2006). Excessive Heat Events Guidebook. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/eheguide_final.pdf

6.49 Effective drought index

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Effective Drought Index	**Natural and Climate Hazards**
Description and justification	Indicators of Drought Risk Resilience sub-criterion will assess the site response to drought phenomena based on susceptibility indicators: land use cover, temperature, moisture, wet weather.
Definition	Byun & Wilhite (1999) developed the Effective Drought Index (EDI), which is an intensive measure that considers daily water accumulation with a weighting function for time passage.

Strengths and weaknesses	
Measurement procedure and tool	The EDI can be calculated with literature formulations. Rain data are needed.
Scale of measurement	Dimensionless
Data source	
Required data	Metrological data (Model)
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	Byun H.R., Wilhite D.A. (1999). Objective Quantification of Drought Severity and Duration. Journal of Climate, 12, 2747-2756. DOI: 10.1175/1520-0442(1999)0122.0.CO;2

6.50 Standardized Precipitation Index

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Standardized Precipitation Index	Natural and Climate Hazards
Description and justification	Indicators of Drought Risk Resilience sub-criterion will assess the site response to drought phenomena based on

	susceptibility indicators: land use cover, temperature, moisture, wet weather.
Definition	The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, whereas at longer timescales, the SPI can be related to groundwater and reservoir storage. The SPI can be compared across regions with markedly different climates. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. The raw precipitation data are typically fitted to a Gamma or a Pearson Type III distribution, and then transformed to a Normal Distribution. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the Long-Term mean.
Strengths and weaknesses	For the operational community, the SPI has been recognized as the standard index that should be available worldwide for quantifying and reporting meteorological drought. Concerns have been raised about the utility of the SPI as a measure of changes in drought associated with climate change, as it does not deal with changes in evapotranspiration (https://climatedataguide.ucar.edu/).
Measurement procedure and tool	The SPI can be estimated with reference to differing periods of 1-to-36 months, using monthly input data.
Scale of measurement	Dimensionless
Data source	
Required data	Metrological data, topography (Model).
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	

References	

6.51 Groundwater level

Project Name: UNaLab (Grant Agreement no. 730052)

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Quantitative status of groundwater	Water management Natural and Climate Hazards
Description and justification	Water covers ca. 71 % of the Earth's surface but only 2.5 % of it is fresh, stored as groundwater and in glaciers. Water is vital for living organisms, and it enables a multitude of human activities such as agriculture, manufacturing and transportation of goods. Available water resources are being extensively used for a variety of purposes, and ensuring that the water quality is monitored and the degraded water bodies are enhanced is essential for protecting the water resources. EU Water Framework Directive (2000/60/EC) sets forth the framework for integrated management of surface waters and groundwater resources in the EU Member States, which are presented as River Basin Management Plans.
Definition	The degree to which a body of groundwater is affected by direct and indirect abstractions (good, moderate, bad, poor, bad)
Strengths and weaknesses	+ A comparable EU-wide applied assessment - Requires arrangements on Member State-level
Measurement procedure and tool	The following procedure is based off the requirements set by the Water Framework Directive (2000/60/EC): 1. Define groundwater bodies within a river basin area 2. Establish type-specific reference conditions per Annex V 3. Identify significant anthropogenic pressures 4. Identify and estimate significant water abstractions for urban, agricultural, industrial and other uses, including seasonal variations and total annual demand 5. Identify and estimate loss of water in the distribution systems

<table>
<tr><td></td><td>6. Estimate recharge and artificial recharge of groundwater bodies
7. Estimate the effects caused by water regulation, flood protection and land drainage
8. Establish monitoring of quantitative status for groundwater:
a. Groundwater level monitoring network
b. Density of monitoring sites
c. Frequency of monitoring
d. Additional monitoring requirements for protected areas as listed under Annex IV
9. Present monitoring results as maps in accordance with Annex V
10. Interpret groundwater quantitative status per Annex V</td></tr>
<tr><td>Scale of measurement</td><td>River basin; Member State</td></tr>
<tr><td colspan="2">Data source</td></tr>
<tr><td>Required data</td><td>Anthropogenic pressures on groundwater reserves; Water abstraction rates; Land-use; Water regulation activities; Water losses</td></tr>
<tr><td>Data input type</td><td>Quantitative and qualitative</td></tr>
<tr><td>Data collection frequency</td><td>Frequency of monitoring for drinking water abstraction points:
<table>
<tr><th>Community served</th><th>Frequency</th></tr>
<tr><td>< 10 000</td><td>4 per year</td></tr>
<tr><td>10 000 – 30 000</td><td>8 per year</td></tr>
<tr><td>> 30 000</td><td>12 per year</td></tr>
</table></td></tr>
<tr><td>Level of expertise required</td><td>Moderate to High</td></tr>
<tr><td>Synergies with other indicators</td><td>Indicators forming parts of the Member States' River Basin Management Plans: Quantitative status of groundwater, Chemical status of groundwater, Ecological status of surface waters, Biological status of surface waters, Hydromorphological status of surface waters, Physicochemical status of surface waters and Ecological potential for heavily modified or artificial water bodies</td></tr>
<tr><td>Connection with SDGs</td><td>SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, SDG 13 Climate action</td></tr>
</table>

Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Parliament. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. 2010. http://data.europa.eu/eli/dir/2000/60/oj European Parliament. Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. 2006. http://data.europa.eu/eli/dir/2006/118/2014-07-11 European Commission. Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans. European Commission, 2012.

6.52 Trend in piezometric levels (TPL)

Project Name: NAIAD (Grant Agreement no. 730497)

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Trend in piezometric levels (TPL)	**Water management Natural and Climate Hazards**
Description and justification	Provides an indication of the capacity of available surface water resources to meet the water demands.
Definition	Difference between surface water supply and demand (m^3/year)
Strengths and weaknesses	

Measurement procedure and tool	Modelling through Medina del Campo surface water allocation model.
Scale of measurement	Groundwater Body scale (Medina del Campo Groundwater Body)
Data source: climatic data from local meteorological stations.	
Required data	Climatic data including rainfall, runoff, evapotranspiration, infiltration.
Data input type	Historical data series
Data collection frequency	Annual
Level of expertise required	
Synergies with other indicators	Groundwater availability due to the surface-groundwater connections
Connection with SDGs	SDG 6
Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain– Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

6.53 Groundwater exploitation index

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Groundwater Exploitation Index (GEI)	**Water management** **Natural and Climate Hazards**
Description and justification	Provides an indication of the pressure of water demand on groundwater availability and the sustainability of the abstractions regime.The GEI addresses directly the good quantity mandate of the European Water Framework Directive. The GEI can be used as a tool to support water management with different purposes both within a particular GB or AV or at River basin scale: to achieve sustainable/desirable exploitation rates; to monitor the expected evolution of available groundwater resources; to monitor the temporal and space changes of both groundwater input and groundwater abstraction; to compare the situation in a set of GB/AV; to provide knowledge to understand socio-economic changes linked to agrarian activities; to support environmental policies related to groundwater ecosystems and to surficial groundwater dependent ecosystems, and their respective services; etc.
Definition	Ratio between total groundwater input to a particular groundwater body (GB) or aquifer volume (AV) and groundwater abstraction from the same GB or AV in a given lapse of time (usually one year). Usually given as ratio, but can also be given as %.
Strengths and weaknesses	+ It is a simple and easy to understand indicator of groundwater use sustainability. - Usually, the best figures that can be obtained for both groundwater input to and abstraction from a particular BG or AV have significant uncertainties. For this reason, the

	index should better be used accompanied by its estimated combined uncertainty (Example:1.4 +- 0.7).
Measurement procedure and tool	Groundwater input is usually quantified by a combination of empirical and numerical hydrological methods (estimation or modelling of groundwater recharge from rainfall, of groundwater lateral transfer from nearby geological formations, of excess irrigation water infiltration, and of surface water infiltration through river beds). Groundwater abstractions are quantified by empirical methods (pumping measurement through meters; accounting irrigation surfaces with particular crops and assigning irrigation provisions; deduction from accurate aquifer water balances). Both terms of GEI can also be estimated from the calibration of accurate groundwater flow models (i.e., the Medina del Campo Groundwater Body iMOD groundwater model, in NAIAD). Tools: simple spreadsheets and specific modelling software.
Scale of measurement	Groundwater-body/aquifer scale. It can also be applied to a particular aquifer volume, whose limits must be accurately defined.
Data source	
Required data	To estimate groundwater input: climatic data (rainfall, air temperature); edaphic data (field capacity, wilting point, evapotranspiration); hydrologic and hydrogeologic data (runoff, porosity, specific yield, infiltration, recharge; piezometry; hydraulic gradients). To quantify groundwater abstraction: groundwater pumped (per well and year); surface irrigated with particular crops, type of crops, water provision per crop. Data can be retrieved from public institutions (national/regional meteorological surveys; water management authorities); groundwater users; public and private research institutions.
Data input type	Total water input and total groundwater abstraction (hm^3/yr).
Data collection frequency	Though the GEI is used on a yearly base, it should be calculated with monthly data.
Level of expertise required	To calculate the indicator: expert level on hydrogeology. To understand the rationale behind it: low to medium expert level on hydrogeology.
Synergies with other indicators	With Surface Water Availability (SWA), due to the surface-groundwater relationships in areas where there are water-table aquifers and rivers, lagoons, and/or wetlands.

	With Trend of Piezometric Levels (TPL).
Connection with SDGs	With SDG 6
Opportunities for participatory data collection	Many types of people can participate in collecting data needed to calculate and/or monitor the GEI. Precipitation and air temperature data can be collected by students of different age and by employees from public and private institutions; groundwater abstraction can be measured by wells' owners. PIEZOMETRIC RECOVERING.
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain–Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

6.54 Calculated drinking water provision

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Calculated drinking water provision	**Water Management** **Natural and Climate Hazards**
Description and cation	Drinking water is commonly stored in dams and water wells, and distributed from them to the consumers. This KPI evaluates the available drinking water in damps or other fonts, and the water which is actually distributed to the consumers in a city or in defined area of a city.
Definition	Measurement method for the drinking water supplied to the consumers, or/and available water provision.
Strengths and weaknesses	+ Each consumer has their own meters, so it is possible to measure the provision in terms of amount of water per flat, building and/or any other facilities - This KPI may require permission to access data
Measurement procedure and tool	Domestic consumption of water is measured by water flow meters, so it can be monitor by the water company/service. With this detailed monitoring consumption of the water can be calculated as $m^3 * ha^{-1} * year^{-1}$. Apart from supplied water, volume of available drinking water is calculated with the measurement of height of water in dams and water wells. Dimensions of

	the dams and wells are known and the height of water gives the current volume and occupancy rate of dams.
Scale of measurement	City
Data source	
Required data	Water flows and water levels
Data input type	Numeric data and geographic data
Data collection frequency	Yearly
Level of expertise required	Technical
Synergies with other indicators	Abortion capacity of green surfaces, bioretention structures and single trees, run-off coefficient in relation to precipitation quantities.
Connection with SDGs	This KPI is directly related with SDG 6 and SDG 11 and indirectly is related with SDG 3 (access to drinking water is a key part of the health and wellbeing).
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-

6.55 Water Exploitation Index

Project Name: UNaLab (Grant Agreement no. 730052)

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Water Exploitation Index	**Water Management** **Climate and Natural Hazards**
Description and justification	The Water Exploitation Index (WEI) compares the volume of water consumed each year to the available freshwater resources. More specifically, the WEI presents total annual freshwater extraction as a proportion (%) of the long-term annual average freshwater available from renewable resources. The WEI warning threshold of 20% distinguishes a water-stressed area from one not suffering water scarcity. Severe scarcity is defined as WEI >40%.
Definition	Annual total water abstraction as a proportion (%) of available long-term freshwater resources in the geographically relevant area (basin) from which the municipality obtains its water
Strengths and weaknesses	+ European Environment Agency (EEA) uses the WEI to evaluate water scarcity across major river basins in Europe with time - Requires substantial amount of external information and data sources
Measurement procedure and tool	The WEI is calculated as follows (European Environment Agency [EEA], 2018): $WEI = \left(\frac{Volume\ of\ water\ abstraction}{Volume\ of\ renewable\ freshwater\ resources}\right) \times 100$ An advanced version of the WEI, called the WEI+, accounts for recharge of available freshwater supplies, or water return (EEA, 2018a): $WEI+ = \left(\frac{Volume\ of\ water\ abstraction - Volume\ of\ water\ returns}{Volume\ of\ renewable\ freshwater\ resources}\right) \times 100$

	The volume of long-term renewable freshwater resources in a natural or semi-natural geographically relevant area (e.g., basin or sub-basin) is calculated as (EEA, 2018): $Long\ term\ renewable\ freshwater\ resources = E_{xIn} + P - ET_a - \Delta S$ where E_{xIn} = external inflow, P = precipitation, ET_a = actual evapotranspiration and ΔS = change in storage (lakes and reservoirs). The equation for renewable freshwater resources can be simplified as follows for highly-modified (i.e., not natural or semi-natural) river basins or sub-basins (EEA, 2018): $Long\ term\ renewable\ freshwater\ resources = outflow + (abstraction - return) - \Delta S$ where outflow = downstream flow or discharge to sea and ΔS = change in storage (lakes and reservoirs).
Scale of measurement	Basin scale
Data source	
Required data	Necessary information about annual volumes of water abstraction (groundwater, surface water) from a given basin or sub-basin can be obtained from records of water supply companies and city documents relating to water abstraction permits. Wastewater treatment companies, water supply companies and municipal environment/environmental management departments are sources of information related to annual volumes of water returns. Information about long-term renewable water resources can be obtained from local water boards, municipal departments and/or national environment agencies.
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Moderate – for data acquisition and processing
Synergies with other indicators	Related to *Depth to groundwater* and *Qunatitative status of groundwater* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	

References	European Environment Agency (EEA). (2018). Use of freshwater resources. Copenhagen: European Environment Agency. Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3

6.56 Net surface water availability

Project Name: NAIAD (Grant Agreement no. 730497)

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Net surface water availability	**Water Management Natural and Climate Hazards**
Description and cation	Provides an indication of the capacity of available surface water resources to meet the water demands.
Definition	Difference between surface water supply and demand (m^3/year)
Strengths and weaknesses	
Measurement procedure and tool	Modelling through Medina del Campo surface water allocation model.
Scale of measurement	Groundwater Body scale (Medina del Campo Groundwater Body)
Data source.	
Required data	Climatic data from local meteorological stations including rainfall, runoff, evapotranspiration, infiltration.
Data input type	Historical data series
Data collection frequency	Annual

Level of expertise required	
Synergies with other indicators	Groundwater availability due to the surface-groundwater connections
Connection with SDGs	SDG 6
Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.2, From hazard to risk: models for the DEMOs. Part 1: Spain– Medina del Campo. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

6.57 Water availability for irrigation purposes

Project Name: UNaLab (Grant Agreement no. 730052)

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Rainwater or greywater use for irrigation purposes	**Water Management** **Natural and Climate Hazards**
Description and justification	Rainwater and greywater have a potential to be reused for irrigation purposes if collected to a storage unit. This is especially prominent for areas exposed to drought. Domestic wastewater consists of greywater, the wastewater discharged from hand basins, showers and baths, dishwashers, and laundry machines, and blackwater from toilets. Depending on local regulations, water from the kitchen sink be regarded as greywater or blackwater. One person generates 90–120 L greywater each day depending on lifestyle, living standard, age, gender, and other factors. Greywater comprises 50-80% of all domestic wastewater but contains a relatively small fraction of the total pollutant load (Antonopoulou, Kirkou, & Stasinakis, 2013; Donner et al., 2010; Li, Wichmann, & Otterpohl, 2009). Separation of domestic greywater from blackwater and on site re-use for toilet flushing or

	irrigation of non-edible vegetation provides an alternative water source in areas facing water shortage. On-site greywater re-use can reduce potable water use by as much as 50% (Gross, Shmueli, Ronen, & Raveh, 2007).
Definition	Volume of rainwater or greywater used for irrigation purposes (L/y or similar unit)
Strengths and weaknesses	+ Secure reserve of water for irrigation at times of drought + Use of automatic meter reading could be a good choice to communicate with stakeholders regarding the benefits of rainwater capture and use for irrigation - Rainwater storage requires a substantial amount of external storage units - There are concerns about the potential for bacterial growth when nutrient-rich waste/greywater remains untreated for a period of time
Measurement procedure and tool	Accurate accounting of rainfall capture and use for irrigation requires use of a water level sensor to measure the volume of water contained within a given rainwater storage unit at any time. If the storage unit is completely sealed and the water level can be easily recorded each time it is opened (and again after water is discharged for use), it may be possible to manually record and calculate the volume of water captured and used for irrigation purposes. An alternate solution is to equip the discharge point of the rainwater storage unit/tank with a water meter, and record the volume of water used over a specific period of time. This is well suited to applications with multiple water storage tanks and/or in situations where it may be challenging to accurately quantify water use manually. The water meter(s) may be connected to an automatic meter reading (AMR) device that enables remote communication of water usage between the water meter and a central point. It is recommended that domestic greywater is filtered (e.g., sand and/or granular activated carbon filter and/or treatment in vertical subsurface-flow wetland or reed bed, etc.) prior to use for irrigation of non-edible vegetation such as landscaping.
Scale of measurement	Plot scale to street scale
Data source	
Required data	Volume of rainwater and greywater used for irrigation purposes

Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Related to *Monthly maximum value of daily maximum temperature, Quantitative status of groundwater* and *Depth to groundwater* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Antonopoulou, G., Kirkou, A. & Stasinakis, A.S. (2013). Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. Science of the Total Environment, 454-455, 426-432. Donner, E., Eriksson, E., Revitt, D.M., Scholes, L., Holten Lützhøft, H.-C. & Ledin, A. (2010). Presence and fate of priority substances in domestic greywater treatment and reuse systems. Science of the Total Environment, 408(12), 2444-2451. Gross, A., Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW)-a novel method of recycling greywater for irrigation in small communities and households. Chemosphere, 66(5), 916-623. Li, Y., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. Science of the Total Environment, 407(11), 3439-3449.

6.58 Avalanche Risk: Snow cover map

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Snow Cover Map	Climate and Natural Hazards
Description and justification	Indicators of Snow Avalanche Risk Resilience sub-criterion will assess the site response to snow avalanche phenomena based on susceptibility indicators: topography, wind, temperature.
Definition	The snow cover was classified by the mean duration of snow cover for each raster cell. A snow cover of less than 10 days was assumed to be a no-risk zone: as the duration relates to the whole year, the snow accumulation is not expected to become unstable and build up avalanches. The land relief was used as second Indicator for avalanche vulnerability. Values in literature define a slope of ± 30° as threshold in starting zones of avalanches (Schweizer & Jamieson, 2000). Due to strong generalization, the threshold for the occurrence of avalanches was assigned at a lower slope value of 15°, to take into account the steeper slope on a smaller scale. A mask was calculated to exclude regions with slope values smaller than 15°. Cells with a slope > 15° were assumed to be in danger of avalanches. The output of the calculation is a raster indicating areas where avalanches could appear, based on snow cover duration and morphology.
Strengths and weaknesses	
Measurement procedure and tool	The vulnerability for avalanches can be calculated based on two data sets: first, a map of snow cover duration; and second, a digital elevation model (DEM).
Scale of measurement	Dimensionless
Data source	
Required data	Snowfall data, topography (GIS/Statistical Data).
Data input type	Quantitative

Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	Schweizer J., Jamieson J.B. (2000). Field observations of skier-triggered avalanches. Proceedings International Snow Science Workshop, Big Sky, Montana, USA, 2-6 October 2000

GREEN SPACE MANAGEMENT

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7 RECOMMENDED INDICATORS OF GREEN SPACE MANAGEMENT

7.1 Green space accessibility

Project Name: RECONECT (Grant Agreement no. 776866), UNaLab (Grant Agreement no. 730052), and URBAN GreenUP (Grant Agreement no. 730426)

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Green space accessibility	Green Space Management
Description and	Public green and blue spaces (referred to as “green space” for simplicity) have positive impacts on quality of life and wellbeing (see e.g., Baidu at al., 2016; Chiesura et al., 2004). Different

justification	types of green spaces such as urban parks and gardens (including community gardens), cemeteries, sportsgrounds, public plazas, urban forests, orchards, arable lands, undeveloped lands, and other partly or completely vegetated areas demonstrated capacity to clean air, cool local temperature and manage surface runoff. Urban green space also plays a role in increasing the value of local real estate (Roebeling et al. 2017). The environmental, ecological and social benefits of urban green spaces are strongly influenced by green space size and their accessibility in terms of distance and travel time. Publicly accessible green spaces provide opportunities for a wide range of different types of nature-based recreational activities, which have been shown to deliver multiple co-benefits (e.g., Eigenschenk et al., 2019; Triguero-Mas et al., 2017). Green space accessibility is an important metric to evaluate the potential for the realisation of recreational opportunities and related co-benefits. Accessibility of green space can also be used to evaluate the relative success of urban greening policies focused on the provision of and equal access to urban green spaces, and to assess NBS co-benefits as a function of distance from accessible public green space. Many methods for the evaluation of accessibility are available (Handy and Niemeier, 1997). Here, we propose **a simplified cumulative measure** (Páez, Scott and Morency, 2012) based upon the World Health Organisation Regional Office for Europe recommendations related to urban green space accessibility for public health (WHO, 2016) and European Common Indicator of the availability of local public open areas and services (Lavalle et al., 2002).
Definition	Proportion of the population living within a 300 m maximum linear distance to the boundary of urban green spaces of at least 0.5 ha in size.
Strengths and weaknesses	+ Rapid and relatively simple method - Occasional lack of accurate data
Measurement procedure and tool	Data processing using QGIS (or other GIS software) has been designed to obtain one KPI value for the whole city. **<u>Steps:</u>** 1. Identify and map arrival points of public green, blue and blue/green spaces equal to or greater than 0.5 ha in size. Data can be provided by the relevant municipality or derived from publicly available land cover maps (e.g., Urban Atlas or Open street maps). 2. Identify and map buildings or census blocks (departure points). Data can be provided by the municipality or national/international statistics institutes.

3. Define circles with radii 300 m from the access point(s) to each identified public green space. This 300 m distance most likely represents a walk of five (Natural England) to 15 (European Common Indicator[5]) minutes, depending on walking pace.
4. Using census area or similar data, determine the total number of residents within all the mapped 300 m walking distance circles.

Alternative method:

1. Spatially join each (building) departure point to its nearest park access point (tool Distance to the nearest hub). As a result, a new shape-file is obtained with an attribute field containing the shortest distance to the closest park.
2. Classify proximity to the parks. Tamosiunas et al (2014) classified the distance to the closest park using a tertiles method. The resultant three categories classify proximity as high, moderate and low based upon distance (shown as an example):

Proximity category	High	Moderate	Low
Distance (m)	≤347.8	347.8-629.6	>629.6

To obtain this KPI in terms of walking time, the Field calculator tool can be used. A conversion factor has to be set to measure a pedestrian walking speed (Bosina & Weidmann, 2017). For example, the average pedestrian walking speed in Spain is 1.59 m/s, or 95.4 m/min. The distance value in minutes can be obtained by diving the distance in metres by the distance walked per minute. Note that it is generally not possible to walk in a completely straight line "as the crow flies" in urban areas. Thus, estimates of walking times based upon linear distances between two points in built-up urban areas (e.g., point of departure from building A to point of access to park B) are unlikely to be highly accurate.

Complementary data that may be useful in contextualizing the green space proximity index:

[5] "*The European Environment Agency, DG Regional Policy and ISTAT (Italian Istituto Nazionale di Statistica) all use the concept 'within 15 minutes' walk' to define accessibility. It may reasonably be assumed that this corresponds to around 500 m walking distance along roads or pathways on foot for an elderly person, which in turn may be equivalent to 300 m linear distance used in the European Common Indicators*" (Ambiente Italia Research Institute, 2003. Pages 79 and 185.).

	- City level descriptive statistics: It will measure the impact of the NBS at municipal level: Overall statistics can also be calculated by a QGIS tool called Basic statistics for numeric fields. As a result a set of measures is derived: - Descriptive statistics in terms of distance and travel time: - Minimum / maximum distance to the closest park (m) - Average distance to the closest park (m). - Statistics regarding number of inhabitants from each defined starting point (building) are also useful to contextualize the index. - Number of people that live in the proximity of the facility - Proportion of people having the closest park in the high, moderate or low proximity category. - District level descriptive statistics: A neighborhood level study is also recommended in order to find deficient areas in greenspace availability, or probability of overcrowded green areas.
Scale of measurement	District scale to city scale
Data source	
Required data	- Size, location and types of green spaces, including public accessibility (land use maps, green space maps, green space qualification, etc.). - Population data, e.g., census data (municipal departments, statistical services, etc.) - Optional data: total urban area (municipal departments, statistical services etc.); specific points of departure from large residential buildings (buildings) This KPI can be measured using specific software, such as GIS software and spreadsheet software. QGIS is the GIS software suggested, as it is an open source and multiplatform software that is distributed under Creative Commons Attribution-Share Alike 3.0 licence (CC BY-SA). Measurement Unit: % (or fraction) of population
Data input type	Spatial data (vector or raster data) on available public green and blue areas Spatial data (vector or raster data) on departure points of the buildings. Optional: Tabular data - population per census or other reporting unit to provide weighted values.

Data collection frequency	Recommend annual assessment; minimum before and after the NBS implementation
Level of expertise required	Moderate
Synergies with other indicators	Synergies with *Distribution of public green space, Proportion of natural area,* and *Availability and equitable distribution of blue-green space* indicators
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Badiu, D.L., Ioja, C.I., Patroescu, M., Breuste, J., Artmann, M., Nita, M.R., Gradinaru, S.R., Hossu, C.A., & Onose, D.A. (2016). Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. Ecological Indicators, 70, 53-66. Bosina, E., Weidmann, U. 2017. Estimating pedestrian speed using aggregated literature data, Physica A: Statistical Mechanics and its Applications, 468, 1-29. https://doi.org/10.1016/j.physa.2016.09.044 Chiesura, A. (2004). The role of urban parks for the sustainable city. Landscape and Urban Planning, 68(1), 129-138. Eigenschenk, B., Thomann, A., McClure, M., Davies, L., Gregory, M., Dettweiler, U. and Inglés, E. 2019. Benefits of outdoor sports for society: A systematic literature review and reflections on evidence. Int J Environ Res Public health 16(6), 937. doi: 10.3390/ijerph16060937 Handy, S. L. and Niemeier, D. A. 1997. Measuring accessibility: an exploration of issues and alternatives, Environment and Planning A, 29. doi: 10.1068/a291175. Lavalle, C., Demicheli, L., Kasanko, M., McCormick, N., Barredo, J. and Turchini, M. Towards an urban atlas. Assessment of spatial data on 25 European cities and urban areas. Copenhagen: European Environment Agency. ISBN 92-9167-470-2. https://www.eea.europa.eu/publications/environmental_issue_report_2002_30 Le Texier, M., Schiel, K. and Caruso, G. 2018. The provision of urban green space and its accessibility: Spatial data effects in Brussels. PLoS ONE 13(10): e0204684. https://doi.org/10.1371/journal.pone.0204684

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7.2 Total green space within a defined area: Share of green urban areas

Project Name: Indicators for urban green infrastructure (EEA) and Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: EEA, ETC/ULS, Ryad Bouzouidja[1], Véronique Beaujouan[1], Barnabás Körmöndi[2]

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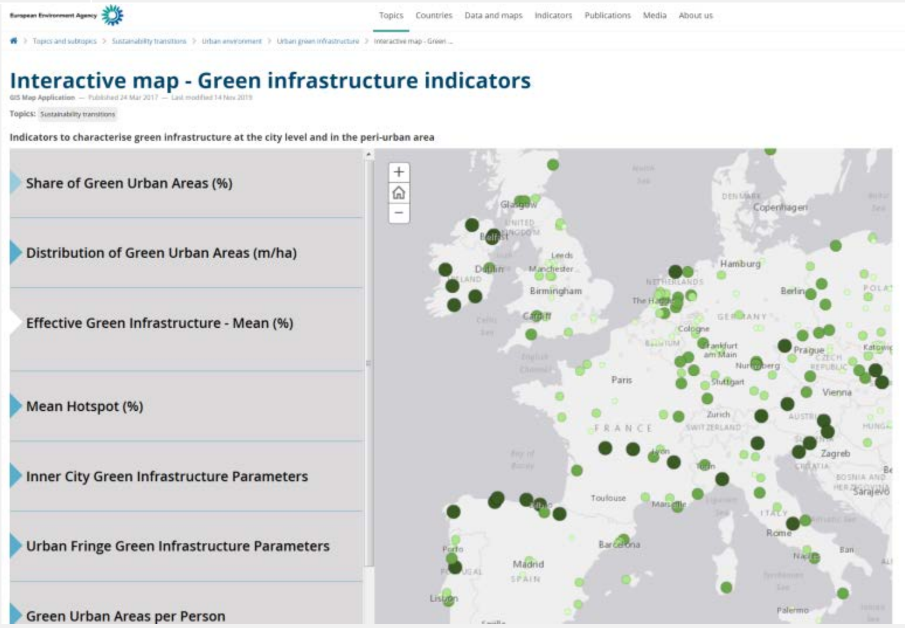
Share of Green Urban Areas	Green Space Management Urban Regeneration
Description and justification	Green urban areas (GUAs) such as parks, public and private gardens, and even trees lining streets can facilitate climate change adaptation and mitigation, improve health and quality of life, and may favour biodiversity conservation. Vegetated areas in cities can generate a cooling effect thanks to evapotranspiration and shading, which may improve the thermal comfort of urban dwellers and increase their resilience to heatwave events. Moreover, green urban areas are unsealed, allowing the infiltration of storm water and decreasing rainwater runoff. The presence of GUAs favours pollution control as vegetation provides cleaner air by removing pollutants such as nitrogen dioxide and microscopic particulate matter. GUAs have an important value beyond their environmental benefits and aesthetic assets. Exposure to greenspaces can restore the physical and mental health of city dwellers by enhancing psychological health and reducing blood pressure and stress levels.
Definition	The proportion of all vegetated areas within the city boundaries in relation to the total area of the city.
Strengths and weaknesses	Strengths: the indicator is easy to measure and it is easy to communicate; it can be used to benchmark cities. It is easily comparable Weaknesses: the indicator does not consider other contextual elements; precision is related to input data. In this application the minimum mapping unit is 0.25 ha And Green linear elements are not currently included.
Measurement procedure and tool	This parameter is based on several classes (11230, 11240, 14100, 14200, 20000, 30000) of the Urban Atlas data, which contain substantial green spaces (the two least dense residential classes with a sealing degree < 30 %, urban parks, sports and leisure facilities, forest, semi-natural and agriculture). It is computed for the core city as defined by Eurostat/Urban Audit. The procedure includes the following steps: 1. Selection of the GUAs typologies to be included

	o In this application the following Urban Atlas classes were included : ▪ 11230-discontonuos low density urban fabric, 11240- discontinuous very low density urban fabric, 14100-green urban areas, 14200-sports and leisure facilities, 20000-agricultiral land, 30000-natural and seminatural areas 2. Sum of the total area of GUAs in the selected city 3. Compute the share of GUAs per city surface In this application the city surface was derived from the Urban Audit data (Eurostat 2017).
Scale of measurement	Minimum mapping unit 0.25 ha
Data source	
Required data	Land use –land cover – in this application Urban Atlas https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012?tab=download Municipal boundary – in this application Urban Audit data (Eurostat 2017). https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/urban-audit Measurement Unit: %
Data input type	
Data collection frequency	Every 6 years. Currently available for 2006 and 2012. Date for 2018 is under production.
Level of expertise required	Land use and GIS expertise
Synergies with other indicators	Distribution of green urban areas (EEA) Access to green areas in Europe (DG Regio)
Connection with SDGs	SDG-11 (Sustainable cities and communities), specifically target 11.7 (universal access to safe, inclusive and accessible, green and public spaces)

Opportunities for participatory data collection	
Additional information	
References	https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/sub-sections/urban-green-infrastructure/typology-for-urban-green-infrastructure https://eea.maps.arcgis.com/apps/MapSeries/index.html?appid=42bf8cc04ebd49908534efde04c4eec8%20&embed=true



7.3 Soil organic matter

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Soil organic matter content	Green Space Management
Description and justification	Soil organic matter influences many soil characteristics including colour, water and nutrient holding capacity (cation and anion exchange capacity), soil pH, nutrient turnover and stability, soil microbial activity and composition, decomposition, which in turn influence water relations, aeration and workability.
Definition	Measure of the soil organic carbon contained within the soil organic matter
Strengths and weaknesses	Strengths: the only true measure of organic carbon present in a soil; easy to measure through loss on ignition (LOI) method -i.e., gravimetric method; elevated temperatures ensure the combustion of all the carbon forms present; possible to generate digital soil maps using a relatively low amount of data inputs. Weaknesses: no universal standard protocol for LOI; it does not include the organic carbon from volatile compounds as these are lost during digestion and drying; LOI method needs site-specific calibration to retrieve information on soil organic matter.
Measurement procedure and tool	Repeated field sampling followed by laboratory analysis by either: a) dry combustion method using elemental analyser [heat a small sample (usually a fraction of a gram) of dry pulverized soil to around 900°C and measure the carbon dioxide gas that is a combustion product]; or, b) Loss on Ignition test (the weight loss of a dry soil sample after it is heated in an oven or muffle furnace to 360–450°C for 2 h). The results are expressed as the percent carbon in the sample.
Scale of measurement	micro
Data source	
Required data	Soil sample Measurement unit: %
Data input type	-

Data collection frequency	Seasonal
Level of expertise required	Low for sampling, intermediate/high for testing/interpretation.
Synergies with other indicators	Moisture content, field capacity, wilting point, soil type, soil strength
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	yes
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Plant-Best: A novel plant selection tool for slope protection. Ecological Engineering 106 (2017) 154–173. Hoogsteen, M.J.J., Lantinga, E.A., Bakker, E.J., Groot, J.C.J. and Tittonell, P.A. (2015), Estimating soil organic carbon through loss on ignition: effects of ignition conditions and structural water loss. Eur J Soil Sci, 66: 320-328.

7.3.1 Soil Organic Matter Index

Project Name: Nature4Cities (Grant Agreement no. 730468)

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Soil Organic Matter Index	Green Space Management
Description and justification	**SOM** is a crucial parameter of soil biological, chemical and physical quality. All soil properties are highly depending on this parameter (soil aggregation, soil nutrients, soil decomposers…)
Definition	This indicator is a numerical value used to ensure/Improve soil organic matter content to allow long-term soil quality. This indicator is available to everyone and easy to implement It is possible to apply the indicator in different locations. The indicator has been used in different circumstances (different soil uses) and delivered reasonable results.

Strengths and weaknesses	This indicator is capable to describe initial planning problems, like soil nutrient deficiency for plant growth, soil compaction
Measurement procedure and tool	• No required tool, No formula, direct parameter
Scale of measurement	Plot or building scale (NBS)
Data source	Measuring this parameter is the best way to calculate this indicator, because urban soil properties are very heterogeneous. If it can't be measured, parameters estimation is possible thanks to the bibliography • Bibliography • Measurement/Monitoring
Required data	• Soil organic matter content (SOM) Measurement Unit : g of organic matter per kg of soil
Data input type	• Soil physico-chemical properties
Data collection frequency	In concept and detailed design phase of urban and object planning.
Level of expertise required	Easy to calculate and requires few data
Synergies with other indicators	In Nature4Cities this indicator can be evaluated (SOM score). The SOM score needs bulk density (B_d) of soil as input data expressed in g/cm^3. Based on Cambou et al. (2018) study, a pedotransfer function has been used. SOM index is given in form of a performance bar with numerical values ranked in terms to the best (1) and worst (0) scenario
Connection with SDGs	SD15 Life on Land
Opportunities for participatory data collection	
Additional information	
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8 Additional Indicators of Green Space Management

8.1 Ecosystem service provision

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Ecosystem service provision (Applied and EO/RS combined)	**Green Space Management**
Description and justification	Studies such as the Millennium Ecosystem Assessment (2005) and the UK National Ecosystem Assessment (Watson et al., 2011), the MAES working group (under Action 5 of the European Biodiversity Strategy to 2020; https://ec.europa.eu/environment/pubs/pdf/factsheets/biodiversity_2020/2020%20Biodiversity%20Factsheet_EN.pdf), MAPPING and assessment of Ecosystems and their services (https://biodiversity.europa.eu/maes; also in support of the European Biodiversity Strategy), KIP INCA (https://ec.europa.eu/environment/nature/capital_accounting/index_en.htm), EnRoute (https://oppla.eu/groups/enroute) and Openness (operationalisation of ecosystem services) demonstrated the linkages between the natural environment, ecosystem services (ES) and human well-being. Urban greenspaces can deliver essential ES and a detailed map of urban GI can provide the baseline for measuring urban ES. Detailed spatial data is needed to identify service providing units, and GI is typically classified according to land cover and land use type. Most techniques therefore involve remote sensed data and modelling approaches. The role of novel Earth observation techniques and data sets is becoming increasingly important in environmental monitoring, both for biodiversity (Vihervaara et al. 2017), and for ecosystem services (Cord et al. 2017). Satellite Earth observation, as well as airborne and drone observations, have huge potential to improve quantification, mapping, and assessment of ecosystems and their services. Optical, radar, and Light Detection And Ranging (LiDAR) data can be used for direct measurements, or to gather information that feeds into the models. Mapping ecosystem service provision in these ways can be used to: • Set targets for ecosystem service provision; • Monitor change in ecosystem service provision over time; • Inform strategic planning decisions in relation to individual sites or networks of sites; • Assess the effects of different scenarios of design/management change on sites.

Definition	Measure number/quantity of a suite of ecosystem services to evaluate change in ES provision in relation to NBS.
Strengths and weaknesses	**Applied methods:** See EO/RS below. **Earth observation / Remote sensing methods:** The integration of RS technologies into ES concepts and practices leads to potential practical benefits for the protection of biodiversity and the promotion of sustainable use of Earth's natural assets. The last decade has seen the rapid development of research efforts on the topic of RS for ES (especially, in the context of spatially explicit RS and valuation of ES), which has led to a significant increase in the number of scientific publications. Remote sensing can be used for ecosystem service assessment in three different ways: direct monitoring, indirect monitoring, and combined use with ecosystem models. Some plant and water related ecosystem services can be directly monitored by remote sensing. Most commonly, remote sensing can provide surrogate information on plant and soil characteristics in an ecosystem. For ecosystem process related ecosystem services, remote sensing can help measure spatially explicit parameters. We conclude that acquiring good in-situ measurements and selecting appropriate remote sensor data in terms of resolution are critical for accurate assessment of ecosystem services. The assessment of ES is often limited by data, however, a gap with tremendous potential can be filled through Earth observations (EO), which produce a variety of data across spatial and temporal extents and resolutions. Despite widespread recognition of this potential, in practice few ecosystem service studies use EO. There are some challenges and opportunities to using EO in ecosystem service modelling and assessment which we can identify: • technical - related to data awareness, processing, and access (these challenges require systematic investment in model platforms and data management); • other challenges – more conceptual but still systemic; they are by-products of the structure of existing ecosystem service models and addressing them requires scientific investment in solutions and tools applicable to a wide range of models and approaches. As stated by a variety of research, more widespread use of EO for ecosystem service assessment will only be achieved if all of these types of challenges are addressed. This will require non-traditional funding and partnering opportunities from private and public agencies to promote data exploration, sharing, and archiving. Investing in this integration will be reflected in better and more accurate ES assessment worldwide.

	Remote sensing provides a useful data source that can monitor ecosystems over multiple spatial and temporal scales. Although the development and application of landscape indicators (vegetation indices, for example) derived from remote sensing data are comparatively advanced, it is acknowledged that a number of organisms and ecosystem processes are not detectable by remote sensing. The potential for applying remote sensing for analysis and mapping of ES efforts has not been fully realised due to concerns about ease-of-use and cost. Historically, RS data have not always been easy to find or use because of specialised search and order systems, unfamiliar file formats, large file size, and the need for expensive and complex analysis tools. That is gradually changing with increasing implementation of standards, web delivery services, and the proliferation of free and low-cost analysis tools. Although data cost used to be a common prohibitive factor, it is no longer a big stumbling block for most users except where high resolution commercial images are needed.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Indicator Metrics Reviews Env85_Applied and Env85_RS
Scale of measurement	**Applied methods:** See EO/RS below. **Earth observation / Remote sensing methods:** Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change at various geographical scales. However, the higher the resolution required, the more expensive would be RS data needed. In some cases, it would be better to use images provided by drones, but in this case permissions for survey mapping will be required and depends on the local and national / government regulations. Methods can be applied from small to large geographical scales but are linked to the limitations of the data sources.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env85_Applied and Env85_RS
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env85_Applied and Env85_RS
Data collecti	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing

on frequency	metrics reviews in: Connecting Nature Indicator Metrics Reviews Env85_Applied and Env85_RS
Level of expertise required	**Applied methods**: See EO/RS below. **Earth observation / Remote sensing methods**: It is important to clarify the resources that are needed to carry out ecosystem services assessments, such as technical and human resources, and the time needed for certain analyses. The methods vary greatly depending on the required expertise, availability of the data and its coverage, available software, time, and financial costs. The most suitable approach will depend on the research questions which need to be addressed, whether the study will be an assessment, or if maps are also required. For mapping methods, the level of scale should be considered. The limitations are often set by the availability of the data. For small research areas more detailed data sources, or even opportunities to conduct field measurements, may be available. However, for larger studies Earth Observation products may offer a solution for areas of poor data coverage. In addition to scale, it is also important to pay attention to the purpose of which the assessment is aimed at: Which biophysical units can and should be used to gain information on ecosystem services? Do we want to know if sufficient ecosystem service potential is available, or do we wish to quantify the rate at which the ecosystem service is delivered? Also, do we wish to deliver spatially explicit information for the chosen locations? The most suitable methods should be identified and selected according to the answers to these questions. Using a mixture of remote sensing and field methods appears to deliver the best results (e.g Mikolajczak et al., 2015; Vihervaara et al., 2017). Yet, this requires ecologists and remote sensing experts to collaborate closely with the newest methods and capabilities.
Synergies with other indicators	In comparison to conventional sources of information on urban environment, remotely sensed data are inherently suited to provide information on urban land cover characteristics and ecosystem services provisioning, and their change over time, at various spatial and temporal scales. Synergies and trade-offs between the type and quantity of UGS and ES supply can also be identified e.g., cooling, carbon storage and air purification demonstrate synergies as these are primarily being supplied by the same UGS types. The method can reveal differences between neighbourhoods in terms of amount and type of ES supplied, and can highlight possible ES shortages in neighbourhoods.
Connection with SDGs	All SDGs except 5; Providing opportunities for employment; Providing opportunities for urban agriculture; Health & Wellbeing benefits; Links to environmental education; Potential co-benefit in relation to clean water; Potential co-benefit in relation to sustainable and clean energy; Opportunities associated with improved economic growth; Opportunities associated with green technologies; Social equality;

	Sustainable urban development; Sustainable consumption and production; Climate change adaptation; Potential co-benefits related to more sustainable water management; Potential positive impact on habitat; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods:** RS review includes community participation. **Earth observation / Remote sensing methods:** Participatory activities can be combined with remote sensing analysis into an integrated methodology to describe and explain land-cover changes and changes in ES provision caused by them. In doing so, semi-structured interviews, focus group discussions, transect walks and participatory mapping can be used to identify and assess priority ES. Local community members and experts can together discuss which (positive) impact (benefits) the implemented NBS will have on various ES for local, regional, national and international users. This participatory process can help to identify priority ES (e.g., air purification, carbon sequestration, water regulation, soil protection, landscape beauty, biodiversity, etc.). The approach will reveal if there any strong variations in the valuation of different ES between local people and experts who apply RS techniques, between genders and between different status and income classes in the local communities. Scientific evidence has demonstrated that participatory tools, combined with free-access satellite images and repeat photography are suitable approaches to engage local communities in discussions regarding ES and to map and prioritise ES values (Brown & Donovan, 2014; Brown et al., 2012).
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References	**Applied methods**: De Groot, R.S., Alkemade, R., Braat, L., Hein, L. and Willemen, L. (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological complexity, 7(3): 260-272. Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. Value of Nature to Canadians Study Taskforce (2017) Completing and Using Ecosystem Service Assessment for Decision-Making: An Interdisciplinary Toolkit for Managers and Analysts. Ottawa, ON: Federal, Provincial, and Territorial Governments of Canada. Watson, R., Albon, S., Aspinall, R., Austen, M., Bardgett, B., Bateman, I., Berry, P., Bird, W., Bradbury, R., Brown, C. and Bullock, J. (2011) UK National Ecosystem Assessment: understanding nature's value to society. Synthesis of key findings. UNEP-WCMC, Cambridge. **Earth observation / Remote sensing methods:** Andrew, M.E., M.A. Wulder, and T.A. Nelson. (2014). Potential contributions of remote sensing to ecosystem service assessments. Progress in Physical Geography. Vol. 38, No. 3, pp. 328-352. DOI. http://dx.doi.org\10.1177/0309133314528942

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8.2 Annual trend in vegetation cover in urban green infrastructure

Project Name: MAvES (Mapping, Assessment and Valuation of Ecosystems and their Services) (JRC-D3- Institutional project)

Author/s and affiliations: Grazia Zulian[1], Joachim Maes[1], Guido Ceccherini[2]

[1] European Commission Directorate-General Joint Research Centre Directorate D (D3 -Land Resources)
[2] European Commission Directorate-General Joint Research Centre Directorate D (D1 -Bio-Economy)

Greenest urban green infrastructure and long-term trend in green spaces pattern	Green Space Management
Description and justification	This indicator examines how and in which direction vegetation cover changes within the Urban Green Infrastructure. Trend detection in Normalized Difference Vegetation Index (NDVI) time series can help to identify and quantify recent changes in ecosystem properties.
Definition	Urban green spaces make an important contribution to the liveability of cities. This indicator examinehow green are urban green infrastructure using remote sensing data. 1- The greenest value per UGI is derived

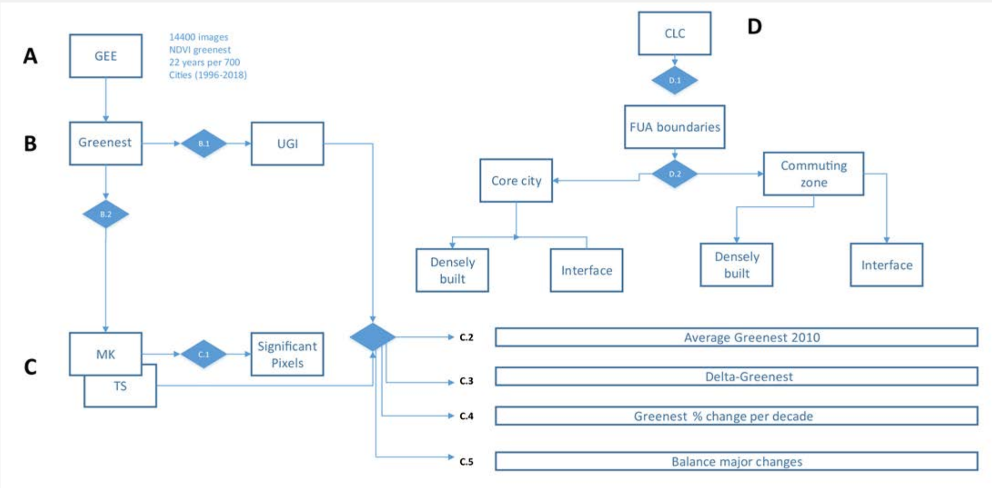
<table>
<tr><td></td><td>2- patterns of changes in the long-term. are reported as:
a. % of change per decade
b. Balance between greening and browning areas
Greenness and temporal trends were measured within core cities and within their commuting zones focusing on:
-Densely built-up areas where artificial areas cover > than the 60% of a 2.25 km2 neighborhood
-not densely built up areas where artificial areas are mixed with urban forest, seminatural vegetation or urban fringes</td></tr>
<tr><td>Strengths and weaknesses</td><td>-spatially explicit -> provides a detailed analysis of change in urban green infrastructure
-relatively complex</td></tr>
<tr><td>Measurement procedure and tool</td><td>Trend analysis employed non-parametric approaches, namely Theil–Sen regressions. The slopes of the regression approach were tested for their statistical significance using the p-value of the Mann–Kendall test for slopes (Forkel et al. 2013; Corbane et al. 2018; Novillo et al. 2019). Pixels for which the p-value (Mann–Kendall) was less than 0.1 (90% confidence interval) were extracted and considered to have a significant medium-term trend. We then applied the Theil–Shen regression to obtain the Theil–Sen positive or negative slopes of all significant NDVI trend pixels from 1996 to 2018.
From the Theil–Sen positive or negative slope we extracted the pixels that overlap areas where (at least once between 1996 and 2018) the highest-NDVI was greater than 0.4. In this way we could focus on changes which affected the urban green infrastructure, minimizing the impact of mixed pixels on the analysis (Dobbs et al. 2018).
Changes were reported for densely and not densely built up areas.

- Medium-term trend summary statistics
o Average value - Coefficient of variation - Minimum - Maximum
- Medium-term trend classes share (%)

Slope was reclassified in 5 classes representing key change thresholds:
<table>
<tr><td>≤-0.015 → hard browning</td><td rowspan="2">Downward trends (Browning) due to housing policies, development of industrial and commercial areas, new grey infrastructures</td></tr>
<tr><td>-0.015 < x ≤ -0.0001 → light browning</td></tr>
</table>
</td></tr>
</table>

-0.0001 < x ≤ 0.0001 → no changes	No changes
≤ 0.007 → light greening	Upward trend (Greening) due to green infrastructure management; vegetation growth; climate change

Percentage of pixels with significant positive and significant negative trends were used as accuracy indicator.



Scale of measurement	Functional Urban Areas (Core cities and Commuting Zone)
Data source	
Required data	- Landsat annual Top-of- INTERNATIONAL JOURNAL OF DIGITAL EARTH 3 Atmosphere (TOA) reflectance composites available as collections in the Google Earth Engine (GEE) platform for the period 1996–2018 - the model can be implemented using NDVI trend data Measurement Unit: - % [change in NDVI (greenest value) per decade] - Greening-Browning balance (difference between share of UGI where there has been a major upward and downward trend in vegetation cover)
Data input type	-raster (vector data will be rasterised)
Precision	30 m
Data collection frequency	Year or time-series range (for available data at EU scale): 1996–2018 (http://data.jrc.ec.europa.eu/collection/GHSL)
Level of expertise required	-GIS programmer (advanced)

Synergies with other indicators	- With structure of Urban green and Urban Forest - With recreation opportunities - With land suitability for pollinators
Connection with SDGs	//
Opportunities for participatory data collection	No
Additional information	
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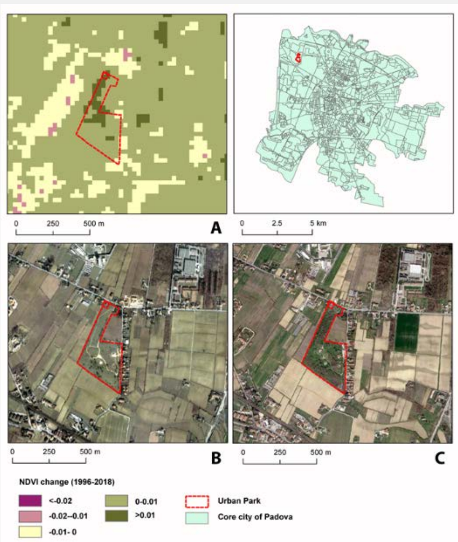
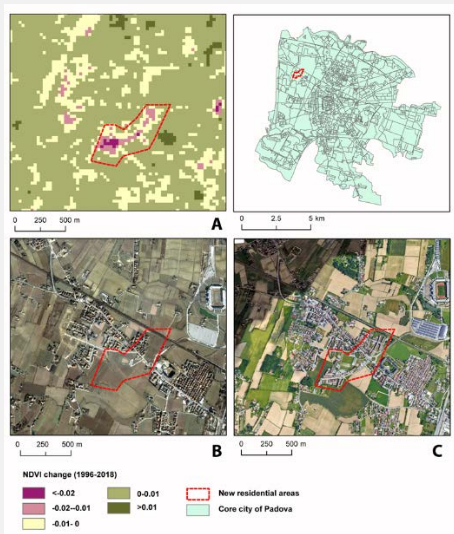
Zhu Z, Fu Y, Woodcock CE, Olofsson P, Vogelmann JE, Holden C, Wang M, Dai S, Yu Y (2016) Including land cover change in analysis of greenness trends using all available Landsat 5, 7, and 8 images: A case study from Guangzhou, China (2000–2014). Remote Sens Environ 185: 243–257. doi: 10.1016/j.rse.2016.03.036

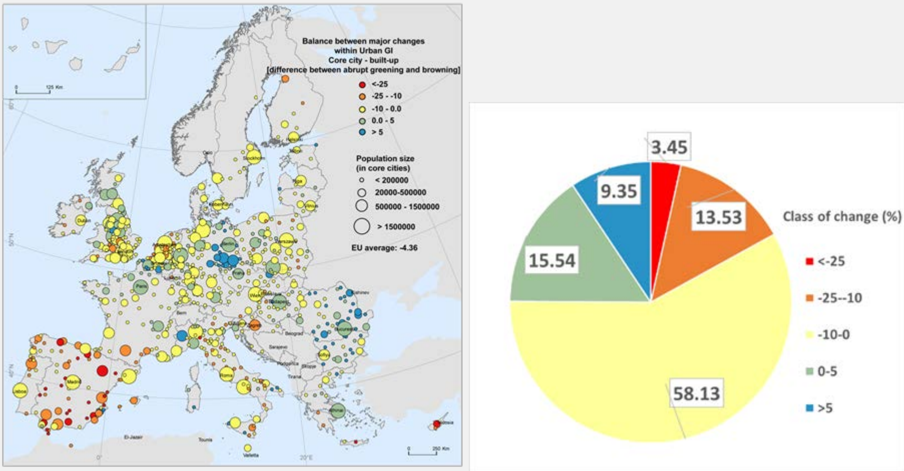
Below, left: Example of abrupt greening (upward trend) due to due to green infrastructure management in Padova core city - not densely built zone (Italy). A. represents the NDVI change between 1996-2018; B represents the park in 2001 and C represents the park in 2018.



Below, right: Example of abrupt browning (downward trend) due to housing policies in Padova core city - not densely built zone (Italy). A. represents the NDVI change between 1996-2018; B represents the area in 2001 and C represents the area with a new residential zone in 2018.



Balance between abrupt greening and browning changes within densely built areas in core cities and commuting zones. Pie charts show the proportion of reporting units per class of change (%).



8.3 Edge density

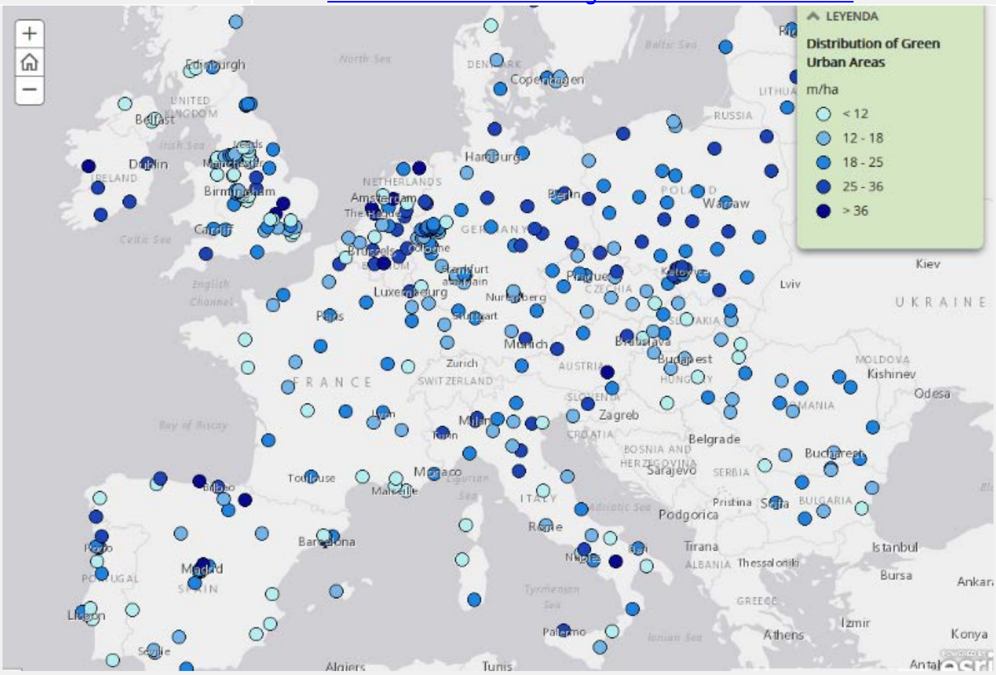
Project Name: Indicators for urban green infrastructure (EEA)

Author/s and affiliations: EEA, ETC/ULS

Edge density	**Green Space Management**
Description and justification	Within cities, green areas may not be equally distributed. An uneven distribution of GUAs prevents equal accessibility for all city dwellers, focuses benefits from exposure on fewer city elements (neighbourhoods, streets, buildings or houses) and prevents connectivity of all the available green spaces in the ecological network. The edge density provides an indication of the distribution of GUAs. A high edge density in a city indicates a relatively high number of green areas that border residential, commercial, and industrial or other public buildings. Consequently, a higher value for the indicator may be due to a long boundary length, i.e., more small patches. This measure provides a proxy for the equal or non-equal distribution of green urban areas in the city. Increasing the green area and distributing it more evenly is an effective measure in reducing the undesired effects of clustered urban green areas.

Definition	Relationship between green area boundaries (edges) and all the other elements present in the city. The total length of the edges is compared with the city's urban area (m/ha)
Strengths and weaknesses	Strength: proxy for equal/non-equal distribution of green urban areas and, hence, accessibility. Weaknesses: resolution of the data (minimum mapping unit 0.25 ha). Green linear elements are not currently included and may contribute to connect larger green areas.
Measurement procedure and tool	Green urban areas are based on several classes (11230, 11240, 14100, 14200, 20000, 30000) of the Urban Atlas data, which contain substantial green spaces (the two least dense residential classes with a sealing degree < 30 %, urban parks, sports and leisure facilities, forest, semi-natural and agriculture). It is computed for the core city as defined by Eurostat/Urban Audit. The indicator is based on the edge density metric. Length of the green urban area perimeter (in metres) is divided by the urban area (in hectares).
Scale of measurement	Minimum mapping unit 0,25 ha
Data source	
Required data	Urban Atlas (or any land use data set) Unit of measure: m/ha
Data input type	Data provided by Copernicus Land Monitoring Service with public access
Data collection frequency	Every 6 years. Currently available for 2006 and 2012. Date for 2018 is under production.
Level of expertise required	Land use and GIS knowledge
Synergies with other indicators	Share of green urban areas (EEA) Access to green areas in Europe (DG Regio)
Connection with SDGs	SDG-11 (Sustainable cities and communities), specifically target 11.7 (universal access to safe, inclusive and accessible, green and public spaces)
Opportunities for participatory data collection	
Additional information	
References	https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-green-infrastructure/indicators_for_urban-green-infrastructure

	https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-green-infrastructure/urban-green-infrastructure-1



8.3.1 Public green space distribution (applied and EO/RS)

Project Name: Connecting Nature

Author/s and affiliations: Connop, S.[1], Dushkova, D.[2], Haase, D.[2] and Nash, C[1].

[1] *Sustainability Research Institute, University of East London, UK*

[2] *Geography Department, Humboldt University of Berlin, Berlin, Germany*

Public greenspace distribution (Applied and EO/RS combined)	Green Space Management
Description and justification	Public greenspace in cities contributes to quality of life in terms of environmental services and social and psychological services. Public greenspace distribution can therefore be an important factor for making a city sustainable. Decisions on where to create greenspace/NBS should be based on criteria related to maximising the equitability of distribution, focusing on areas lacking greenspace and in areas where ES valuation identifies greatest benefit/need.

	Data on public greenspace distribution generated in these ways can be used to: • Quantify the benefits of a nature-based solution project in terms of improving the distribution of public greenspace; • Support the planning of new nature-based solution greenspace initiatives; • Underpin other indicators that require an understanding of greenspace distribution as a foundation (e.g., green space provision and availability).
Definition	Measure of the distribution of public greenspace (total surface or per capita) and categories (i.e., street trees, residential gardens, school green areas, parks) using more applied and participatory approaches as an index to increase quality/quantity of green/blue existing, restored and new NBS with a high degree of multifunctionality (informed by ES Valuation e.g., includes cultural ES value, needs of residents, socio-economics etc) and adapted to the type of urban area (e.g., size of urban area/landscape structure).
Strengths and weaknesses	**Applied methods:** Accuracy will be influenced by the resolution of satellite imagery and the complexity of metrics used to quantify distribution. Mapping combined with census data provides the most basic level data on distribution of greenspace in relation to population patterns. Using a more comprehensive range of metrics can provide greater evidence for supporting equality in urban greenspace distribution. **EO/RS methods:** data such as Lidar and high-resolution images are not easily accessible for many regions or users, due to the high costs of data acquisition and it is usually impractical to provide full coverage of extensive metropolitan areas, with limited data available over long periods. With the advantages of global availability, repetitive data acquisition, and long-term consistency, Landsat series satellites have become the best compromise to overcome these limitations
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects, refer to Connecting Nature Indicator Metrics Reviews Env23_Applied and Env23_RS.
Scale of measurement	**Applied methods:** Typically carried out over a city-scale but can be assessed at a local level also.

	EO/RS methods: Possible at various geographical scales
Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env23_Applied and Env23_RS.
Data input type	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env23_Applied and Env23_RS.
Data collection frequency	Data collection frequency will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env23_Applied and Env23_RS.
Level of expertise required	**Applied methods:** Expertise in relation to mapping and modelling will be necessary. Also expertise in leading participatory processes would be of value to maximise the quality of outputs. **EO/RS methods:** Selecting an applicable data source and the method to process data is a complicated process which needs expert knowledge. The assessment should be made by experts engaged in the NBS project who have expertise not only in RS, but also in urban planning, forestry, landscape ecology, regional planning. Each of them will then assess all built and land cover type combinations.
Synergies with other indicators	Synergies with other greenspace mapping indicators, and the data can be used as an index for other environmental and health/wellbeing indicators.
Connection with SDGs	SDG3, SDG4, SDG8, SDG9, SDG10, SDG11, SDG13, SDG14, SDG15, SDG16, SDG17: Access to greenspace; Environmental education; Job creation; Improved green infrastructure; Social equality in relation to flood risk; Sustainable urban development; Climate change adaptation; More sustainable water management; Habitat creation; Environmental Justice; Opportunities for collaborative working
Opportunities for participatory data collection	It may be possible to validate greenspace type and distribution using a PPGIS type citizen science exercise and/or workshops with stakeholder groups holding tacit knowledge.
Additional information	
References	**Applied methods:**

de la Barrera, F., Reyes-Paecke, S. and Banzhaf, E. (2016) Indicators for green spaces in contrasting urban settings. Ecological Indicators 62, 212-219.

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EO/RS methods:

Atiqul Haq SM. (2011) Urban green spaces and an integrative approach to sustainable environment. Journal of Environmental Protection.;2:601–608. 10.4236/jep.2011.25069

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Taylor BT, Fernando P, Bauman AE, Williamson A, Craig JC, Redman S. (2011) Measuring the quality of public open space using Google Earth. American Journal of Preventive Medicine.;40(2):105–112. 10.1016/j.amepre.2010.10.024

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8.5 Distribution of blue space

Project Name: Connecting Nature

Author/s and affiliations: Stuart Connop[1], D. Dushkova[2], D. Haase[2], C. Nash[1]

[1] *Sustainability Research Institute, University of East London, UK*

[2] *Geography Department, Humboldt University of Berlin, Berlin, Germany*

Bluespace area (Applied and EO/RS)	**Green Space Management**
Description and justification	Measuring bluespace change in urban areas can provide an index representing the degree of nature conservation, and improving public health and quality of life, as they are directly related to the natural water circulation, environmental purification and the green/blue network. More green and blue space also reduces vulnerability to extreme weather events like urban heat islands and flooding by heavy rainfall. Bluespace area can be used as an indicator of these environmental, social and economic benefits. In addition to ground-truthed mapping, in order to characterise urban blue infrastructure and assess changes of different bluespace types over varying time periods different remote sensing techniques and GIS can be used. The most common use of RS data is for the purpose of greenness identification. Many of these metrics are equally applicable to bluespaces. Data on bluespace area collected in these ways can be used to: • Quantify the distribution of bluespace across target areas; • Support the equitable distribution of bluespace through urban planning for environmental, social and economic benefits; • Provide underpinning data for other indicators such as ecosystem service mapping, stormwater management, biodiversity mapping, etc.
Definition	Measure change in blue space (ponds, rivers, lakes) in urban area (%, hectares or ha/100km) due to NbS based on more applied and participatory methods.
Strengths and weaknesses	**Applied methods:** Available greenspace datasets, for example in the UK, are pretty comprehensive and accurate, but there can be limitations for area i.e., >0.25ha depending on resources available. A weakness is it does

	not capture the quality/health of the green/bluespace which would influence ES benefits **Earth observation / Remote sensing methods:** Currently, there is a variety of research focused on mapping of UGS, based on remote sensing data including the mapping of bluespace. With the capacity to differentiate land cover (LC) types at a large scale, remote sensing has been widely used for vegetation mapping in various environments. Satellite imagery has been adopted for the monitoring of vegetation both in urban and rural areas. The techniques applied for this can generally be equally applicable for bluespace areas. As with greenspace mapping, strength of evidence is based on the scale of bluespace analysed compare to the resolution of the satellite data and confidence of identifying bluespace compared to surrounding infrastructure. However, with suitable data, strong evidence can be provided.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Indicator Metrics Reviews Env56_Applied and Env56_RS
Scale of measurement	**Applied methods:** City-scale typically, but may be possible to use the data to monitor local-level changes in greenspace. **Earth observation / Remote sensing methods:** Remote sensing and geographic information system (GIS) provide powerful tools for mapping and analysis of UGS at various spatial and temporal scales.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env56_Applied and Env56_RS
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env56_Applied and Env56_RS
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env56_Applied and Env56_RS

Level of expertise required	**Applied methods**: Accessing the public datasets should be straightforward but likely some expertise in GIS is needed, particularly for more comprehensive ILM methodology. **Earth observation / Remote sensing methods**: Experience of working with large datasets related to remotely sensed, climatic and environmental parameters as well as their statistical analysis using tools is important. Knowledge of GIS techniques such as multi-criteria evaluation and sensitivity analysis are also desirable. Knowledge of ecosystem services is required and experience of their quantitative and/or spatial assessment is advantageous.
Synergies with other indicators	Synergies with other greenspace mapping indicators, and the data can be used as an index for other environmental and health/wellbeing indicators.
Connection with SDGs	All SDGs except 1 and 5: Fishing opportunities; Health & Wellbeing benefits; Links to environmental education; Clean water benefits; Hydro-electric opportunities; Job creation; Improved blue infrastructure; Social equality in relation to bluespace; Sustainable urban development; Responible use of water; Climate change adaptation; More sustainable water management; Associated terrestrial habitat benefits; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods:** If used, public perception questionnaires would be the main participatory process. **Earth observation / Remote sensing methods:** The accuracy of the resulting classification derived from the RS can be improved by incorporating digitised landscape and environmental data available from local environmental NGOs (e.g., City of Trees etc.) or community groups, which served principally to correct misclassification. Similarly, participatory approaches can also be vital to supplement quantity of bluespace data with quality assessments.
Additional information	
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8.6 Effective green infrastructure in the urban-rural interface

Project Name: Indicators for urban green infrastructure (EEA)

Author/s and affiliations: EEA, ETC/ULS

Effective green infrastructure in the urban-rural interface	Green Space Management
Description and justification	Green infrastructure at the fringes of cities performs similar ecosystem services to that in inner urban areas, though direct benefits from urban-rural interactions are highlighted. Green spaces in the peri-urban area may improve air quality and mitigate climate change. A well-connected network of green elements, which form ventilation channels, facilitates the circulation of fresher and cleaner air from the periphery into the city. The vegetated ventilation network may reduce traffic emissions, mitigate noise and provide a cooling effect. Open areas at the urban fringe may favour species richness. These natural and semi-natural areas generally host a diversity of landscapes, as they are dynamic locations surrounded by a variety of land uses. Moreover, GI elements may be used to join urban areas with the neighbouring countryside. This improved connectivity may support the functioning of ecosystems, both urban and rural, mitigating the negative affects of the built environment. Moreover, the urban-rural interface forms a vital recreational and cultural pool for urban society that is equally connected to nature and the countryside.
Definition	Percentage of potential green infrastructure on the peri-urban area.
Strengths and weaknesses	Strength: Weaknesses: resolution of the data (minimum mapping unit 25 ha).
Measurement procedure and tool	The delineation of potential green infrastructure in the peri-urban area is based on a proximity analysis of selected Corine land cover classes associated with green infrastructure (EEA, 2006; EEA, 2014). The proximity analysis follows the Corilis methodology (EEA, 2006). This method uses the gridded structure of the data to measure the potential or influence of a given land cover type in the area around the place where it is found, using a weighting distance function. The approach assumes that the influence of a given land parcel on its surroundings declines with increasing distance. Thus, the methods can be used to produce scaled maps with cell values ranging

	from from 0 to 100 to show the degree of influence that the distribution of a stock of a given cover type has on its neighbourhood. Intensity maps are generated after weighting values of neighbouring cells. In order to be as restrictive as possible, the spatial smoothing is applied to a radius of 1 km, which means that all neighbouring green infrastructure elements within a distance of 1 km will be considered to influencing on each point of the territory. Several previous tests revealed that the selected threshold to represent the green potentiality is to be set on a minimum of 70%.
Scale of measurement	Minimum mapping unit 25 ha **Note:** the indicator is now based on the 25 ha MMU Corine Land Cover dataset. In 2020, the Copernicus Urban Atlas data will be used and hence the MMU will improve to 0.25 ha.
Data source	
Required data	Corine Land Cover
Data input type	Data provided by Copernicus Land Monitoring Service with public access
Data collection frequency	Every 6 years (2000, 2006, 2012, 2018).
Level of expertise required	Geospatial analysis. Thematic knowledge on green infrastructure and urban environment.
Synergies with other indicators	Share of green urban areas (EEA) Access to green areas in Europe (DG Regio)
Connection with SDGs	SDG-11 (Sustainable cities and communities), specifically target 11.7 (universal access to safe, inclusive and accessible, green and public spaces)
Opportunities for participatory data collection	
Additional information	
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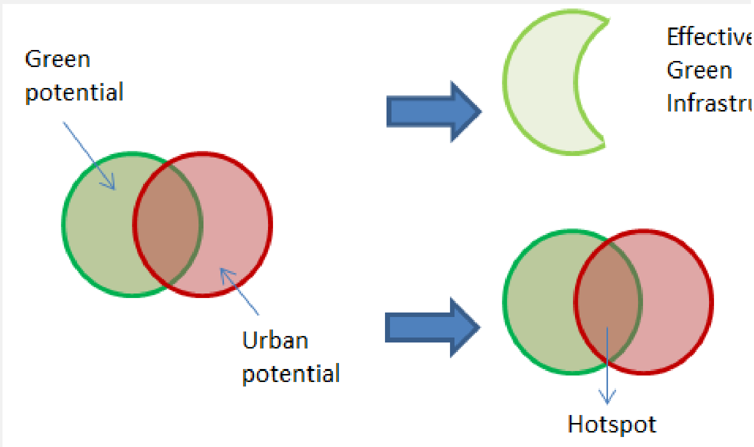
	https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-green-infrastructure/indicators_for_urban-green-infrastructure https://eea.maps.arcgis.com/apps/MapSeries/index.html?appid=42bf8cc04ebd49908534efde04c4eec8%20&embed=true

8.7 Hot spot in peri-urban green infrastructure

Project Name: Indicators for urban green infrastructure (EEA)

Author/s and affiliations: EEA, ETC/ULS

Hot spot in peri-urban green infrastructure	Green Space Management
Description and justification	The urban-rural interface, the area where a city or town meets the countryside, has no clear delineation due to the permeability of its boundaries. It is a dynamic and highly diverse region, where development processes and changes occur at different spatial and temporal scales. The urban fringe is characterised by the trade-off of land uses and the compensation of derived impacts. Here, a strong competition for land use takes place and, accordingly, potential conflicts of interest may arise among a variety of end-users. However, it also presents an opportunity for greening and for connecting existing green spaces to build a solid and functional natural network. The hotspot identifies those areas where the influence of green spaces and the impact of artificial elements overlap. This indicator provides information about the amount and location of areas where potential conflicts may exist or, from a positive perspective, where management actions present major opportunities for enhancement. On the one hand, high hotspot values may be due to the negative effects of the encroachment of artificial areas into green landscapes and the related loss of ecosystem services and functions. On the other hand, it may represent an opportunity to use green spaces to alleviate the urban heat island effect or to clean up pollution.
Definition	The hotspot ratio is the percentage of potential GI in peri-urban areas, strongly influenced by the proximity of built-up areas. Potential and a considerable urban effect coincide.
Strengths and weaknesses	Strength: Weaknesses: resolution of the data (minimum mapping unit 25 ha).

Measurement procedure and tool	The indicator is based upon two metrics: a) the delineation of NBS, and b) the potential area of influence of built-up areas. Delineation of NBS in the peri-urban area is described in the factsheet Effective GI. The potential area of influence of built-up is calculated by selecting the Corine Land Cover classes 1.1, 1.2 and 1.3. Then, Corilis methodology is applied (EEA, 2006), which results in intensity maps after weighting values of neighbouring cells. Therefore, the outcome is a map of probability for the presence of built-up areas (varying from 0 to 100). The hot spot is the intersection of areas with a minimum value of 50% for the green potential and 25% for the urban. 
Scale of measurement	Minimum mapping unit 25 ha **Note:** the indicator is now based on the 25 ha MMU Corine Land Cover dataset. In 2020, the Copernicus Urban Atlas data will be used and hence the MMU will improve to 0.25 ha.
Data source	
Required data	Corine Land Cover
Data input type	Data provided by Copernicus Land Monitoring Service with public access
Data collection frequency	Every 6 years (2000, 2006, 2012, 2018).
Level of expertise required	Geospatial analysis. Thematic knowledge on green infrastructure and urban environment.

Synergies with other indicators	Share of green urban areas (EEA) Access to green areas in Europe (DG Regio) Effective GI in peri-urban areas (EEA)
Connection with SDGs	SDG-11 (Sustainable cities and communities), specifically target 11.7 (universal access to safe, inclusive and accessible, green and public spaces)
Opportunities for participatory data collection	
Additional information	
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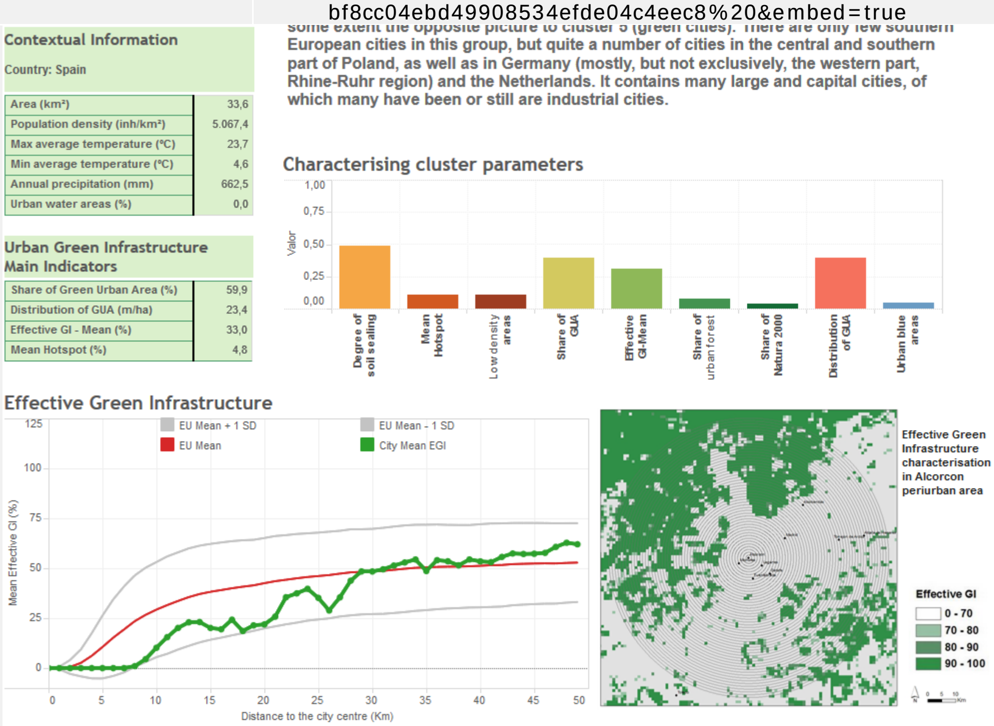

8.8 Biotope Area Factor

Project Name: Nature4Cities

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Biotope Area Factor	Green Space Management
Description and justification	The BAF is calculated by dividing the amount of surface area available for nature and vegetation by the total surface area considered. Each type of soil/ ground cover/ land use is affected a coefficient related to its potential for vegetation growth & nature implementation (e.g., sealed surface = 0; semi-permeable = 0.3; green wall = 0.5; green roof = 0.7; in-ground plantations = 1).
Definition	Thresholds and goals can then be determined based on the expected performance or current land use / urban planning objectives (e.g., the City of Berlin expects BAF to be produced for each new project – the result must be between 0.3 and 0.6, depending of the project's nature). The BAF takes values between 0 and 1. It increases with in-ground planted areas (Nature4Cities, D2.1). The literature shows a dozen of different ground cover typologies, each with different coefficients (Casella et al., 2016; Dizdaroglu et al., 2009; Farrugia et al., 2013; Hirst et al., 2008; Huang et al., 2015; Kazmierczak et al., 2010; Kruuse, 2011; Lakes et al., 2012; SenStadtUm, 2009; Vartholomaios et al., 2013). Based on those examples, a new BAF version was proposed for Nature4Cities, based on the literature, partners' inputs and considering the projects goals (Nature4Cities, D2.4). The Nature4Cities BAF takes values between 0 and 1.7. A score of 0 means that the whole area is sealed. A score of 1 means that the whole area is vegetated, and that vegetation substrate is the natural soil or connected to it. A score superior to 1 indicates that different woody stratum is present, enhancing the ecological interest of the area in an urban setting. For this indicator, outputs can be both map-like and numerical. For the simplified assessment, that outputs will be numerical only.
Strengths and weaknesses	This indicator is interesting : • To describe / maximize the amount of surface area available for greening / planting • To set goals or thresholds relative to expected performances, local urban planning rules, soil preservation, local offer in nature / open space / green space It is capable to describe initial planning problems, like e.g., green / grey ratio ; proportion of artificialized area, etc.
Measurement procedure and tool	MEASUREMENT UNIT: % GIS analysis $\text{BAF} = \dfrac{\text{ecologically-effective surface areas}}{\text{total land area}}$

	This indicator calculation is integrated in the Nature4Cities platform.
Scale of measure ment	☒ Neighbourhood/catchment ☒ Object
Data source	• Geodatabase of land use / land cover Parameters with BAF coefficients
Required data	• Land use map • Ground cover / surface materials
Data input type	• surface area
Data collection frequency	• Once, during conception, to characterize the project • Before / after the project's implementation, to characterize it is effects on the local environment
Level of expertise required	Easy to calculate but requires data. The uncertainty of the result resides in the accuracy of the surface area measures.
Synergies with other indicators	
Connectio n with SDGs	SDG 13 Climate action, SDG 15 Life on land
Opportuni ties for participat ory data collection	
Additional information	
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Nature4Cities, D2.2 - Expert-modelling toolbox

Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies

Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

8.9 Total vegetation cover

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Total Vegetation Cover	**Green Space Management**
Description and justification	Indicators of Structural Diversity sub-criterion will assess the vegetation structural diversity in order to characterize the soil cover. Maintaining a permanent soil cover is important in conservation agriculture, it protects the top soil from soil erosion, maintains soil moisture, smothers weeds and aids in nutrient cycling.
Definition	Soil covered by assemblage of plant species and the ground, without specific reference to particular taxa, life forms, structure, spatial extent, or any other specific botanical or geographic characteristics.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Project Data Unit of Measure: %
Scale of measurement	
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3; 13
Opportunities for participatory data collection	
Additional information	

References	

8.9.1 *Woody vegetation cover*

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Woody Vegetation Cover	Green Space Management
Description and justification	Indicators of Structural Diversity sub-criterion will assess the vegetation structural diversity in order to assess the soil cover. Maintaining a permanent soil cover is important in conservation agriculture, it protects the top soil from soil erosion, maintains soil moisture, smothers weeds and aids in nutrient cycling.
Definition	Soil covered by trees, bushes and shrubs.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Project Data Units of measure: %
Scale of measurement	%
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3; 13

Opportunities for participatory data collection	
Additional information	
References	

8.9.2 *Non-woody vegetation cover*

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Non Woody Vegetation Cover	Green Space Management
Description and justification	Indicators of Structural Diversity sub-criterion will assess the vegetation structural diversity in order to assess the soil cover. Maintaining a permanent soil cover is important in conservation agriculture, it protects the top soil from soil erosion, maintains soil moisture, smothers weeds and aids in nutrient cycling.
Definition	Soil covered by non woody and herbaceous plants.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Project Data Unit of measure: %
Scale of measurement	
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium

Synergies with other indicators	
Connection with SDGs	3; 13
Opportunities for participatory data collection	
Additional information	
References	

8.9.3 Total Leaf Area

Project Name: Nature4Cities (Grant Agreement no. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

[1] *Green4Cities GmbH/GREENPASS GmbH*

Leaf Area (LA)	**Green Space Management** **Climate Resilience** **Air Quality**
Description and justification	The LA (Leaf Area) is a Key Performance Indicator of the GREENPASS® system. It expresses the sum of leaf area of NBS within project area. The Leaf Area is the operating surface of NBS and therefore decisive for climate regulation, carbon storage and air purification.
Definition	The LA (Leaf Area) describes the total amount of leaf area of all NBS in a project area.
Strengths and weaknesses	+ key performance indicator regarding biodiversity + easy for communication, understanding and decision-making + useful for design optimization + link the NBS performance to a single number - needs area analysis and calculation
Measurement procedure and tool	- NBS analysis of an area and calculation (eg with GREENPASS® system and tools) - numerical value in m^2
Scale of measurement	Object, neighbourhood and city scale
Data source	
Required data	- project area - NBS typologies and areas

Data input type	- numerical analysis of vegetation types incl. characteristics (eg LAI)
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy to understand – for planners and decision makers
Synergies with other indicators	-
Connection with SDGs	SDG 11 Sustainable Cities and Communities, SDG 13 Climate action
Opportunities for participatory data collection	-
Additional information	
References	Kraus, F.; Scharf, B. (2019): Management of urban climate adaptation with NBS and GREENPASS®. Geophysical Research Abstracts. Vol. 21, EGU2019-16221-1, 2019 EGU General Assembly 2019. Kraus, F.; Scharf, B. (2019): Climate-resilient urban planning and architecture with GREENPASS illustrated by the case study 'FLAIR in the City' in Vienna. OP Conf. Ser.: Earth Environ. Sci. 323 012087. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

8.10 Diversity of green space

Project Name: Nature4Cities (Grant Agreement no. 730468)

Author/s and affiliations: Flora Szkordilisz[1], Federico Silvestri[2], Barnabás Körmöndi[1]

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Shannon Diversity Index of Habitats	**Biodiversity Green Space Management**
Description and justification	This indicator is defined as the simple ratio of the natural areas (An) per the total area (Ac). The objective is to determine if the NBS solution increases or maintains the proportion of areas supporting biodiversity in the city or neighbourhood.
Definition	Indicates the proportion of bare turf and sparse vegetation, grassland and herbs, shrubs, trees and of built environment to the total area.
Strengths and weaknesses	+ standardizable, which makes the comparison with other cities easier
Measurement procedure and tool	- spreadsheet methods - or GIS-based models (spatial resolution of 1 meter) - calculation method: $D = -\sum_{i=1}^{5} (p_i \log_2 p_i)$ Where pi corresponds to the proportion of each of the five kind of habitat
Scale of measurement	Object and neighbourhood scale
Data source	
Required data	- Proportion of each class of habitat
Data input type	quantitative
Data collection frequency	Before and after the NBS implementation
Level of expertise required	It is relatively easy to calculate, but field data is required.
Synergies with other indicators	Shannon Index and Biotope Area Factor are also based on landcover data and assess the vegetation coverage and their quantities comparing to the total surveyed area.
Connection with SDGs	SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	-

Additional information	
References	Cornelis, Johnny, and Martin Hermy. "Biodiversity Relationships in Urban and Suburban Parks in Flanders." Landscape and Urban Planning 69, no. 4 (October 30, 2004): 385–401. doi:10.1016/j.landurbplan.2003.10.038. Nagendra, H. (2002). Opposite trends in response for the Shannon and Simpson indices of landscape diversity. Applied Geography, 22(2), 175-186. Whitford, V., A. R. Ennos, and J. F. Handley. "'City Form and Natural Process'—indicators for the Ecological Performance of Urban Areas and Their Application to Merseyside, UK." Landscape and Urban Planning 57, no. 2 (November 20, 2001): 91–103. doi:10.1016/S0169-2046(01)00192-X Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. -Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

8.11 Stages of forest stand development -Number of class diameter

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Number of Class Diameter	Green Space Management
Description and justification	Indicators of Stages of Forest Stand Development sub-criterion will assess the forest stand stages development.
Definition	A classification of trees based on diameter outside bark, measured at breast height 4.5 feet (DBH) (1.37 m) above the ground or at root collar (DRC). Diameter classes are

	commonly in 2-inch (5 cm) increments, beginning with 2-inches (5 cm). Each class provides a range of values with the class name being the approximate mid-point. For example, the 6-inch class (15-cm class) includes trees 5.0 through 6.9 inches (12.7 cm through 17.5 cm) DBH, inclusive.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Sampling/Model
Scale of measurement	Unit of measure: number of individuals (unitless)
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	15
Opportunities for participatory data collection	
Additional information	
References	https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp

8.12 Tree regeneration

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

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Tree Regeneration	Green Space Management
Description and justification	Indicators of Stages of Forest Stand Development sub-criterion will assess the forest stand stages development.
Definition	Forest regeneration is the act of renewing tree cover by establishing young trees naturally or artificially-generally, promptly after the previous stand or forest has been removed.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Sampling/Model
Scale of measurement	no.
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	15
Opportunities for participatory data collection	
Additional information	
References	http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=235

8.13 Canopy gaps

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

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Canopy Gaps	Green Space Management
Description and justification	Indicators of Stages of Forest Stand Development sub-criterion will assess the forest stand stages development.
Definition	A space occurring in the general forest crown cover caused by the fall or death of one or more trees forming it.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Sampling/Model
Scale of measurement	Dichotomic (Yes/No)
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	15
Opportunities for participatory data collection	
Additional information	
References	https://definedterm.com/canopy_gap

8.14 Tree biomass stock change

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Tree Biomass Stock Change	**Green Space Management**
Description and justification	Indicators of Aboveground C Cycle sub-criterion will assess the forest carbon storage and sequestration.
Definition	Several studies analysed carbon stocks in forest ecosystems using forest inventory data (Cannell et al., 1992; Kauppi et al., 1992), using data directly from national inventories (e.g., Baritz & Strich, 2000), or from data reported to the FAO, which are originally based on national inventories. At regional and larger scales, changes in carbon stocks are commonly assessed by comparing the stocks from several inventories over time (Wutzler et al., 2011).
Strengths and weaknesses	
Measurement procedure and tool	Survey/GIS
Scale of measurement	ton/ha/year
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Connection with SDGs	13

Opportunities for participatory data collection	
Additional information	
References	Cannell M., Dewar R., Thornley J. (1992). Carbon flux and storage in European forests. Responses of Forest Ecosystems to Environmental Changes, 256–271. DOI: 10.1007/978-94-011-2866-7_23 Kauppi P.E., Mielikäinen K., Kuusela K. (1992). Biomass and carbon budget of European forests, 1971 to 1990. Science 256(5053): 70–74. DOI: 10.1126/science.256.5053.70 Baritz R., Strich S. (2000). Forests and the national greenhouse gas inventory of Germany. Biotechnology, Agronomy, Society and Environment, 4, 267–271. Wutzler T., Profft I., Mund M. (2011). Quantifying tree biomass carbon stocks, their changes and uncertainties using routine stand taxation inventory data. Silva Fennica, 45(3), 359–377. DOI: 10.14214/sf.449

8.15 Soil carbon content

8.15.1 Measured soil carbon content

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Total carbon storage and sequestration in soil per unit area per unit time	**Climate Resilience Green Space Management**
Description and justification	Accounting for C stored in soil and vegetation in an urban area can provide an indication of the condition of natural green spaces, total free surface area and total quantity of vegetation in the area examined. Measures of C storage and sequestration also provide a tangible connection to climate change mitigation, and the impacts of local land use, planning and management decision-making. It is important to note the substantial variation in C sequestration and storage capacity of different types of NBS.

Definition	Total amount of carbon (tonnes) stored in soil per unit area and unit time (e.g., t/ha/y)
Strengths and weaknesses	+ Physical sampling and laboratory analysis of soil C yields accurate information, with improved accuracy of estimated C storage in soil with increasing sampling intensity + Combustion-based analytical methods are relatively simple and widely applicable - Small changes in soil C may be difficult to quantify in carbonate-rich soils, in which case multiple analytical steps may be required to obtain reliable measurements - Soil sample collection is relatively labour-intensive; analyses typically require an external laboratory (rather than analysed in-house)
Measurement procedure and tool	The most reliable and accurate method of determining soil C content is field sampling followed by laboratory analysis. Combustion is an accurate, commonly used analytical technique to quantify total C in soil – including both organic and inorganic soil C. Combustion analysis involves converting all forms of C in the soil to CO_2 by wet or dry combustion, then measuring evolved CO_2. Change in soil C content occurs most readily in the SOC fraction, so observed changes in total soil C content with time are most likely to represent changes to SOC content. Sampling is performed using a measuring tape (for establishment of sampling transect or grid), soil corer, and plastic bags. It may be challenging to detect small changes in soil C content in soils that contain substantial inorganic (mineral) C. A rapid field test of the soil's reactivity to acid can indicate whether it may be necessary to undertake more intensive analyses of soil samples to quantify both the organic and inorganic C fractions, rather than total (inorganic + organic) C by combustion. Rapid assessment of soil carbonate content involves reacting a small sample (ca. 1 g) of soil with 1-2 drops of 1 M hydrochloric acid (HCl) in a glass or porcelain container and observing the reaction for ~5 min. The reaction between soil carbonate minerals and HCl is visible as bubbles/effervescence as bubbles of CO_2 are produced. If the HCl 'field test' indicates the presence of inorganic C then the soil sample should be pre-treated to remove inorganic C prior to determination of organic C content by wet digestion. A sample of the carbonate-containing soil should be treated at room with a mixture of dilute sulphuric acid (H_2SO_4) and ferrous sulphate ($FeSO_4$) for at least 20 min or until effervescence appears to cease. The flask containing the soil and H_2SO_4/$FeSO_4$ mixture should then

	be heated over a flame and boiled slowly for 1.5 min to destroy any remaining carbonate. Finally, pulverised potassium dichromate ($K_2Cr_2O_7$) should be added to the mixture and organic C determined by chromic acid digestion (wet combustion) (Nelson & Sommers, 1996).
Scale of measurement	Plot scale; it is possible to extrapolate results from small number of field samples based on soil maps to approximate soil C storage at landscape (regional) scale
Data source	
Required data	Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3; can be measured or estimated based on soil type). Obtainable from local municipality, department of environment, geological survey.
Data input type	Quantitative
Data collection frequency	Annually, including at a minimum measurement before and after NBS implementation
Level of expertise required	Low to Moderate – field sampling Moderate – combustion analysis in laboratory conditions High – soil sample pre-treatment for determination of organic C content
Synergies with other indicators	Used for evaluating C storage necessary for *Carbon removed or stored per unit area per unit time* indicator
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection is feasible through soil sample collection
Additional information	
References	Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc. Rowell, D.L. (2014). *Soil Science: Methods & Applications*. New York: Routledge. Soil Survey Staff. (2009). *Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt (Ed.).* Lincoln, NE: United States Department of Agriculture, Natural Resources Conservation Service.

8.15.2 Modelled carbon content of the upper soil layer

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Modelled carbon content of the upper soil layer	**Climate Resilience** **Green Space Management**
Description and justification	Indicators of Carbon Sequestration in Soil sub-criterion will assess the carbon sequestration in soil.
Definition	In soils and sediments, there are three basic forms of carbon that may be present: elemental, inorganic, and organic C. The quality of organic matter in sediments is critical to the partitioning and bioavailability of sediment-associated contaminants. Elemental carbon forms include charcoal, soot, graphite, and coal. The primary sources for elemental carbon in soils and sediments are as incomplete combustion products of organic matter (i.e., charcoal, graphite, and soot), from geologic sources (i.e., graphite and coal), or dispersion of these carbon forms during mining, processing, or combustion of these materials. Inorganic carbon forms are derived from geologic or soil parent material sources. Inorganic carbon forms are present in soils and sediments typically as carbonates. Naturally-occurring organic carbon forms are derived from the decomposition of plants and animals. In soils and sediments, a wide variety of organic carbon forms are present and range from freshly deposited litter (e.g., leaves, twigs, branches) to highly decomposed forms such as humus. In addition to the naturally-occurring organic carbon sources are sources that are derived as a result of contamination through anthropogenic activities.
Strengths and weaknesses	
Measurement procedure and tool	Model/Sampling/Survey
Scale of measurement	ton/ha
Data source	

Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	-
Additional information	
References	http://webcache.googleusercontent.com/search?q=cache:http://bcodata.whoi.edu/LaurentianGreatLakes_Chemistry/bs116.pdf

8.15.3 Soil carbon to nitrogen ratio

Project Name: UNaLab (Grant Agreement no. 730052)

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Soil carbon to nitrogen ratio (C/N)	**Climate Resilience** **Green Space Management**
Description and justification	The respective quantities of carbon and nitrogen in soil is critical to soil microbial activity and a fundamental indicator of biogeochemical cycling in ecosystems. Changes to soil C/N ratio impacts nutrient cycling in soils and the structure and function of plant communities, thereby affecting ecosystem service functions. Soils with higher C/N ratio are better able to buffer soil and water N pollution, because soils with greater C/N ratio generally exhibit slower rates of N mineralisation and nitrification, and greater capacity for N immobilisation (Groffman et al., 2006). The accumulation of C and N in urban green space soils is determined both by the length of time following urbanisation that an area is managed as a green space and the structural composition of green space vegetation. Factors such as the presence of

trees, an understory, and surface litter are key to soil C and N accumulation. Urban green space soils under tree canopies have been shown to have significantly greater soil C and N content and higher C/N ratios compared with grassed areas (Livesley et al., 2015). Planting and placement of trees within urban green spaces should facilitate accumulation of understory vegetation and litter to promote high C/N ratios and C and N storage in soils.

Soil microorganisms require C and N in a ratio of about 24:1 to support metabolic processes (USDA-NRCS, 2011). The majority of N in soil is present in organic form. Organic N is mineralised to ammonium (NH_4^+) via organic matter breakdown, then, under oxygenated conditions, oxidised to nitrate (NO_3^-). Plants are able to take up both NH_4^+ and NO_3^-, with some evidence for direct plant uptake of organic N, particularly in N-limited environments. Microbiological uptake of all forms of N is called immobilisation because the N is taken up or ‘immobilised’ in microbial biomass. Nitrogen mineralisation/ immobilisation reactions in soil are dependent upon the total N content and the C/N ratio. If decomposing organic material contains more N than microorganisms need for cell growth (i.e., where C/N < 24:1), surplus nitrogen is excreted as NH_4^+. Conversely, if decomposing organic materials contain less N than required by soil microorganisms for cell growth (i.e., C/N >24:1), the soil microorganisms must acquire additional N from the soil. In the longer term, this can lead to reduced soil fertility due to a deficit of N.

Management of urban landscapes can disrupt C and nutrient cycling through irrigation, litter removal, fertiliser or mulch addition, or other practices. Studies have shown that soil C/N ratios of urban green spaces increase with time since green space establishment, or with the duration of altered management intensity (Golubiewski, 2006; Livesley et al., 2015). Understanding the C/N ratio can promote C storage whilst maintaining adequate soil fertility, as well as management of soil N to minimise leaching of nitrate (NO_3^-) to local waterbodies and/or gaseous losses (i.e., as N_2, N_2O, NO, NH_3).

Nitrogen accumulates in soil through fixation of atmospheric N to organic forms. Soil organic matter is typically 5-6% N, so N levels in soil closely follow soil organic matter content. The N content of soil parent materials is low because N does not form stable minerals. Soil N pools:

- Gaseous: N_2, N_2O, NO, NH_3
- Mineral N: NH_4^+, NO_2^-, NO_3^- (<2% of total N but very important)

	• Fixed N: NH_4^+ trapped in vermiculite-like clays (4-8% of total N) • Organic N: 80-95% of total soil N, needs to be mineralised prior to biological uptake Soil N moves between pools via a series of reactions. Soil organic matter is mineralised to form ammonium (NH_4^+). In the presence of oxygen, the NH_4^+ undergoes nitrification to form nitrate (NO_3^-). Both NH_4^+ and NO_3^- are forms of N available for plant and microbial uptake. Excess NH_4^+ in soil may be bound to soil clay minerals. If not taken up by plants or microorganisms, soil nitrate (NO_3^-) may be lost from the system by leaching to local waterways or through volatilisation as N2, N_2O, NO or NH_3 gas.
Definition	The ratio between the total mass of carbon and the total mass of nitrogen in soil
Strengths and weaknesses	+ Physical sampling and laboratory analysis of soil C and N yields accurate information, with improved accuracy of estimated C and N content of soil with increasing sampling intensity + Combustion-based analytical methods are relatively simple and widely applicable - Small changes in soil C may be difficult to quantify in carbonate-rich soils, in which case multiple analytical steps may be required to obtain reliable measurements - Soil sample collection is relatively labour-intensive; analyses typically require an external laboratory (rather than analysed in-house)
Measurement procedure and tool	The most reliable and accurate method of determining soil C and N content is field sampling followed by laboratory analysis. Sampling is performed using a measuring tape (for establishment of sampling transect or grid), soil corer, and plastic bags. Soil cores should be taken to a depth of at least 0.3 m, and up to 1.0 m depth depending on the rooting depth of local vegetation. Combustion is an accurate, commonly used analytical technique to quantify C and N in soil. A carbon-nitrogen combustion analyser can provide measures of total carbon, total organic carbon and total inorganic carbon (after sample acidification), total nitrogen, and C/N ratio.
Scale of measurement	Plot scale
Data source	
Required data	Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3; can be measured or estimated based on

	soil type). Obtainable from local municipality, department of environment, geological survey.
Data input type	Quantitative
Data collection frequency	Annually, including at a minimum measurement before and after NBS implementation
Level of expertise required	Low to Moderate – field sampling Moderate – combustion analysis in laboratory conditions High – soil sample pre-treatment for determination of organic C content
Synergies with other indicators	Similar method used to determine *Carbon removed or stored per unit area per unit time* indicator
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection is feasible through soil sample collection
Additional information	
References	Bremner, J.M. (1996). Nitrogen – total. In In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc. Golubiewski, N.E. (2006). Urbanization increases grassland carbon pools: Effects of landscaping in Colorado's Front Range. *Ecological Applications*, 16(2), 555-571. Groffman, P.M., Pouyat, R.V., Cadenasso, M.L., Zipperer, W.C., Szlavecz, K., Yesilonis, I.D., Band, L.E. & Brush, G.S. (2006). Land use context and natural soil controls on plant community composition and soil nitrogen and carbon dynamics in urban and rural forests. *Forest Ecology and Management*, 236(2-3), 177-192. Livesley, S.J., Ossala, A., Threlfall, C.G., Hahs, A.K. & Williams, N.S.G. (2015). Soil carbon and carbon/nitrogen ratio change under tree canopy, tall grass, and turf grass areas of urban green space. *Journal of Environmental Quality*, 45, 215-223. Nelson, D.W., & Sommers, L.E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed.), *Methods of Soil Analysis Part 3, Chemical Methods* (pp. 961-1010). Madison, WI: Soil Science Society of America, Inc. Rowell, D.L. (2014). *Soil Science: Methods & Applications*. New York: Routledge. Soil Survey Staff. (2009). *Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt (Ed.).* Lincoln, NE: United States Department of Agriculture, Natural Resources Conservation Service. USDA-NRCS. (2011.) Carbon to Nitrogen Ratios in Cropping Systems.

	https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf

8.15.4 Soil carbon decomposition rate

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Soil carbon decomposition rate	**Climate Resilience** **Green Space Management**
Description and justification	Indicators of Carbon Sequestration in Soil sub-criterion will assess the carbon sequestration in soil.
Definition	Decomposition of Carbon is a part of the Carbon cycle and is essential for recycling the finite matter that occupies physical space in the biosphere. Decomposition is the process by which organic substances are broken down into simpler organic matter. One can differentiate abiotic from biotic decomposition (biodegradation). The former means "degradation of a substance by chemical or physical processes, e.g., hydrolysis" (Water Quality Vocabulary. IShaO 6107-6:1994). The latter means "the metabolic breakdown of materials into simpler components by living organisms", typically by microorganisms.
Strengths and weaknesses	
Measurement procedure and tool	Model/Sampling/Survey
Scale of measurement	%
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	

Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	-
Opportunities for participatory data collection	
Additional information	
References	

8.16 Soil matric potential

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Soil matric potential	**Green Space Management**
Description and justification	Soil matric suction increases soil strength and contributes towards strength and stability against landslides and erosion
Definition	The pressure dry soil and plant water uptake exerts on the surrounding soils to equalise the moisture content in the overall block of soil.
Strengths and weaknesses	Strengths: little suction provides large increase in strength Weaknesses: difficult to measure; changes rapidly; uncertain relationship with meteorological drivers
Measurement procedure and tool	Field tensiometer inserted in the soil at a certain depth.
Scale of measurement	Micro / point measurement
Data source	
Required data	Soil matric suction (in kPa)
Data input type	Electrical (voltage)

Data collection frequency	continuous
Level of expertise required	Low for collection, high for interpretation
Synergies with other indicators	Soil temperature, rainfall; aggregate stability; soil water flux; plant uptake; evapotranspiration; Hydro-mechanical stability and strength of soil materials
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Yes, citizen science
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Hydrological effect of vegetation against rainfall-induced landslides. Journal of Hydrology, 549 (374–387) Gonzalez-Ollauri. A., Stokes, A., Mickovski, S.B., 2020. A novel framework to study the effect of tree architectural traits on stemflow yield and its consequences for soil-water dynamics. Journal of Hydrology, 582 (124448)

8.17 Soil temperature

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Soil temperature	**Climate Resilience** **Natural and Climate Hazards** **Green Space Management**
Description and justification	Soil temperature is intrinsically related to soil microbial activity and to biogeochemical and hydrological fluxes in the soil. Different soil temperatures would be preferred by different vegetation whose roots would provide strengths and resistance against erosion or sliding.
Definition	The degree or intensity of heat present in soil, especially as expressed according to a comparative scale and shown by a thermometer or perceived by touch.

Strengths and weaknesses	Strengths: standard measurement methods exist; closely linked to air temperature; linked to complex soil biogeochemical processes; Weaknesses: high resolution intrusive investigation is needed; site-specific investigation needed to establish connections with other environmental variables and processes.
Measurement procedure and tool	Trial pits or boreholes excavated and samples taken or thermometer and/or thermocouples inserted and measurement taken in situ
Scale of measurement	Micro / point measurement
Data source	
Required data	Temperature
Data input type	Value (units of temperature)
Data collection frequency	continuous
Level of expertise required	Low
Synergies with other indicators	Soil strength, soil type, aggregate stability, soil matric suction, plant evapotranspiration, soil water flux, soil carbon flux
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	Yes.
Additional information	
References	Gonzalez-Ollauri. A., Stokes, A., Mickovski, S.B., 2020. A novel framework to study the effect of tree architectural traits on stemflow yield and its consequences for soil-water dynamics. Journal of Hydrology, 582 (124448)

8.18 Soil water holding capacity (field capacity)

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

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Soil field capacity	**Green Space Management Water Management**
Description and justification	Soils that can hold water effectively can support more plant growth and are less susceptible to leaching losses of nutrients and pesticides. All of the water held by soil is not available for plant growth i.e., for the success of the NBS. Field capacity marks the boundary between the saturated and transitional hydrological regimes in the soil. When this transition occurs, air begins entering the soil-pore space and the soil strength changes.
Definition	Field capacity is the amount of soil moisture or water content held in the soil after excess water has drained away by gravity (usually 24 hours after rainfall) and the rate of downward movement has decreased.
Strengths and weaknesses	+: standardised procedures for determination exist; databases based on soil type exist; can be determined through soil pedotransfer functions; related to water available to plants; related to soil strength; related to root spread in the soil -: direct measurement requires significant time and effort from suitably qualified personnel
Measurement procedure and tool	In the laboratory: using a pressure plate to apply a suction of 1/3 atmosphere to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture in the sample is determined gravimetrically and equated to field capacity. In the field: irrigating a test plot until the soil profile is saturated to a depth of one metre. Then the plot is covered to prevent evaporation. The soil moisture is measured each 24 hours until the changes are very small, at which point the soil moisture content is the estimate of field capacity.
Scale of measurement	Micro to plot scale
Data source	
Required data	Moisture content
Data input type	Quantitative, numerical

Data collection frequency	Once as a baseline and then periodically or sporadically during the growth/life of the NBS
Level of expertise required	Low to intermediate
Synergies with other indicators	Soil type, degree of saturation, moisture content, soil stability (FoS), organic matter content; soil water retention capacity, wilting point
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	yes
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S. B., 2017. Plant-soil reinforcement response under different soil hydrological regimes. Geoderma, 285 (141-150) Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Plant-Best: A novel plant selection tool for slope protection. Ecological Engineering 106 (2017) 154–173.

8.19 Plant-available water

8.19.1 Plant available soil water

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Soil water retention capacity	**Water Management Green Space Management**
Description and justification	Soils can store water in their matrix and skeleton depending on their structure, texture and mineral composition. There is an intrinsic relationship between the amount of water stored in the soil and the matric suction, which is established through the soil water retention function. This function defines field capacity and wilting point, which difference establishes the water available to plants in the soil. Soil water retention is also related to soil strength and bridges soil hydrology with mechanics.

	Soils that can hold a lot of water support more plant growth and are less susceptible to leaching losses of nutrients and pesticides. All of the water held by soil is not available for plant growth. Soil water retention capacity is mainly determined by the soil texture (sand, silt, clay contents), structure (bulk density and porosity), and organic matter content. It can influence the choice of NBS as well as the stability/effectiveness of the NBS put in place to mitigate against natural hazards. In general, the higher the percentage of silt and clay sized particles, the higher the water holding capacity. The small particles (clay and silt) have a much larger surface area than the larger sand particles. This large surface area allows the soil to hold a greater quantity of water.
Definition	It is the ability of the soil to store water under changing hydrological regimes -i.e., residual, transition and saturation Soil water retention (or holding) capacity is the amount of water that a given soil can hold for an intended use.
Strengths and weaknesses	+: standardised procedure for determination exists; it can be estimated based on soil type; bridges soil hydrology and mechanics; established the boundaries for the water available to plants in the soil. -: direct measurement requires significant time and effort from suitably qualified personnel; difficult to measure on site; requires measurement of matric suction; requires numerical modelling; limited availability of sensors measuring high soil suctions; difficult to establish under vegetated soil
Measurement procedure and tool	Determine water content at field capacity Determine water content at wilting point Plant available water = field capacity – wilting point moisture content Create a soil water retention curve
Scale of measurement	Micro, point but the results can be extrapolated to meso (field) scale
Data source	
Required data	Moisture contents at different air pressures
Data input type	numerical
Data collection frequency	periodic
Level of expertise required	Intermediate to high

Synergies with other indicators	Soil type, degree of saturation, moisture content, soil stability (FoS), organic matter content; soil field capacity, wilting point
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	Yes, especially for sampling
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S. B., 2017. Plant-soil reinforcement response under different soil hydrological regimes. Geoderma, 285 (141-150) Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Hydrological effect of vegetation against rainfall-induced landslides. Journal of Hydrology, 549 (374–387)

8.19.2 Soil water available for plant uptake (SAW metric)

Project Name: Nature4Cities

Author/s and affiliations: Ryad Bouzouidja[1], Patrice Cannavo[1], Stéphanie Decker[2]

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Soil Available Water - SAW	**Green Space Management**
Description and justification	**The SAW** represents the capacity of the soil to provide water for plant uptake (Yilmaz et al. 2016; Bouzouidja et al. 2018).
Definition	The use of this indicator aims to : ● Provide water for plants growth ● Favor plant transpiration and cooling effect
Strengths and weaknesses	This indicator can be capable to describe initial planning problems, like soil compaction. It is an important indicator to assess plant water uptake. This indicator is available to everyone and easy to implement. It is possible to apply the indicator in numerous cases (different locations). The indicator has been used in different circumstances (different soil uses) and delivered reasonable results (Nature4Cities D2.1).
Measurement procedure and tool	SWR = (Hfc-Hwp)*Bd*z*F with Hfc is the massic water content at field capacity (in kg water/kg dry soil), Hwp the volumetric water content at the wilting point (m^3/m^3), Bd is the bulk density in (kg/m^3), z is the depth of soil in (m), F is the stone fraction content (in m^3 of small soil per m^3 of total soil)

Scale of measurement	☒ Object
Data source	• Bibliography • Measurement/Monitoring
Required data	Several input data is required. Measuring these parameters is the best way to calculate this indicator, because urban soil properties are very heterogeneous. If it can't be measured, parameters estimation is possible thanks to the bibliography • Soil water field capacity (Hfc) • Soil water content at the wilting point (Hwp) • Soil thickness (z) • Soil bulk density (Bd) • Stone fraction content (F)
Data input type	• Soil physical properties Measurement Unit : mm water / cm of soil
Data collection frequency	In concept and detailed design phase of urban and object planning.
Level of expertise required	Easy to calculate and requires few data
Synergies with other indicators	In Nature4Cities this indicator can be evaluated (SAW score) (Nature4Cities D2.4). It was defined using Bruand et al., (2004) study. It represents the soil water storage capacity available for plant uptake. This is the most common indicator used to assess soil fertility. The SAW score needs soil texture information. Bruand et al. used soil sample depth and % sand, % silt and % clay. SAW score is given in form of a performance bar with numerical values ranked in terms to the best (1) and worst (0) scenario.
Connection with SDGs	SD15 Life on Land
Opportunities for participatory data collection	
Additional information	
References	Yilmaz, D., M. Sabre, L. Lassabatère, M. Dal, and F. Rodriguez. 2016. "Storm Water Retention and Actual Evapotranspiration Performances of Experimental Green Roofs in French Oceanic Climate." European Journal of Environmental and Civil Engineering 20 (3): 344–62. https://doi.org/10.1080/19648189.2015.1036128. Bouzouidja, Ryad, Gustave Rousseau, Violaine Galzin, Rémy Claverie, David Lacroix, and Geoffroy Séré. 2018. "Green Roof Ageing or Isolatic Technosol's Pedogenesis?" Journal of Soils and Sediments 18 (2): 418–25. https://doi.org/10.1007/s11368-016-1513-3. Bruand, Ary, Odile Duval, and Isabelle Cousin. 2004. "Estimation Des Propriétés de Rétention En Eau Des Sols à Partir de La

	Base de Données SOLHYDRO: Une Première Proposition Combianant Le Type d'horizon, Sa Texture et Sa Densité Apparente." Etude et Gestion Des Sols 11: 3–323. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

8.20 Vegetation Wilting Point

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

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Vegetation wilting point	**Green Space Management**
Description and justification	If vegetation is to thrive in the soil it will need a certain moisture in the soil. Thriving vegetation can prevent/mitigate against shallow landslides or erosion.
Definition	Minimum moisture content in the soil that the plant requires not to wilt. Sometimes defined as the soil water content when the soil is under a pressure of −15 bar.
Strengths and weaknesses	+: can be obtained from predictions using soil survey data. -: can be difficult to measure directly
Measurement procedure and tool	Measurement: soil sample needs to be brought to matric suction of 15 bar, after which a sub-sample is taken, mass measured, put in an oven at 110C, and then dry mass measured. The moisture content at wilting point will be the mass of evaporated water from the sub-sample divided by the mass of dry soil. Prediction: using pedotransfer functions (e.g., Bouma, 1989; Gonzalez-Ollauri and Mickovski, 2017)
Scale of measurement	micro

Required data	Soil type, particle size distribution, soil moisture, matric suction
Data input type	Numerical, category
Data collection frequency	once
Level of expertise required	Low for sampling/measurement; high for prediction
Synergies with other indicators	Moisture content, soil strength, vegetation cover
Connection with SDGs	11, 13, 15, 17
Opportunities for participatory data collection	yes
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Plant-Best: A novel plant selection tool for slope protection. Ecological Engineering 106 (154–173) Bouma, J. (1989). "Using soil survey data for quantitative land evaluation". Advances in Soil Science. 9: 177–213.

8.21 Soil water flux and degree of soil saturation

Project Name: OPERANDUM (Grant Agreement no. 776848)

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Soil water flux and degree of saturation	**Water Management Green Space Management**
Description and justification	Soil water flux – is the transport of water into the soil from the atmosphere, into the atmosphere from the soil and within the soil, establishing the soil water mass balance. It is intrinsically related to the stress state of the soil and to ecohydrological processes occurring at the plant-soil-atmosphere continuum (e.g., plant uptake and evapotranspiration).

	Degree of saturation is a measure of the soil water mass balance. It is directly related to soil strength, matric suction, and soil water flux. Vegetation plays a key role in ecosystems by linking biophysical processes—such as absorption of solar radiation, rainfall interception, and evapotranspiration—to biogeochemical processes—such as photosynthesis and volatile organic compound emission. Moreover, vegetation links the terrestrial carbon cycle to hydrology through stomatal aperture (Jarvis and McNaughton, 1986), and through other processes such as soil-water extraction by roots (de Jong van Lier et al., 2006). Terrestrial water fluxes are controlled to a large extent by above-ground and below-ground biological processes where vegetation plays a major role.
Definition	The degree of saturation is the ratio of the volume of water to the volume of voids, usually represented as percentage, it can vary from 0 (totally dry soil) to 100 (completely saturated soil). The gradient of the total potential of soil water in both, the soil fully saturated by water (saturated flow) as well as in soil not fully saturated by water (unsaturated flow) creates a flow (flux) in the soil.
Strengths and weaknesses	+: a number of models exist for monitoring and prediction of fluxes, albeit usually at a larger scale. Degree of saturation: easy to measure with gravimetric methods in the lab and in situ with reflectometers; intrinsically related to matric suction through soil water retention function; related to meteorological variables rainfall and temperature -: some phenomena associated with vegetation, and this NBS, have not been modelled through the soil water flux
Measurement procedure and tool	Soil water flux is calculated using the hydraulic gradient measured with a tensiometer at two depths and the hydraulic ·conductivity corresponding to the average soil water content between the two depths determined with a neutron probe or by direct sampling and lab testing (moisture content determination). The degree of saturation is calculated as a ratio of the moisture content and specific gravity on one side and the void ratio on the other. Time domain reflectometry sensors
Scale of measurement	Point, micro
Data source	
Required data	For the flux: hydraulic gradient between two points; soil water content

	For the saturation degree: soil water content, specific gravity of the soil particles, void ratio of the soil
Data input type	Quantitative, numerical
Data collection frequency	Continuous
Level of expertise required	Intermediate to high
Synergies with other indicators	Digital terrain model; soil moisture content, groundwater table level, soil strength
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	Yes, through citizen science
Additional information	
References	Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Hydrological effect of vegetation against rainfall-induced landslides. Journal of Hydrology, 549 (374–387) Gonzalez-Ollauri, A. and Mickovski, S.B., 2017. Plant-Best: A novel plant selection tool for slope protection. Ecological Engineering 106 (2017) 154–173.

8.22 Stemflow funnelling ratio

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Slobodan B. Mickovski[1], Alejandro Gonzalez-Ollauri[1], Karen Munro[1]

[1] *Built Environment Asset Management Centre, Glasgow Caledonian University, Glasgow, Scotland, UK*

Stemflow funnelling ratio	**Water Management** **Green Space Management**
Description and justification	Aboveground vegetation parts funnel rainfall around the plant stem and promote its infiltration preferentially into the soil. The volume of water funnelled around the stem is substantial and its infiltration into the soil may promote changes in the stress state of the soil. Also, when rainfall interacts with the canopy it becomes richer with nutrients and organic matter that will then be transported into the soil.

Definition	Proportion of rainfall that is funnelled around the plant stem and then into the soil. Funnelling ratio > 1 implies substantial concentration of rainfall around the plant stem.
Strengths and weaknesses	+: well established procedures exist for NBS that include trees; it can be related to tree architectural traits; easy-to-establish empirical models with incident rainfall; related to soil biogeochemical processes; opportunities to use soil temperature as an indicator of stemflow funnelling belowground -: requires significant effort and suitably qualified workforce for measurement/monitoring; difficult to measure effect in the soil
Measurement procedure and tool	Installation of small diameter gutters spiralling along the tree stem and collection of the volume of water flowing through the gutters. Measurement of rainfall volume beyond the canopy's influence. Linear regression between stemflow and gross rainfall. Data collection of tree architectural traits and implementation of multivariate statistics to relate both tree architecture and stemflow
Scale of measurement	Point (micro, individual) to field (meso)
Data source	
Required data	Water volume; tree architectural traits (canopy cover fraction, leaf area index, number of leaves, number of branches, branches inclination, tree basal area)
Data input type	Numerical, quantitative
Data collection frequency	During every rainfall event
Level of expertise required	Intermediate to high
Synergies with other indicators	Moisture content, soil temperature, matric suction, interception, throughflow, vegetation type, vegetation cover, precipitation
Connection with SDGs	11,13,15,17
Opportunities for participatory data collection	yes
Additional information	
References	Gonzalez-Ollauri. A., Stokes, A., Mickovski, S.B., 2020. A novel framework to study the effect of tree architectural traits on stemflow yield and its consequences for soil-water dynamics. Journal of Hydrology, 582 (124448).

	Gonzalez Ollauri, A & Mickovski, SB 2017, 'Hydrological effect of vegetation against rainfall-induced landslides', Journal of Hydrology, vol. 549, pp. 374–387

8.23 Soil Erodibility

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Soil Erodibility	Green Space Management
Description and justification	Indicators of Soil Physical Resilience sub-criterion will assess if the project scenarios enhance the ability of a soil to resist or recover their healthy state in response to destabilising influences.
Definition	Soil erodibility is a parameter of the soil profile reaction to the process of soil detachment and transport by raindrops and surface flow. The soil erodibility is expressed as the *K*-factor in the widely used soil erosion model, the Universal Soil Loss Equation (USLE) and its revised version (RUSLE). The *K*-factor, which expresses the susceptibility of a soil to erode, is related to soil properties such as organic matter content, soil texture, soil structure and permeability. With the Land Use/Cover Area frame Survey (LUCAS) soil survey in 2009 a pan-European soil dataset is available for the first time, consisting of around 20,000 points across 25 Member States of the European Union.
Strengths and weaknesses	
Measurement procedure and tool	Model/Survey
Scale of measurement	Unit of measure: mm^3/ha
Data source	
Required data	Soil properties
Data input type	Quantitative

Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	

8.24 Total Predicted Soil Loss (RUSLE)

Project Name: PHUSICOS – According to Nature (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Total Predicted Soil Loss (RUSLE)	**Natural and Climate Hazards** **Green Space Management**
Description and justification	Indicators of Soil Physical Resilience sub-criterion will assess if the project scenarios enhance the ability of a soil to resist or recover their healthy state in response to destabilising influences.
Definition	RUSLE is widely applied to estimate the rate of soil loss by water. The landscape profile is defined by a slope length, which is the length from the origin of overland flow to the point where the flow reaches a major flow concentration or a major area of deposition. The soil loss is an average erosion rate for the landscape profile.
Strengths and weaknesses	

Measurement procedure and tool	RUSLE (model/survey)
Scale of measurement	Unit of measure: ton/ha/year
Data source	
Required data	Rain data, soil characteristics, land use information.
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	

8.25 Soil Ecotoxicological Factor

Project Name: Nature4Cities

Author/s and affiliations: Ryad Bouzouidja[1], Patrice Cannavo[1], Stéphanie Decker[2]

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Soil Ecotoxicology factor (EcoF)	Green Space Management
Description and justification	This Ecotoxicology factor is able to describe initial planning problems, like ecotoxicity for plant growth, soil microorganisms, micro- meso- and macro- fauna It gives an assessment of the environmental risk due to soil pollution and will help urban planners in choosing the best soil management solution according to the intended use.
Definition	EcoF is based on (i) an evaluation of the concentration of pollutants for which an effect is measured in 50% of a population (EC50) and (ii) the time needed for 50% of a pollutant disappears (DT 50) (Nature4Cities D2.1).

	It will be used for the : ● Evaluation of the effect of contaminants on soil organisms (microorganisms, micro- meso- or macro-fauna) ● Evaluation of the dissipation (sorption, full or partial degradation) of contaminant over time
Strengths and weaknesses	It is possible to apply the indicator in numerous cases (different locations). The indicator has been used in different circumstances (different soil uses) and delivered reasonable results. However it requires a number of samples adapted to soil heterogeneity
Measurement procedure and tool	● soil sampling materials ● calculations must be done to get EC50 Calculating CE50 and DT50 require to collect soil samples and to perform experiments in laboratory.
Scale of measurement	☒ City ☒ Neighbourhood ☒ Object
Data source	● Bibliography ● Measurement/Monitoring
Required data	● Soil or water content in pollutant Measurement unit : ● for EC 50 : mg/L (for water), mg/kg (for soil) ● for DT 50 : in days
Data input type	● quantitative data
Data collection frequency	● Initial diagnostic ● At least 2 times of sampling for being able to measure DT50
Level of expertise required	Medium calculation difficulty and required data
Synergies with other indicators	In Nature4Cities the EcoF Score indicator is based on an evaluation of the concentration of pollutants for which an effect is measured in 50% of a population (EC50) expressed in mg L^{-1} (in case of water) and mg kg^{-1} (in case of soil). EC50 is determined using ISO 6341 (2012) standard method. The index is given in form of a performance bar with numerical values ranked in terms to the best (1) and worst (0) scenario.
Connection with SDGs	SD15 Life on Land, SD14 Life bellow water
Opportunities for participatory data collection	
Additional information	
References	Hommen, U., Baveco, J. M., Galic, N., & van den Brink, P. J. (2010). Potential application of ecological models in the European environmental risk assessment of chemicals I: review of protection goals in EU directives and regulations. Integrated environmental assessment and management, 6(3), 325-337.

	Garcia, M. (2004). Effects of pesticides on soil fauna: development of ecotoxicological test methods for tropical regions (Vol. 19). Cuvillier Verlag. Thompson, Dean G., and David P. Kreutzweiser. "A review of the environmental fate and effects of natural" reduced-risk" pesticides in Canada." 2007. 245-274. van Gestel, C. A., van der Waarde, J. J., Derksen, J. G. M., van der Hoek, E. E., Veul, M. F., Bouwens, S., ... & Stokman, G. N. (2001). The use of acute and chronic bioassays to determine the ecological risk and bioremediation efficiency of oil-polluted soils. Environmental Toxicology and Chemistry, 20(7), 1438-1449. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

8.26 Soil structure

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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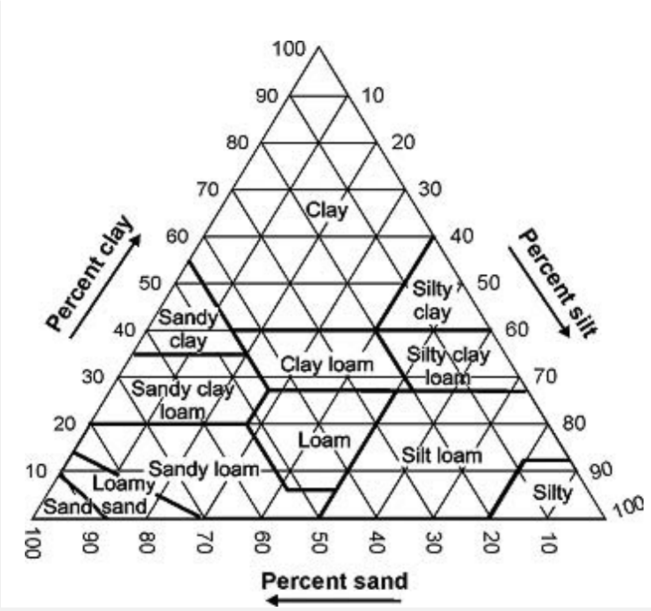
Soil Structure	**Biodiversity**
Description and justification	This indicator evaluates the soil fertility, in terms of nutrients, structure and *C* and *N* cycling.
Definition	Defined by the way individual particles of sand, silt, and clay are assembled. Single particles when assembled appear as larger particles. They are called aggregates. Aggregation of particles can occur in different patterns, resulting in different soil structures. The circulation of

	water in the soil strongly varies according to the soil structure.
Strengths and weaknesses	+ Good granular structure allows rapid movement of air and water within the soil. Poor granular structure decreases movement of air and water. - Soil sample collecting could be time and money consuming.
Measurement procedure and tool	The size, shape and character of the soil structure varies (e.g., cube-like, prismlike or platter-like). On the basis of size, the soil structure is classified as: - very coarse: > 10 mm; - coarse: 5–10 mm; - medium: 2–5 mm; - fine: 1–2 mm; - very fine: < 1 mm. Depending on the stability of the aggregate and the ease of separation, the structure is classified as: - poorly developed; - weakly developed; - moderately developed; - well developed; - highly developed.
Scale of measurement	Ordinal scale
Data source	
Required data	Soil samples
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	Indicators related to soil fertility (soil available nutrients and texture).
Connection with SDGs	2
Opportunities for participatory data collection	
Additional information	

References	Motsara M.R., Roy R.N. (2008), *Guide to laboratory establishment for plant nutrient analysis*. FAO fertilizer and plant nutrition bulletin.



Soil texture classes according to proportions of sand, silt and clay (Motsara, Roy, 2008)

8.27 Soil chemical fertility

Project Name: Nature4Cities

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Chemical fertility of soil - Cfer	Green Space Management
Description and justification	**Cfer** relates to the mineral nutrition of plants via the concepts of biodisponibility of elements, deficiencies, toxicities and equilibria
Definition	Evaluation of the quality of soil, in this case chemical soil fertility (Nature4Cities D2.1) : - to assess the ability of soil to grow ornamental plants and food (vegetables) - to improve the soil properties if necessary (1) addition of limestone to adjust pH, (2) addition of compost to increase

	the organic carbon content, (3) addition of mineral nutrients if there is a risk of chlorosis... The output is qualitative (poor, moderate or optimal) or 0 to 1
Strengths and weaknesses	This indicator is capable to describe initial planning problems, like soil nutrient deficiency for plant growth. It is possible to apply the indicator in numerous cases (various locations). The indicator has been used in different circumstances (different soil uses) and delivered reasonable results. However it requires a number of samples adapted to soil heterogeneity
Measurement procedure and tool	REQUIRED TOOL ● soil sampling materials ● laboratory analytical tools CALCULATION METHOD ● measurement of each parameter ● global evaluation from evaluation of each parameter
Scale of measurement	☒ City ☒ Neighbourhood ☒ Object
Data source	● Bibliography ● Measurement/Monitoring
Required data	Organic C, Total N, K, C/N, pH method: (water, $CaCl_2$), $CaCO_3$, CEC (methods : Metson, CobaltiHexamine), P (Olsen method)
Data input type	● physicochemical measurements ● chemical analyses
Data collection frequency	● Initial diagnostic/ assessment in case of hardly growth of vegetation
Level of expertise required	Easy to calculate but requires data. This indicator requires laboratory or on-site measurements The data could have been already collected in case of soil characterisation but usually not. Measuring the parameters is the best way to calculate this indicator, because urban soil properties are very spatially heterogeneous.
Synergies with other indicators	In Nature4Cities the Cfer KPI is calculated using cation exchange capacity parameter (CEC in meq/100 g) (Nature4Cities D2.4). This parameter is a measure of the quantity of negatively charged sites on soil surfaces that can retain positively charged ions (cations) such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), by electrostatic forces. Cation exchange capacity of soil is measured according a standardized method: the ammonium acetate method according to Kahr and Madsen (1995). The Cfer score is on one hand also expressed in form of a performance bar with numerical values ranked in terms to the best (1) and worst (0) scenario
Connection with SDGs	SD15 Life on Land

Opportunities for participatory data collection	
Additional information	
References	Damas, O., & Rossignol, J. P. (2009, June). Identification of mineral and organic waste resources as alternative materials for fertile soil reconstitution. In II International Conference on Landscape and Urban Horticulture 881 (pp. 395-398). Kahr, G, and FT Madsen. 1995. "Determination of the Cation Exchange Capacity and the Surface Area of Bentonite, Illite and Kaolinite by Methylene Blue Adsorption." Applied Clay Science 9 (5): 327–336. https://doi.org/10.1016/0169-1317(94)00028-O. Vidal-Beaudet, L., Rokia, S., Nehls, T., & Schwartz, C. (2016). Aggregation and availability of phosphorus in a Technosol constructed from urban wastes. Journal of Soils and Sediments, 1-11. Rokia, S., Séré, G., Schwartz, C., Deeb, M., Fournier, F., Nehls, T., ... & Vidal-Beaudet, L. (2014). Modelling agronomic properties of Technosols constructed with urban wastes. Waste management, 34(11), 2155-2162. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

8.28 Flammability Index

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Flammability Index	Green Space Management

	Natural and Climate Hazards
Description and justification	Indicators of Flammability sub-criterion will assess the ability of a landscape to burn or ignite, causing fire or combustion.
Definition	Ability of a landscape to burn or ignite, causing fire or combustion.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Survey
Scale of measurement	-
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	13
Opportunities for participatory data collection	
Additional information	
References	

8.29 Community garden area

Project Name: Connecting Nature

Author/s and affiliations: Stuart Connop[1], D. Dushkova[2], D. Haase[2], C. Nash[1]

[1] *Sustainability Research Institute, University of East London, UK*

[2] *Geography Department, Humboldt University of Berlin, Berlin, Germany*

Community garden area per capita and within a defined distance (Applied and EO/RS combined)	Green Space Management
Description and justification	Measuring community gardens as part of the greenspace network in cities gives an indicator of a range of factors such as: accessible greenspace provision and preservation, diversity of land use for humans and biodiversity, sustainable use of vacant land, climate regulation (cooling, stormwater, reduced GHG emissions associated with food transportation), food security, physical activity, access to healthy food/fruit and vegetable consumption, community cohesion and empowerment. Ultimately community gardens deliver a social function. Mapping exercises can also be used to identify areas where future community garden (CG) projects should be targeted (i.e., need for CGs). Mapping community garden accessibility in these ways can be used to: • Identify deficits and inequalities in relation to community garden access; • Assess changes in access in relation to new projects/sites; • Inform strategic planning decisions in relation to community garden provision; • Assess different types of accessibility; • Set targets in relation to community garden provision and monitor progress towards targets.
Definition	A measure of per capita garden area per target distance - public community gardens provide active interaction with nature and opportunities for social cohesion.
Strengths and weaknesses	**Applied methods:** Robustness of evidence will be biased by how detailed existing data is on CGs in a city and accuracy of census data. Similarly, the accuracy of distance to CG will vary based on the distance measure used. They can however represent a useful indicator basis for urban planning. **Earth observation/Remote sensing methods:** See Applied above.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics see: Connecting Nature Indicator Metrics Review Env89_Applied
Scale of measurement	**Applied methods:** typically used at city-scale, but other scales are possible.

	Earth observation / Remote sensing methods: See Applied above.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Review Env85_Applied
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Review Env85_Applied
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Review Env85_Applied
Level of expertise required	**Applied methods**: Some mapping/GIS expertise is likely to be needed. **Earth observation / Remote sensing methods**: See applied above.
Synergies with other indicators	Strong synergies with health and wellbeing indicators and social cohesion indicators in terms of physical activity, bringing together people from different backgrounds, education about nature and healthy food. Also, synergies with other environmental indicators (e.g., biodiversity measures, water regulation and air temperature) and possibly economic indicators if enterprises emerge selling produce.
Connection with SDGs	All SDGs except 5 and 12 : Job and urban agriculture opportunities around greenspace; Urban agriculture opportunities; Links to access to greenspace; Links to environmental education; Possible co-benefits; Links between biodveristy and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure; Social equality in relation to greenspace; Sustainable urban development; Climate change adaptation; Potential co-benefits related to more sustainable water management; Habitat creation; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods:** No specific examples identified during the review but it may be possible to validate CG distribution using a PPGIS type citizen science exercise. **Earth observation / Remote sensing methods:** See Applied above.
Additional information	
References	**Applied methods**:

	Balfour, R., Allen, J., 2014. Local action on health inequalities: Improving access to green spaces. London, UK Dennis, M., James, P., 2016. User participation in urban green commons: Exploring the links between access, voluntarism, biodiversity and well being. Urban For. Urban Green. 15, 22–31. https://doi.org/10.1016/j.ufug.2015.11.009 La Rosa, D. (2014) Accessibility to greenspaces: GIS based indicators for sustainable planning in a dense urban context. Ecological Indicators, 42: 122-134. Jakubowski, B. and Frumkin, H. (2010) Environmental Metrics for Community Health Improvement. Preventing chronic disease, 7(4): 1-10. Senes, G., Fumagalli, N., Ferrario, P.S., Gariboldi, D. and Rovelli, R. (2016) Municipal community gardens in the metropolitan area of Milano: assessment and planning criteria. Journal of Agricultural Engineering, XLVII: 509 [82-87]. Speak, A.F., Mizgajski, A. and Borysiak, J. (2015) Allotment gardens and parks: Provision of ecosystem services with an emphasis on biodiversity. Urban Forestry & Urban Greening, 14(4): 772-781.

8.30 Food production in urban allotments and NBS

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Alicia Villazán[1], Isabel Sánchez[1], Raúl Sánchez[2], Jose Fermoso[2], Silvia Gómez[2], María González[2], Jose María Sanz[2], Esther San José[2]

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[2] *CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain*

Food production in urban allotments and NBS	Green Space Management
Description and justification	Production of food in urban orchards (agriculture, eggs, etc.). Measurement of the amount of food produced.
Definition	The production of food will be reported in tonnes/Ha per year.
Strengths and weaknesses	This KPI will require citizens' collaboration, so recovering the data could be difficult.
Measurement procedure and tool	Measurement of the amount of food produced. If it cannot be measured, an estimate of the amount generated will be made. Users will be asked directly using surveys (online and in situ). In the individual orchards, at the end of the summer campaign (September-October), users are asked directly using surveys. The producers might measure (scale) or

	estimate the quantities (how many bags, how many units and technician have to "translate" this into weight units. On the other hand, community orchards measure every year the food amount that they produce, because the products are destined for social purposes. The food production of the community orchards will be measured with a scale, not estimated. This KPI for food production is measured/estimated by tones/Ha per year and tones/year.
Scale of measurement	Area/neighbourhood
Data source	
Required data	Online or in situ surveys.
Data input type	Sum of the produced food expressed as kg per user on a yearly basis
Data collection frequency	Yearly
Level of expertise required	Technical/basic
Synergies with other indicators	This KPI is highly related with KPI Green intelligence awareness, as well as KPI Perceptions of citizens on urban nature – green space quality, KPI Number of jobs created; gross value added, KPI Accessibility: distribution, configuration and diversity of green space and land use changes, KPI Monetary values.
Connection with SDGs	This KPI is directly related with SDG 3 and SDG 11.
Opportunities for participatory data collection	This KPI requires citizens' collaboration via surveys.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Ecological orchards of Valladolid Annual Report (2016-2017)

	http://pai.inea.org/wp-content/uploads/2016/11/memoria-2016MEJOR-CALIDAD.pdf http://www.valladolid.es/es/actualidad/noticias/huertos-ecologicos-2016-2017

8.31 Recreational opportunities provided by green infrastructure

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Raúl Sánchez[1], Jose Fermoso[1], Silvia Gómez, María González[1], Jose María Sanz[1], Esther San José[1]

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Weighted recreational opportunities provided by green infrastructure	Green Space Management
Description and justification	This KPI aims to measure the increase of opportunities related to green infrastructures (Derkzen et al. 2015), being valued for recreation, social interaction, education and supporting healthy living (satisfaction).
Definition	This KPI measures the recreation opportunities available by urban green infrastructure.
Strengths and weaknesses	This KPI requires specific software (GIS software).
Measurement procedure and tool	The availability of recreation opportunities can be measured considering different elements: types of urban green infrastructure; degree of naturalness; aesthetics-scenic beauty; and presence of water. Users were asked to score these elements according to the relative importance. Scores were discussed during a focus group.
Scale of measurement	City/neighbourhood
Data source	
Required data	Baseline and post-intervention measurements of user engagement with NBS through walking and cycling, types of activity undertaken in/with NBS (other than walking and cycling), frequency of interaction with NBS. Reported as frequency count data (interactions/week) (number of visitors, number of recreational activities) (Number of cultural events, people involved, and children in educational activities) value (Kabiisch and Haase 2014). Surface measurements shall be calculated with Geographical Information Systems (GIS). A Social Survey shall be calculated with the measurement of a questionnaire through standard software (Excel or SPSS).

Data input type	GIS data (vectorial, raster)
Data collection frequency	Pre and post intervention.
Level of expertise required	Technical/expert
Synergies with other indicators	This KPI is strongly related with KPI Accessibility: distribution, configuration and diversity of green space and land use changes (multi-scale, green spaces quantity), and Perceptions of citizens on urban nature – green spaces quality.
Connection with SDGs	This KPI is directly related with SDG 11 and SDG 3.
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Questionnaires applied to the population for the recreational and cultural benefits of green spaces (Kabisch and Haase, 2014). Derkzen, M.L., van Teeffelen, A.J.A., Verburg, P.H., 2015. Quantifying urban ecosystem services based on high-resolution data of urban green space: An assessment for Rotterdam, the Netherlands. J. Appl. Ecol. 52, 1020–1032. doi:10.1111/1365-2664.12469 QGIS 3 – Userguide. https://www.qgis.org/en/site/ QGIS Development Team 2013. QGIS Geographic Information System. Open Source Geospatial Foundation. URL http://qgis.osgeo.org

8.31.1 *ESTIMAP nature-based recreation model*

Project Name: MAvES (Mapping, Assessment and Valuation of Ecosystems and their Services) (JRC-D3- Institutional project)

Author/s and affiliations: Grazia Zulian[1], Joachim Maes[1], Guido Ceccherini[2]

[1] *European Commission Directorate-General Joint Research Centre Directorate D (D3 -Land Resources)*

[2] *European Commission Directorate-General Joint Research Centre Directorate D (D1 -Bio-Economy)*

ESTIMAP nature-based recreation model	**Green Space Management**
Description and justification	Capacity of ecosystems to provide opportunities for nature-based recreation activities
Definition	Nature based recreation or “Physical and experiential interactions with natural environment” (CICES, https://cices.eu/) include a wide list of possible experience and activities such as Biking; boating; climbing; hiking; horseback riding, Walk the dog in a nice area; enjoy a local play ground; find an urban park nearby. ESTIMAP (Ecosystem Services Mapping Tool) nature-based recreation model was developed to map recreation opportunities at European scale. It is an ‘Advanced multiple layer LookUp Tables” model which measures the capacity of ecosystems to provide nature-based recreational and leisure opportunities. It is a “context based indicator”, to create hot spot maps for recreation activities and, simultaneously represent their territorial context. The original model (Zulian et al. 2013b; Paracchini et al. 2014; Liquete et al. 2016; Vallecillo et al. 2019), up to now applied at European scale was adapted to fit the urban setting. In previous applications the approach was used in urban context (Zulian et al. 2017), but only with reference to specific local applications, such as in Barcelona (Baró et al. 2016) or Trento (Cortinovis et al. 2018). Urban ESTIMAP-recreation consists of four basic sections: (1) The Recreation Potential (RP), which estimates the potential capacity of ecosystems to support nature-based recreational activities based on land suitability for recreation and the natural, infrastructure and water features influence recreational opportunity provision;

	(2) The Opportunity map (OS), which expresses the presence of facilities to enjoy and reach areas with potential opportunities. (3) The Recreation Opportunity Spectrum map (ROS), which combines the Opportunity map (OS) and the Recreation Potential (RP). Figure 1 (4) A potential accessibility map which represent the cumulative potential visitors based on a fuction of the distance and the total opportunities available within a defined distance.
Strengths and weaknesses	-spatially explicit -> provides maps of potential areas where opportunities for nature-based recreation are available -relatively complex
Measurement procedure and tool	The concept of the recreation opportunity spectrum is presented in Figure 1. Areas in dark blue are top areas for nature-based recreation within the boundaries of the city offering a high recreation potential and with a high availability of facilities that support recreation.

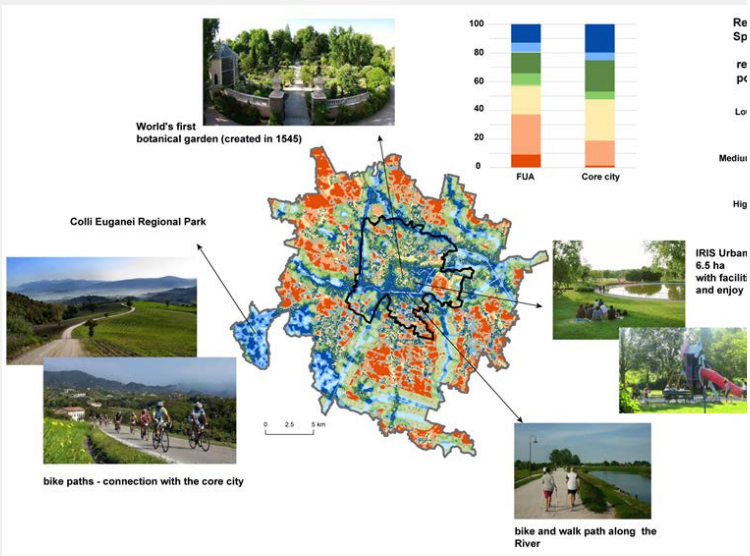

Figure 1: The Recreation Opportunity Spectrum.

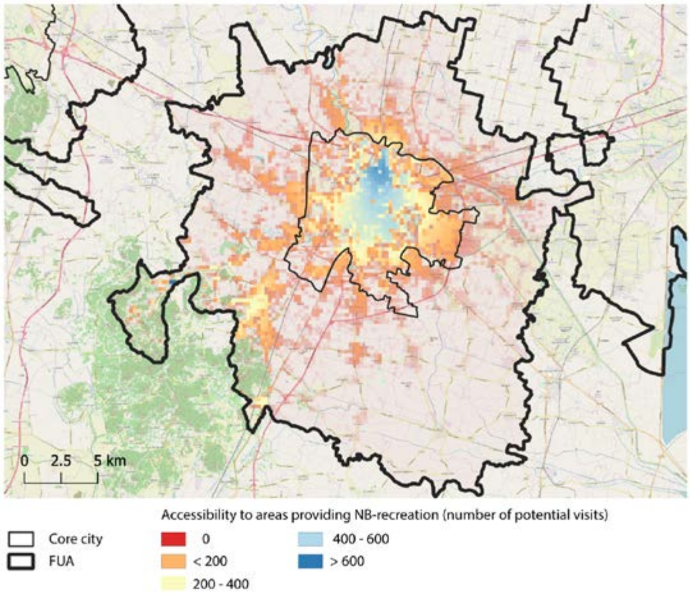

Figure 2: Potential accessibility map

Scale of measurement	Functional Urban Areas

Required data

Data (version)	Data holder	Spatial resolution	website
Corine Land Cover	EEA	100 m	https://land.copernicus.eu/pan-european/corine-land-cover
CDDA[6]	EEA	vector	https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-12/gis-data/cdda-shape-file
Natura 2000			https://www.eea.europa.eu/data-and-maps/data/natura-5
Bathing water quality[7]	EEA	vector	https://www.eea.europa.eu/data-and-maps/data/bathing-water-directive-status-of-bathing-water-11
Coast geomorphology	EEA	1:100 000	http://www.eea.europa.eu/ data-and-maps http://www.eurosion.org/

[6] The European inventory of nationally designated areas holds information about protected areas and the national legislative instruments, which directly or indirectly create protected areas.

[7] The European Topic Centre on Water (Database May 2019), national submissions to the Bathing Water Directive

Urban greenness	Earth Engine's public data catalog	30 m	https://developers.google.com/earth-engine/datasets/catalog/ LANDSAT_LE07_C01_T1 _ANNUAL_GREENEST_TOA
Open Street Map	OpenStreet Map contributors. (2015)	vector	" Planet dump [Data file from: 25/06/2019$]. Retrieved from https://planet.openstreetmap.org."
Population data	GHSL	250 m	https://data.jrc.ec.europa.eu/dataset/42e8be89-54ff-464e-be7b-bf9e64da5218

Data input type	-raster and vector data - the model can be applied with any type of data suitable to represent opportunities for nature based recreation activities
Precision	100 m
Data collection frequency	Year or time-series range (for available data at EU scale): 2000 2012 2018
Level of expertise required	-GIS programmer (advanced)
Synergies with other indicators	Cultural ecosystem services
Connection with SDGs	//
Opportunities for participatory data collection	no
Additional information	
References	Baró F, Palomo I, Zulian G, Vizcaino P, Haase D, Gómez-Baggethun E (2016) Mapping ecosystem service capacity, flow and demand for landscape and urban planning: A case study in the Barcelona metropolitan region. Land use policy. doi: 10.1016/j.landusepol.2016.06.006 Cortinovis C, Zulian G, Geneletti D (2018) Assessing Nature-Based Recreation to Support Urban Green Infrastructure Planning in Trento (Italy). Land 7(4): 112. doi: 10.3390/land7040112 Liquete C, Piroddi C, Macías D, Druon J-N, Zulian G (2016) Ecosystem services sustainability in the Mediterranean Sea: Assessment of status and trends using multiple modelling approaches. Sci Rep. doi: 10.1038/srep34162 Maes J, Zulian G, Günther S, Thijssen M, Reynal J (2019) Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute) Final Report. Luxembourg.

Paracchini ML, Zulian G, Kopperoinen L, Maes J, Schägner JP, Termansen M, Zandersen M, Perez-Soba M, Scholefield PA, Bidoglio G (2014) Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU. Ecol Indic 45: 371–385. doi: 10.1016/j.ecolind.2014.04.018

Vallecillo S, La Notte A, Zulian G, Ferrini S, Maes J (2019) Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people. Ecol Modell 392(April 2018): 196–211. doi: 10.1016/j.ecolmodel.2018.09.023

Zulian G, Paracchini M-L, Maes J, Liquete Garcia MDC (2013) ESTIMAP: Ecosystem services mapping at European scale. European Commision

Zulian G, Stange E, Woods H, Carvalho L, Dick J, Andrews C, Baró F, Vizcaino P, Barton DN, Nowel M, Rusch GM, Autunes P, Fernandes J, Ferraz D, Ferreira dos Santos R, Aszalós R, Arany I, Czúcz B, et al (2017) Practical application of spatial ecosystem service models to aid decision support. Ecosyst Serv. doi: https://doi.org/10.1016/j.ecoser.2017.11.005

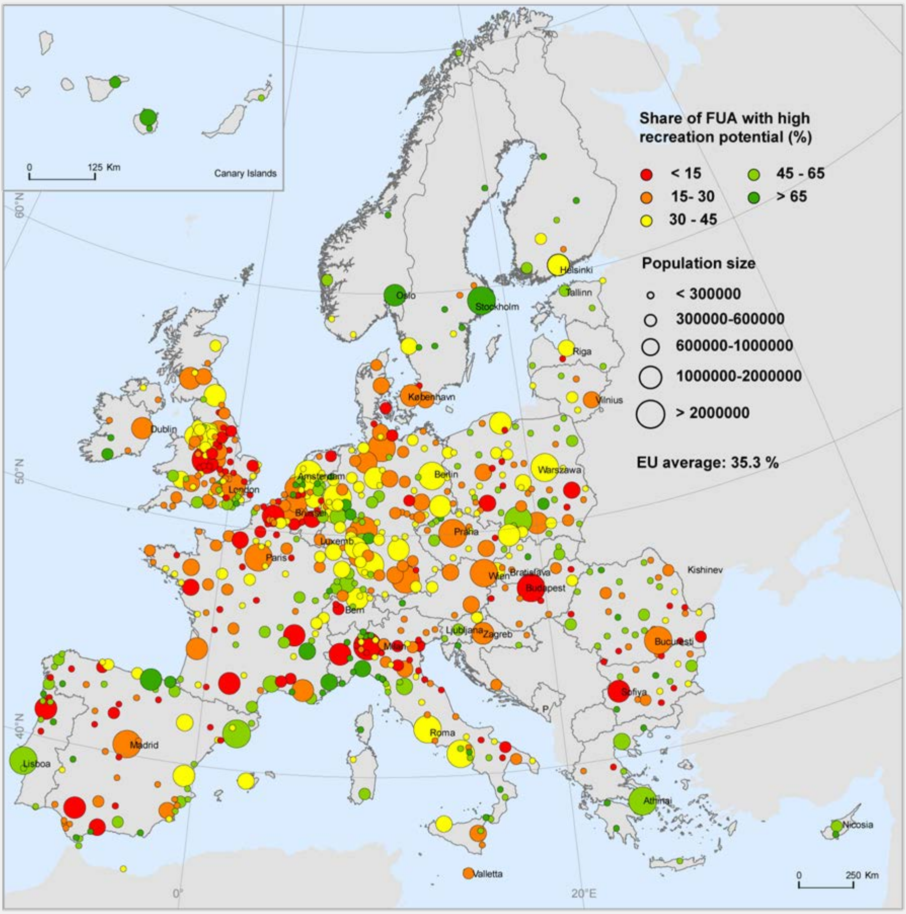

Figure 3: Areas with an high potential to provide recreation opportunities (% with the FUA)- figure extracted from the Final Report of the EnRoute Project (Maes et al. 2019)

8.31.2 Number of visitors in new recreational areas

Project Name: PHUSICOS (Grant Agreement no. 776681)

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[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Number of Visitors to Recreational Areas	**Green Space Management**
Description and justification	A new infrastructure (both NBS, Hybrid solutions and Grey infrastructures), implemented in a rural landscape in order to achieve a risk reduction, could, at the same time, enhance the quality of life in the area, making new areas available for leisure, recreation or other cultural activities (Raymond et al., 2017; Byrd et al., 2017; Sandstrom 2002). For instance, the stabilization of a riverbank through NBS could give these areas back to the community for different leisure purposes (e.g., creation of a promenade, cycling paths, panoramic viewpoints, etc.), attracting visitors in these new recreational areas. The higher the number of visitors in this area is, the higher the contribution given to life quality is supposed to be.
Definition	The number of visitors can be defined as the amount of people visiting, for leisure purpose over a year, the area where the new infrastructure (both NBS, Hybrid solutions and Grey infrastructures) is implemented. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design scenarios (e.g., NBS Scenario or Hybrid Scenario) computing the number of new visitors.
Strengths and weaknesses	Collecting the needed data to assess the indicator could be time and money consuming.
Measurement procedure and tool	The number of visitors can be monitored through a direct survey or assessed using models. Both these approaches entail an ex-post indicator evaluation. Ad hoc direct survey can be carried out in different periods over the year, for instance one week for each season, and the number of visitors detected can be multiplied by the number of weeks in a year. If the recreational site is within a paid area, the number of visitors can be approximated to the number of tickets sold over a year. When there is no time and/or economic resources for an ad hoc direct survey the number of visitors can be estimated

	through models that need official data concerning tourists (National institute of statistics, Regional tourism agency, etc.) and/or other proxy data (amount of solid urban waste produced; electricity consumption in private houses; number of houses available for vacation).
Scale of measurement	NBS
Data source	Public agencies (National institute of statistics, Regional tourism agency, Municipalities, etc.) Unit of measure: number of visitors
Required data	Number of visitors in the area where the new infrastructure (both NBS, Hybrid solutions and Grey infrastructures) is implemented (Model/Survey).
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	Medium
Synergies with other indicators	Touristic Activeness Enhancing
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	
References	Byrd C., Andersson E., Kronenberg J., Hansen R., Buijs A. (2017). Understanding and Promoting the Values of Urban Green Infrastructure: a learning module. GREEN SURGE project Deliverable 4.5, University of Copenhagen, Copenhagen, Denmark Raymond C.M., Berry P., Breil M., Nita M.R., Kabisch N., de Bel M., Enzi V., Frantzeskak N., Geneletti D., Cardinaletti M., Lovinger L., Basnou C., Monteiro A., Robrecht H., Sgrigna G., Munari L., Calfapietra C. (2017). An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom Sandstrom U.F. (2002). Green infrastructure planning in urban Sweden. Planning Practice and Research, 17(4), 373-385. DOI:10.1080/02697450216356

8.31.3 Number of and reasons for visits to an NBS area

Project Name: RECONECT (Grant Agreement no. 776866)

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[1] *University of Exeter Medical School, Knowledge Spa, Royal Cornwall Hospital, Truro, TR1 3HD*

[2] *Department of Environmental Engineering, Technical University of Denmark, Denmark*

[3] *IHE Delft Institute for Water Education, Delft, the Netherlands*

Number and reason of visits to an NBS area	**Green Space Management**
Description and justification	A tangible physical characteristic of the NBS by providing information about the number of people visiting the area and also making inference about the purpose of the stay. It has a value in itself in providing a non-debatable tangible input, but is also a critical input to other core indicators described in this note.
Definition	Visits means discretionary time, ranging from a few minutes out of the home to an all day trip. Visits may include time spent close to home or further afield, potentially while on holiday.
Measurement procedure and tool	Changes in use and user characteristics would be of interest both immediately post-intervention and also after a longer interval, to establish the sustainability of any impact on recreational use. Visitor count and characteristic estimation surveys could therefore be carried out before and after the NBS intervention to estimate the impact on recreational use. A good example of this kind of approach is (Vert et al., 2019). Suggested Priority for Data Collection and Assessment We suggest a key opportunity for estimating a range of impacts of the NBS is to measure changes in visit frequency and characteristics following the intervention. If data collection at only one time point is possible, this is still useful as it may be possible to estimate the potential for change associated with intervention. Therefore a priority measure to carry out before RECONECT NBS work is started (or post intervention for some Demonstrator B sites) would be to use observational surveys within the NBS area itself and/or surveys of the surrounding population to investigate local people's use of their neighbourhood green/blue space. A) NBS-specific area We recommend the implementation of SOPARC, System for Observing Play and Recreation in Communities. Full details of the SOPARC observation process and training materials are available here: https://activelivingresearch.org/soparc-

	system-observing-play-and-recreation-communities. Typically, observers with basic training will observe visitors and their activities at a range of times of day and days of the week, and record counts of visitors and so on, on standard record sheets. B) Local community We recommend the inclusion of several specific questions on visits to natural spaces in any survey (which could be delivered by post, online or face-to-face). These questions are used in UK government surveys that have been used extensively for evaluation of population visits to nature. These questions have also been used across multiple countries in the H2020 BlueHealth project. The recommended questions and associated information are below. The definition of 'visits' has been adapted here to focus on visits in the local area around the home, so should reflect primarily the natural spaces in the immediate surroundings of the community, including the NBS site. Economic valuation The number of people visiting can be converted to an economic value using several economic methods for assessing non-market value. The value people associate with using the NBS may be inferred by how far they travel to use the NBS. A basic introduction to the Travel cost method can be found here: http://www.ecosystemvaluation.org/travel_costs.htm Another method can be to use the WHO HEAT tool - economic value of changes in walking and cycling impact on all cause mortality - https://www.heatwalkingcycling.org A note on ethics • Any study involving human participants is likely to require ethical approval to ensure any risk to participants and people carrying out the work (e.g., surveys, observations in situ) is minimised, and data governance is appropriate. Municipal authorities may have their own ethical approval committees, or may need to work with local universities or related institutions to gain ethical approval for their work.
Data source	
Required data	User/visitor survey and count data can be used to assess the numbers of people visiting the NBS area for recreation and their individual and visit characteristics. These data can be used to derive associated values.

	The total number of recreational users of the NBS area, and their characteristics, can be estimated through: A) automated pedestrian/cycle counters (many commercial products available[1]) B) observational surveys using standardised tools such as SOPARC[2] User and visit characteristics may be of interest, for example: • Age • Gender • Activities undertaken (e.g., physically active or sedentary) • Duration of visit Some of these can be captured through observational surveys, but some may require face-to-face user surveys. **Local population** Survey of the local population may also be used to understand the recreational patterns of the local community, in terms of how they use their local green/blue space for recreation. Questions can be included in a survey (postal, online, face-to-face) to establish how often community members visit natural spaces, how long they spend there, and what they typically do. NBS may have the potential to increase visit frequency and/or duration and/or physical activity levels in the spaces, which all have potential wellbeing benefit. **Economic valuation** The potential (economic) value of recreational visits can be calculated in two primary ways, requiring different data inputs: • Travel cost method • -Economic valuation of wellbeing improvement associated with increased visit frequency/duration
Data collection frequency	
Level of expertise required	Good. Permission maybe required if accessing large quantities of data and the duration for which the data will be assessed
Synergies with other indicators	
Connection with SDGs	

Additional information	
References	[1] Example: https://www.eco-compteur.com/en/application/parks-recreation/ [2] https://activelivingresearch.org/soparc-system-observing-play-and-recreation-communities

8.31.4 Frequency of use of green and blue spaces

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Carmen de Keijzer[1], Payam Dadvand[1]

[1] *Fundacion Privada Instituto de Salud Global Barcelona, Barcelona, Spain*

Use frequency of green and blue spaces	Green Space Management Health and Wellbeing
Description and justification	This is an indicator of the frequency of visits to and time spent in different types of green and blue spaces, separately for spring-summer and autumn-winter. Previous studies have demonstrated that the use of green and blue spaces is an important measure of exposure to these spaces and could provide important benefits for health.
Definition	Self-reported time spent in green and blue spaces in hours per week, separately during summer and winter
Strengths and weaknesses	A strength of this indicator is that it obtains information on use of several different green and blue spaces and takes into account the season. However, a limitation is that it is prone to recall bias.
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes a section which is adapted from questionnaires applied in previous studies of the health effects of exposure to natural environments. The indicator is obtained from the question "*In a normal week during the last 12 months, on average, how many hours did you spend in the following green or blue spaces?*" The answers are the number of hours, given separately for a week in spring-summer and a week in autumn-winter and for the following natural environments: parks/public gardens, woods/other natural green spaces, agricultural fields, and blue spaces. This survey is repeated before and after the implementations of NBS in order to observe a potential change in use of green and blue spaces.

Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables (i.e., number of hours of a normal week spent in green and blue spaces)
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators of exposure to green space
Connection with SDGs	Good health and wellbeing: accumulating evidence demonstrates that increased green space exposure has been associated with better health and wellbeing. An increased use of green and blue spaces is likely to contribute to improved health and wellbeing. Sustainable cities and communities: The implementation of nature-based solutions and the increased use of these nature-based solutions contributes to sustainable cities and communities.
Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Nieuwenhuijsen, et al. (2014). Positive health effects of the natural outdoor environment in typical populations in different regions in Europe (PHENOTYPE): a study programme protocol. BMJ Open; 4, 4 Grellier et al (2017) BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and wellbeing from Europe's blue spaces. BMJ Open. 2017 Jun 14;7(6):e016188.

8.31.5 Activities allowed in recreational areas

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Activities Allowed In Recreational Areas	Green Space Management
Description and justification	In the new areas made available for leisure and recreation after the implementation of a new infrastructure (both NBS, Hybrid solutions and Grey infrastructures), a different range of activities could be carried out (e.g., walking, cycling, refreshment in picnic areas, watching cultural performances in natural arenas, etc.). The more the Design Scenarios will ensure a high variety of activities allowed in the area where the new infrastructure will be built, the more effective will be the benefits in terms of quality of life for the community (Kronenberg, 2017).
Definition	The indicator can be defined as the number of activities allowed in the recreational areas planned in the Design Scenarios. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario or Hybrid Scenario) computing the number of leisure activities that people can carry out in the areas created by the project.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of quality of life for the community.
Measurement procedure and tool	The indicator is equal to the number of leisure activities allowed in the recreational area by the project. In a long-term scenario, the indicators could be re-calculated, monitoring, through a direct survey, if the leisure spaces planned are actually used for the purpose they were designed. Unit of measure: number of activities
Scale of measurement	NBS
Data source	Project team
Required data	Project functional layout map
Data input type	Maps

Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	Kronenberg J., Andersson E., Rall E., Haase D., Kabisch N., Cummings C., Cvejić R. (2017). Guide to Valuation and Integration of Different Valuation Methods. A Tool for Planning Support. GREEN SURGE project Deliverable 4.4, University of Copenhagen, Copenhagen, Denmark.

8.32 Visual access to green space

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Carmen de Keijzer[1], Payam Dadvand[1]

[1] *Fundacion Privada Instituto de Salud Global Barcelona, Barcelona, Spain*

Visual access to green space	**Green Space Management** **Health and Wellbeing**
Description and justification	Visual access to green space is an indicator of exposure to green spaces. Previous experimental studies have shown short-term looking at green spaces could have mental health benefits such as reducing stress, restoring attention, and improving mood. An emerging body of evidence is also suggestive of the health benefits of the long-term visual exposure to green spaces.
Definition	Self-reported amount of green space in the view from windows at home and the frequency of looking at the view.
Strengths and weaknesses	A strength of this indicator is that few epidemiological studies have considered visual access to green space in the long-term association between green spaces and health. A limitation is that the indicator is self-reported.

Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes a section with the following questions: "*At home, how much green space (trees, grasses, flowers, etc.) can you see through the following window(s)?*" with possible answers on a scale from 0 (no green space/no window) to 4 (all of the view completely filled green space) "*How often (during the day) do you look out through the following window(s)?*" with possible answers on a scale from 0 (no window/never) to 3 (often) This survey is repeated before and after the implementations of NBS in order to observe a potential change in visual exposure to green and blue spaces.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators of exposure to green space
Connection with SDGs	Good health and wellbeing: accumulating evidence demonstrates that increased green space exposure has been associated with better health and wellbeing. An increased visual exposure to green spaces is likely to contribute to improved health and wellbeing. Sustainable cities and communities: The implementation of nature-based solutions may contribute to increased visual exposure to nature and to sustainable cities and communities.
Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Van den Bosch et al (2015) Autonomic Nervous System Responses to Viewing Green and Built Settings: Differentiating Between Sympathetic and Parasympathetic Activity. Int J Environ Res Public Health; 12(12): 15860–15874 Berto (2014) The role of nature in coping with psycho-physiological stress: a literature review on restorativeness. Behav Sci (Basel). 2014 Oct 21;4(4):394-409

	Bratman et al (2012) The impacts of nature experience on human cognitive function and mental health. Annals of the New York Academy of Sciences; 1249(1): 118-136 Abkar et al (2010) Influences of viewing nature through windows. Australian Journal of Basic and Applied Sciences; 4(10): 5346-5351

8.32.1 Viewshed

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy

[3] Norwegian Geotechnical Institute (NGI), Oslo, Norway

Viewshed	**Place Regeneration** **Green Space Management**
Description and justification	Some NBS could contribute to enhance landscape enjoyment increasing the amount of perceivable scenic sites. If the project foreseen the built of new natural trails, the scenic enjoyment of new viewsheds could be a co-benefit for population and tourists.
Definition	A viewshed is the geographical area that is visible from a location. It includes all surrounding points that are in line-of-sight with that location and excludes points that are beyond the horizon or obstructed by terrain and other features (e.g., buildings, trees). This Indicator could be calculated both in the Baseline Scenario taking into account the viewshed from all the scenic sites already existing, and in the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) considering, in addition, the new scenic sites created by the project.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of landscape perception. It could be difficult to find accurate data concerning digital terrain models.
Measurement procedure and tool	Given the vector data of the scenic site locations (point features) and a digital terrain model of the study area, common GIS software tools allow to achieve.

	The viewshed of a scenario is equal to the envelope of the viewshed obtained considering each scenic sites in the study area. In the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) the viewsheds from the new scenic sites created by the project have to be taken into account too.
Scale of measurement	km^2
Data source	Project team; Regional or Municipal Geographic Information System
Required data	Project layout map (vector data); Digital terrain model
Data input type	Maps; Vectorial and Raster data
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

8.33 Satisfaction with green and blue spaces

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Carmen de Keijzer[1], Payam Dadvand[1]

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Satisfaction with green and blue spaces	Green Space Management
Description and justification	Satisfaction with green and blue spaces is an indicator of the quality of these spaces. The quality of green and blue spaces is not only an important determinant of use of those spaces but also a potential modifier of the health effects of these spaces. The implementation of nature-based

	solutions is hypothesized to improve the availability and quality of green and blue spaces in the neighbourhood.
Definition	Self-reported satisfaction with the green and blue spaces in the neighborhood
Strengths and weaknesses	A strength of this indicator is that few studies have considered the quality of green space in the association between green space exposure and health. A limitation is that the indicator is self-reported.
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes a questionnaire, adjusted from a previous questionnaire, using the question "*Overall, in your neighbourhood, how satisfied are you with the following aspects?*", referring to the following aspects: the quality, the amount, the maintenance, and the safety of the green/blue environment. The answers are given on a scale from 1 (very dissatisfied) to 5 (very satisfied). This survey is repeated before and after the implementations of NBS in order to observe a potential change in the satisfaction with green and blue spaces.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators of exposure to green space
Connection with SDGs	Good health and wellbeing: accumulating evidence demonstrates that increased green space exposure has been associated with better health and wellbeing. An increased satisfaction with (and thus quality of) green spaces is likely to contribute to improved health and wellbeing. Sustainable cities and communities: The implementation of nature-based solutions contributes to the quality of green spaces in the neighbourhood and to sustainable cities and communities.

Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Nieuwenhuijsen, et al. (2014). Positive health effects of the natural outdoor environment in typical populations in different regions in Europe (PHENOTYPE): a study programme protocol. BMJ Open; 4,4 Grellier et al (2017) BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and wellbeing from Europe's blue spaces. BMJ Open. 2017 Jun 14;7(6):e016188.

8.34 Betweenness centrality

Project Name: Nature4Cities (Grant agreement no. 730468)

Author/s and affiliations: Flora Szkordilisz[1], Federico Silvestri[2], Barnabás Körmöndi[1]

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Betweenness centrality	**Green Space Management**
Description and justification	The betweenness centrality is a mathematical concept of graph theory. It can be measured for a node or an edge, and quantifies the number of times a node or an edge acts as a link in the shortest path between two other green areas with certain size. This can be used to assess the importance of streets and connections in the urban green infrastructure, and to detect missing links. It needs a representation of the urban green network as a graph, an abstract structure that sums up the relation between objects disregarding their actual physical appearance. Here you provide examples: An new NBS can change the physical communication network affecting the pedestrian flows, with repercussions or benefits to economic activities in the area nearby, and conversely on a social level. Dismissed tramway tracks converted in a walkway would change the connectivity of an area, turning a barrier to a space of connectivity between green areas.
Definition	The computation of betweenness centrality in urban green networks needs a representation of the city street network as graph. The edges of a graph represent the streets, while the nodes represent the intersections and NBS. The weight of an edge is the actual distance between two

	nodes. The graph can be undirected for the modelling of pedestrian fluxes, and directed in for vehicular traffic.
Strengths and weaknesses	
Measurement procedure and tool	The betweenness centrality of a node *v* is the sum, on every couple of nodes (*s*,*t*), of the ratios between the number of shortest paths, between those two nodes *s* and *t*, passing through the node *v* and the total number of shortest paths between *s* and *t*. $C_b(v) \ = \sum_{s \neq t \neq v \in V} \frac{\sigma_{st}(v)}{\sigma_{st}}(1)$ where $C_b(v)$ is the betweenness centrality for the v node σ_{st} (v) is the sum of shortest paths between two nodes s and t passing through v σ_{st} is the total number of shortest paths in the graph between s and t. This can be calculated for edges (i.e., streets) too. $C_b(a)$ is the betweenness of an edge. The formula is virtually the same, but the path has to pass through the entire edge and not just through a node. $$C_b(a) \ = \sum_{(s,t) \neq a} \frac{\sigma_{st}(v)}{\sigma_{st}}$$ In graphs representing urban networks, it could be more convenient to use a special case of the betweenness centrality, called stress centrality $C_s(v)$, which does not account for equivalent shortest paths since in most urban context given two nodes there is only one. $$C_s(v) \ = \sum_{s \neq t \neq v \in V} \sigma_{st}(v)$$ Tools: graph representation and centrality computation softwares or libraries, like: Osmnx, NetworkX, GraphTool, BoostGraph.
Scale of measurement	Neighbourhood and city scale
Data source	
Required data	- Urban graph: an abstract representation of the street networks of a city or neighbourhood, where the links between green spaces and NBS with certain minimum area represented by streets and nodes

Data input type	- Municipality databases - Open sources like Open Street Map - Proprietary sources like Google, TomTom etc.
Data collection frequency	Before / after the project's implementation, to characterize it is effects on the local environment
Level of expertise required	It requires some kind of training, but it can be related to generally known concept such as congestion.
Synergies with other indicators	Connectivity of green spaces and Accessibility indicators have similar aspects, measuring the availability of green areas or the network of green areas in an urban area.
Connection with SDGs	SDG 11 Sustainable Cities and Communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Citizens can upload data to a specific website, where a database is created to gather information from users.
Additional information	
References	Barabási, Albert-László. Network science book. Boston, MA: Center for Complex Network, Northeastern University. Available online at: http://barabasi. com/networksciencebook, 2014. Swyngedouw, E. and Kaika, M. (2003) The Environment of the City… or the Urbanization of Nature, in A Companion to the City (eds G. Bridge and S. Watson), Blackwell Publishing Ltd, Oxford, UK. doi: 10.1002/9780470693414.ch47 Jeff Speck: Walkable City, North Point Press, 2013. Andrés Duany, Jeff Speck, Mike Lydon: The Smart Growth Manual, McGraw-Hill Education, 2009. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

8.35 Proportion of road network dedicated to pedestrians and / or bicyclists

Project Name: UnaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Proportion of road network dedicated to pedestrians and / or bicyclists	**Green Space Management**
Description and justification	Increase in pedestrian and bicycle traffic is regarded beneficial for its economic, environmental, health and life quality effects. Availability of pedestrian paths and bicycle lanes can decrease the dependency on automobile ownership and use and related costs, free space from automobile traffic and congestion, reduce air pollution, increase physical activity and related health benefits and improve social activity and interaction within communities.
Definition	Proportion of road network dedicated to pedestrians and/or bicyclists (% of network)
Strengths and weaknesses	+ The numeric indicator is easy to obtain and can be compared to different areas of interest - Path length as a variable does not yield information regarding their use, utility, or perceived value by the community, which depend for instance on their coverage, consistency, terrain, safety and connectivity.
Measurement procedure and tool	The proportion of road network dedicated to pedestrians and/or bicyclists is calculated as the total pedestrian/bicycle path length measured as a percentage of the total road network in the whole urban community in question. The pedestrian/bicycle paths are roads or lanes designated and marked for use by pedestrians and/or bicycles. The calculation can be performed from a map with adequate markings of path types and lengths, from which pedestrian/bicycle paths are summed. Pedestrian paths and bicycle routes can be considered together or separately, depending on the specific metric desired. $Pedestrian\ or\ bicycle\ paths\ (\%) = \left(\frac{Length\ of\ pedestrian\ or\ bicycle\ paths}{Length\ of\ entire\ road\ network}\cdot 100\right)$
Scale of measurement	Street to metropolitan scale
Data source	

Required data	Length of pedestrian and/or bicycling paths (e.g., from a map) Length of the entire road network
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	Moderate
Synergies with other indicators	Synergies with *Area devoted to roads*, and *Encouraging a healthy lifestyle* indicators
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	

8.35.1 New pedestrian, cycling and horse paths

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Pedestrian, Cycling And Horse Paths	**Green Space Management**
Description and justification	The implementation of the design scenario can introduce new pedestrian, cycling and horse paths. The development and the permanent maintenance of a well-connected and safe bike, pedestrian, horse paths network could provide the opportunity for the enjoyment of natural resources, due to a higher accessibility. Therefore, the measure of the

	length of these new paths can be used as an indicator of the improvement of quality of life induced by the project
Definition	The indicator can be defined as the length of new pedestrian, cycling and horse paths created in the Design Scenario. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario or Hybrid Scenario) computing the length of new pedestrian, cycling and horse paths created by the project.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of quality of life for the community.
Measurement procedure and tool	The indicator is equal to the length of new cycling/pedestrian/horse paths network created by the project. Given the vector data of the new cycling/pedestrian/horse paths network, common GIS software tools allow calculating its length.
Scale of measurement	Unit of measure: km
Data source	Project team
Required data	Project layout map (vector data)
Data input type	Maps; Vector data
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3, 11
Opportunities for participatory data collection	
Additional information	
References	

8.35.2 Sustainable transportation modes allowed

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Sustainable Transportation Modes Allowed	**Green Space Management**
Description and justification	The Design Scenario should enhance the use of sustainable transportation modes. The number of sustainable transportation modes allowed by each scenario can be used as an Indicator. The higher the number of sustainable and low impacts means of transport in the scenario, the more effective will be the benefits in terms of quality of life for the community.
Definition	The Indicator can be defined as the number of sustainable transportation mode allowed in each scenario. This Indicator can be calculated both in the Baseline Scenario and in the Design Scenarios (e.g., NBS Scenario or Hybrid Scenario).
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of quality of life for the community.
Measurement procedure and tool	The Indicator is equal to the number of sustainable and low impacts means of transport allowed in the scenario by the provision of designated paths (i.e., bike lanes, pedestrian paths, etc.)
Scale of measurement	No.
Data source	Project team
Required data	Project layout map
Data input type	Maps
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	11

Opportunities for participatory data collection	
Additional information	
References	

8.36 New links between urban centres and NBS

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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New Links Between Urban Centres/Activities	**Green Space Management** **Urban Regeneration**
Description and justification	NBS or Hybrid solutions should enhance the connectivity between rural areas and urban centres, train stations and outdoor activities. The number of new links can be adopted as an Indicator of the benefits provided by NBS and Hybrid scenarios. The higher the number of new links created by the project, the more effective will be the benefits in terms of accessibility and therefore of quality of life for the community.
Definition	The Indicator can be defined as the number of new physical connections between urban centres and/or activities. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario or Hybrid Scenario) computing the number of new links created by the project.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of accessibility and therefore of quality of life for the community.
Measurement procedure and tool	The indicator is equal to the number of new physical connections between urban centres and/or activities created in the Design Scenario (i.e., new paths or roads).
Scale of measurement	No.

Data source	Project team
Required data	Project layout map
Data input type	Maps
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	
References	

8.37 Walkability

Project Name: proGIreg (Grant Agreement no. 776528)

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Walkability	**Green Space Management Urban Regeneration**
Description and justification	GIS derived raster image, function of connectivity, accessibility and perceived pleasantness with values ranging from 0 to 1 where 1 indicates the most walkable area (e.g., a park with pedestrian lanes well connected to city hot spots like residential and working areas) and 0 indicates the least walkable area (e.g., a major urban road)
Definition	Spatial map indicating, for each pixel, the degree of walkability on a scale from highly walkable to least walkable
Strengths and weaknesses	Strengths: It is a good indicator concerning accessibility of public urban green spaces Weaknesses: it is strongly dependent on the quality and scale of input data

Measurement procedure and tool	Remote sensing and GIS software (e.g., ArcMap, Google Earth Engine, R) Calculated from Spatial data provided by city administrations and population data (e.g., Landscan Global population -https://landscan.ornl.gov/)
Scale of measurement	Normalized index (30-1000 m pixel)
Data source	
Required data	Population density, road networks, land use, public transportation
Data input type	GIS data, remote sensing images (if required)
Data collection frequency	Yearly (depending on data availability)
Level of expertise required	High
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness.
Connection with SDGs	• Good health and wellbeing • Reduced inequalities • Sustainable cities and communities • Peace, justice and strong institutions
Opportunities for participatory data collection	None
Additional information	
References	Fan, P., Xu, L., Yue, W., & Chen, J. (2017). Accessibility of public urban green space in an urban periphery: The case of Shanghai. Landscape and Urban Planning, 165, 177-192.

8.38 Land composition

Project Name: MAvES (Mapping, Assessment and Valuation of Ecosystems and their Services) (JRC-D3- Institutional project)

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Land composition	**Green Space Management Urban Regeneration**
Description and justification	Land composition is used to assess the co-occurrence of land types within each Functional Urban Area. It represents the arrangements of ecosystem types within and around cities.
Definition	Land composition or co-occurrence of land use types, is a measure of spatial distribution of elements or components of a landscape. To quantify land composition we use the Landscape Mosaic (LM), model available in Guido's tool box (Vogt and Riitters 2017). A land mosaic is a tri-polar classification scheme that represents the land type dominance, the interface zone and the mix zone within a defined area. The classification uses the threshold values of 10%, 60%, and 100% along each axis to partition the tri-polar space into 19 classes. These threshold values are indicative for the presence (10%), dominance (60%), or uniqueness (100%) of each land cover type. The model measures land type heterogeneity and allows to consider trade-offs occurring between intra-land type changes (i.e., modification of the area of a given land type) and inter-land types changes (i.e., direction of change). It provides a measure of the relative contributions of the three key land types in percentage within a given neighborhood/observation area.
Strengths and weaknesses	-spatially explicit -> provides a detailed analysis of change in urban green infrastructure -relatively complex
Measurement procedure and tool	Dominant land types were extracted from Corine Land Cover. Agricultural areas include all agricultural land types identified in Corine, natural areas include all natural and semi-natural land types, developed areas include all artificial land types including urban green. Parameters applied for the analysis of 700 EU Functional Urban Areas

Dominant land types		
Dominant type	Corine Land Cover	notes
A = Agricultural	[12 -> 22]	all agricultural land types included in CLC

	N= Natural	[23-36]	for cities we exclude lakes
	D = Developed	[1 -> 11]	Urban green is classified as artificial

Spatial parameters

resolution (m)	moving window	observation area (km^2)
100	15 pixels	2.25

Scale of measurement	Functional Urban Areas
Data source	
Required data	- Corine Land Cover (CLC) 2000-2018, Version 20 - the model can be implemented using any land use land cover data
Data input type	-raster (vector data will be rasterised)
Precision	100 m
Data collection frequency	Year or time-series range (for available data at EU scale): 2000–2018 https://land.copernicus.eu/pan-european/corine-land-cover
Level of expertise required	-GIS programmer (advanced)
Synergies with other indicators	With structure of Urban green and Urban Forest
Connection with SDGs	//
Opportunities for participatory data collection	no
Additional information	
References	Landscape Mosaic (LM), model available in Guido's tool box (http://forest.jrc.ec.europa.eu/download/software/guidos/) Vogt P, Riitters K (2017) GuidosToolbox: universal digital image object analysis. Eur J Remote Sens 50(1): 352–361. doi: 10.1080/22797254.2017.1330650 + next MAES report will include the methodology applied to all EU cities

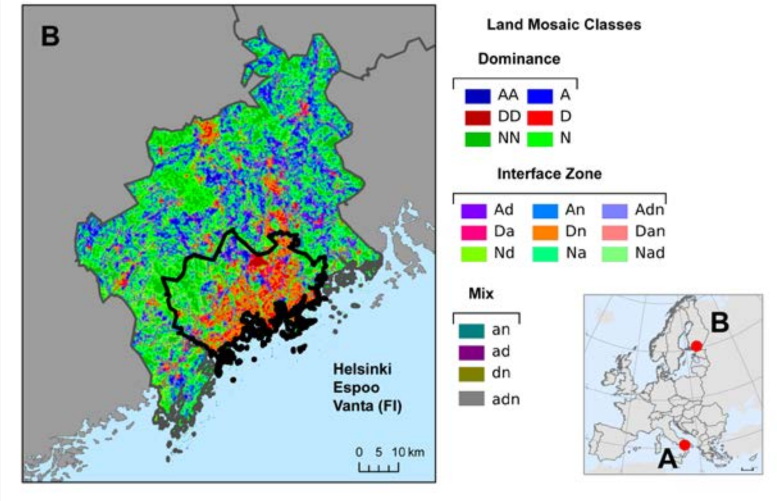

Figure 1: Example of Land Mosaic maps in Helsinki (FI) and Naples (IT). A = Agriculture; D = Developed; N = Natural; Mix = Mixed presence of all land classes.

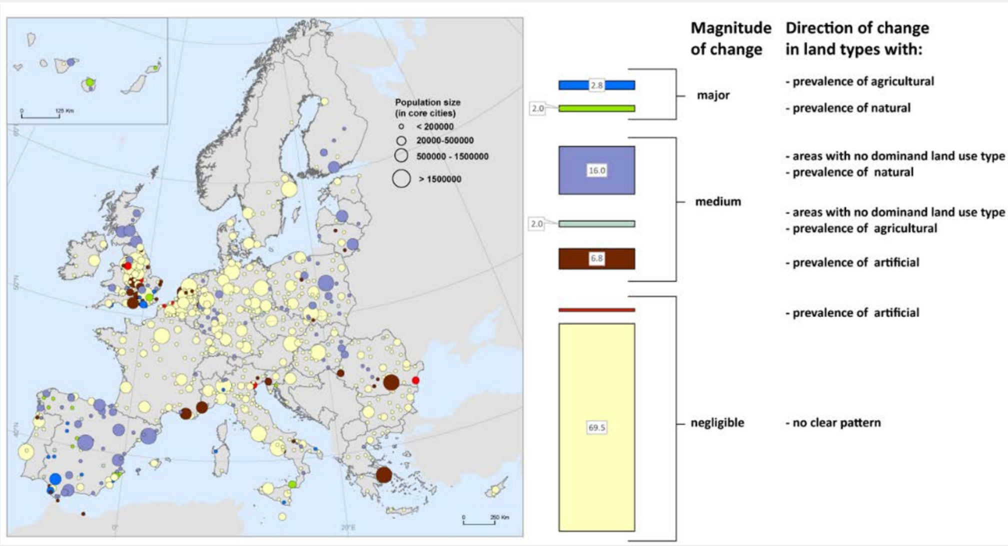

Figure 2: FUAs classified in terms of land types magnitude and direction of change between 2000 and 2018.

8.39 Land use change and green space configuration

Project Name: Connecting Nature (Grant Agreement no. 730222)

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Land use change and green space configuration (Applied and EO/RS)	Green Space Management
Description and justification	Identifying urban land-use patterns is important for decision-makers to ensure sustainable development. Typical metrics for this indicator comprise the use of land use and land cover maps. These are typically obtained by classifying and modelling Remotely Sensed (RS) data, for example Landsat in a GIS environment. Use of remote sensing involves the application of multi-temporal datasets to quantitatively analyse the temporal effects of the land use changes as well as green space configuration. Due to the high degree of complexity of urban issues, GIS and remote sensing (RS) technologies have long been used to facilitate scientists to assess the overall state of urban environment, to manage the urban infrastructures and improve the efficiency and rationality of its spatial management. A necessary prerequisite for the improvement of urban environment is rationality of its spatial management – the optimal division of urban spaces by their functional predestination. One of approaches suited to this is functional zonation of the city – a spatial management of basic types of activities – labour, household, recreational. Data on landuse change and greenspace configuration collected in these ways can be used to: • Track landuse change on sites in relation to ecosystem service provision; • Track trends in private garden use to monitor a substantial green infrastructure asset over which local authorities have little influence; • Set targets for landuse change, for example recognising the highest quality brownfield sites for biodiversity and ecosystem service delivery and prioritising the beneficial reuse of brownfield sites with little environmental value.
Definition	Records change in land use (e.g., from brownfield to green areas by adding vegetated brownfield to UGI resource) and

	accounting for configuration (e.g., individual gardens, groups of gardens and socio-economic factors impact on the utility of private gardens for native biodiversity conservation).
Strengths and weaknesses	**Applied methods:** Applied methods are used to support and supplement evidence generated through remote sensing metrics. As such, they should strengthen the evidence generated. **Earth observation / Remote sensing methods:** During the last decades, geographic information systems (GIS), historical maps, aerial imagery, and remotely sensed images have proven very effective in studying land change dynamics. These tools have been widely used also on the city level to assess changes over time and to predict future scenarios based on long-term sets of observations. Agarwal et al. (2002) presented a framework to compare models of land use change with respect to scale (spatial and temporal), complexity, and their ability to incorporate space, time, and human decision making. Several different approaches have been developed to predict future land use transformations.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Indicator Metrics Reviews Env42_Applied and Env42_RS
Scale of measurement	**Applied methods:** This indicator is generally applied at a city-scale, but neighbourhood and site level assessments can also be made. **Earth observation / Remote sensing methods:** methods suitable for a range of geographical scales.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env42_Applied and Env42_RS
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env42_Applied and Env42_RS
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote

	sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env42_Applied and Env42_RS
Level of expertise required	**Applied methods**: As this indicator is generally associated with remote sensing, GIS expertise and a familiarity with modelling are required. Supplementing this with local ground-truthed data requires expertise in habitat assessment and, potentially, participatory processes. **Earth observation / Remote sensing methods**: It is a challenge and a critical need to understand the methods for extracting useful information from the data, as well as to interpret the time-series signals correctly. We need to be able to interpret both slow variations due to gradual ecosystem transformations, and faster variations due to disturbances or other rapid events. Methods based on remote sensing theory, process modelling, and statistical data analysis will help developing this understanding.
Synergies with other indicators	The synergy between geographic information systems (GIS) and remote sensing comes into play here. To be interpreted accurately, remotely sensed data are often supplemented with other data. Often these ancillary geospatial data can be found or included in a GIS for analysis. But to be more valuable in decision-making contexts, GIS data layers should be up-to-date as is practical. Remotely sensed data are a key technology for updating many types of GIS data. Thus when environmental planners, resource managers, and public policy decision-makers want to measure, map, monitor, or model future scenarios in order to facilitate better management decision-making, remote sensing is being employed more and more within the context of a GIS as a decision support system. Due to this link between GIS and Remote Sensing, there are strong synergies with other mapping indicators and other environmental indicators such as UHI, drainage, air quality, biodiversity as well as health and wellbeing.
Connection with SDGs	All except SDG 4: Economic opportunites (e.g., grow-your-own); Urban agriculture; Links to access to greenspace; Links to environmental education; Co-benefits for clean water; Links between greenspace and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure; Social equality in relation to greenspace; Sustainable urban development; Opportunities around responsible management of greenspace; Climate change adaptation; Potential co-benefits related to more sustainable water management; Habitat creation;

	Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods** Participatory processes are possible to supplement remote sensing data with ground-truthed data to avoid the pitfalls of the heterogeneity in land use of high-density urban areas. Citizen science and participatory GIS processes can be used for this. **Earth observation / Remote sensing methods**: A combination of remote sensing, field observations and focus group discussions is often suggested to be used to analyse the dynamics and drivers of LULC change. Supervised image classification can be applied to map LULC classes. In addition, focus group discussions and ranking can support to explain the drivers and causes linked to the land cover changes.
Additional information	
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8.40 Soil sealing

Project Name: Connecting Nature (Grant Agreement no. 730222)

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Soil sealing (Applied and EO/RS combined)	Green Space Management
Description and justification	Impermeable ground and modified ecosystems transform natural soil and alter important environmental processes (e.g., water cycle, energy balance, etc.). Mapping impermeable surfaces provides an indicator of urban development, e.g., densification/urban sprawl, and can aid assessments of drainage, urban heat island, biodiversity and health and wellbeing. Data on soil sealing collected in these ways can be used to: • Set targets for soil unsealing; • Monitor changes in relation to loss of permeable surfaces; • Linking to other indicators such as land use change and stormwater management;

	• Support initiatives to improve soil health and promote groundwater recharge.
Definition	De-sealing, reusing sealed sites to reduce land take/soil sealing (with impermeable surfaces), and use of permeable materials and surfaces, e.g., green roofs.
Strengths and weaknesses	**Applied methods:** Not typically a method for generating solid evidence. Tends to be more of a focus on generating an index to help quantify change. **Earth observation / Remote sensing methods:** If appropriate pixel and/or sub-pixel classification is carried out, a high level of evidence can be generated. Error factors can also be calculated based on sample areas.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Indicator Metrics Reviews Env81_Applied and Env81_RS
Scale of measurement	**Applied methods:** City-scale typically, but may be possible to use the data to monitor local-level changes in greenspace if combined with high-resolution remote sensing imagery methods. **Earth observation / Remote sensing methods:** Analysis possible at various geographical scales.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env81_Applied and Env81_RS
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env81_Applied and Env81_RS
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env81_Applied and Env81_RS
Level of expertise required	**Applied methods**: Data is generally added to background digital maps, so some expertise in mapping/GIS is needed. **Earth observation / Remote sensing methods**: There are many kinds of remote sensing data available, but to find out the best fitting ones needs expert knowledge. Expertise in

	mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing. Given the large number of remote sensing data available, it is difficult to select the appropriate one because each satellite has different revisit times, ordering requirements, delivery schedules, pixel resolutions, sensors, and costs.
Synergies with other indicators	There are synergies with other indicators related to mapping urban form. The data can be used as an index for other environmental (i.e., UHI, flooding) and health/wellbeing indicators that require blue-green space mapping as the foundation for analysis. For example, impervious surface % and UHI (Yuan & Bauer, 2007) and flooding (Mejía & Moglen, 2009). Combining RS and in-situ observations takes advantage of their complementary features.
Connection with SDGs	Links to SDGs 2 to 4, 8 to 11, and 13 to 17: More opportunity for urban agriculture; Proportion of greenspace linked to health & well-being; Links to environmental education; Links to healthy working environments; Links to attractive working environments; Social equality in relation to greenspace; Sustainable urban development; Climate change adaptation; Potential co-benefits related to more sustainable water management; Potential for habitat creation; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods:** Lots of opportunity for community participation if appropriate methods are adopted. The LandSense app provides a mechanism to engage citizen participation and update data. **Earth observation/Remote sensing methods:** Since assessment of soil sealing is based on land use change data, modeling of future soil sealing and soil loss can also involve participatory impact assessment. The major data inputs for soil sealing are satellite image based land use maps and soil maps. The participatory impact assessment involves meetings with stakeholders and collecting their opinions in a semi-quantitative form.
Additional information	
References	**Applied methods**: Grant, G (2017) Urban Greening Factor For London. Report produced by the Ecology Consultancy for the Greater London Authority. Available at: https://www.london.gov.uk/sites/default/files/urban_greening_factor_for_london_final_report.pdf) Kruuse, A (2011) The green space factor and the green points system. GRaBS expert paper 6. Available from:

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8.41 Ambient pollen concentration

Project Name: UNaLab (Grant Agreement no. 730052)

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Ambient pollen concentration	**Green Space Management Air Quality**
Description and justification	Urban green spaces frequently have a limited number of plant species, including a higher proportion of non-native species in comparison with rural areas (McKinney, 2002). The low species diversity in many urban areas is directly linked to the formation of concentrated pollen emission sources. In particular, large-scale use of a small number of roadside tree species results in production of large quantities of a single species of pollen. Areas of concentrated pollen may not be readily dispersed by air currents. Some studies indicate that urban citizens are 20% more likely to suffer airborne pollen allergies than people living in rural areas, largely due to the uniformity of green spaces, where a small number of species that have proved highly suited to urban environmental conditions are overwhelmingly used, and the interaction of pollen with air pollutants (Cariñanos & Casares-Porcel, 2011).
Definition	Number of grains of pollen per cubic metre of air (pollen grains/m^3)
Strengths and weaknesses	The method of identifying and characterising trapped pollen and spores is time-consuming and requires considerable expertise, but the results are widely accepted and known to be consistent.
Measurement procedure and tool	The volumetric Hirst-type pollen and spore trap designed in 1952 remains one of the devices most commonly used for pollen and spore monitoring (Buters et al., 2018). The Hirst-type trap is standard in pollen monitoring networks in Europe. The Hirst-type pollen and spore trap uses a vacuum pump to continuously draw air at a known rate (e.g., 10 L/min). A wind vane attached to the sampler head ensures that the trap inlet is always facing the prevailing wind. Depending on the configuration of the trap, pollen and spores are captured on adhesive coated transparent plastic tape (Melinex) or on a microscope slide coated with an adhesive. Adhesive tapes are attached to a metal drum that rotates with time.

	Pollen traps can be fitted with a drum specific to a 24-h or a 7-day sampling period. At the conclusion of the sampling period, the tape with adhered pollen and spores is cut into pieces representing 24-h periods of time and mounted on a microscope slide. Where the pollen and spores are captured directly on a microscope slide, the slide must be changed every 24 h. These slides are examined by microscopy for counting and identification of pollen and spores.
Scale of measurement	Plot to neighbourhood scale
Data source	
Required data	Pollen measurement data
Data input type	Quantitative
Data collection frequency	Continuous collection with a 24 h or a 7-day sampling period
Level of expertise required	Moderate
Synergies with other indicators	Synergies with *Distribution of public green space*, *Accessibility of urban green spaces,* and *Proportion of natural area,* and *Availability and equitable distribution of blue-green space* indicators
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Buters, J.T.M., Antunes, C., Galveias, A., Bergmann, K.C., Thibaudon, M., Galán, C. … & Oteros, J. (2018). Pollen and spore monitoring in the world. Clinical and Translational Allergy, 8, 9. Cariñanos, P., & Casares-Porcel, M. (2011). Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. Landscape and Urban Planning, 101(3), 205-214. McKinney, M. (2002). Urbanization, Biodiversity, and Conservation: The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. BioScience, 52(10), 883-890.

BIODIVERSITY ENHANCEMENT

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9 Recommended Indicators of Biodiversity Enhancement

9.1 Structural and functional connectivity of urban green and blue spaces

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Connectivity of urban green and blue spaces (structural and functional) (Applied & EO/RS combined)	**Biodiversity**
Description and justification	One of the major impacts of urbanization is the *fragmentation of open spaces* into smaller and more isolated patches. Increased fragmentation of green in urbanized areas can reduce intra- and inter-species connectivity and lead to a loss of biodiversity (Kettunen *et al.*, 2007). Fragmentation of green areas and distance between habitat patches is thus an important factor in determining biodiversity. A *Green Infrastructure* approach, linking parks and other green spaces, is therefore considered essential for the preservation of biodiversity and to counter further habitat fragmentation and increase connectivity (Sylwester, 2009). Connectivity of landscapes can be evaluated in terms of:

	- Structural connectivity – relating to the spatial configuration of patches, without considering the movement of individual organisms among these patches (Ioja et al. 2014) and - Functional connectivity – relating to the ability of organisms to move among patches (Tischendorf and Fahrig 2000). Both types of connectivity can be quantified using metrics that span different ranges of scale and complexity. Evaluation of blue-green space structural and functional connectivity can be used to: - Underpin green infrastructure and biodiversity spatial planning; - Prioritise sites for interventions; - Assess that impacts of NBS projects on pre-existing green networks; - Promote active transport initiatives.
Definition	Measuring the potential for green or blue areas to amplify the connectivity and multifunctionality of other urban green/blue areas.
Strengths and weaknesses	**Applied methods**: Robustness of evidence for structural connectivity tends to be based on the methodology used to identify and characterise urban greenspace, the scale of resolution of the data, and the age of the data in relation to current state. If up-to-date data from reliable sources is used, calculation of distances using GIS mapping provides solid evidence. For functional connectivity, the robustness of data tends to be correlated with the level of understanding in relation to the spatial dynamics of the target group or activity, and the suitability of habitat. **Earth observation/Remote sensing methods**: The potential for satellite remote sensing to provide key data has been highlighted by many researchers, offering repeatable, standardized and verifiable information on long-term trends in biodiversity indicators and characteristics of connectivity and fragmentation. As concluded by a variety of research (listed in the references), remote sensing permits one to address questions on scales inaccessible to ground-based methods alone, facilitating the development of an integrated approach to natural resource management, where biodiversity, pressures to biodiversity and consequences of management decisions can all be monitored. Remote sensing (RS)—taking images or other measurements of Earth from above—provides a unique perspective on what is happening within the urban landscape and thus plays a special role in green infrastructure analysis, environmental monitoring as well as biodiversity and conservation

	applications. The periodic repeat coverage of satellite-based RS is particularly useful for monitoring change and so is essential for understanding trends, and also provides key input into assessments of vegetation, connectivity and conservation management.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. *Applied/public participation metrics review*: Connectivity of landscapes can be evaluated in terms of: • Structural connectivity – relating to the spatial configuration of patches, without considering the movement of individual organisms among these patches (Ioja et al. 2014) and • Functional connectivity – relating to the ability of organisms to move among patches (Tischendorf and Fahrig 2000). Both types of connectivity can be quantified using metrics that span different ranges of scale and complexity. Structural connectivity is measured by the proximity of blue-green spaces and the infrastructure matrix that these form across a city. These are typically measured through a blue-green space mapping exercise that orientates and measures distribution and proximity on a city or regional level (Zhang et al. 2019). Typically, such mapping is done using the interrogation of satellite imagery and or land use maps. Examples of methodologies for such mapping include STURLA (Hamstead et al 2016) and FRAGSTATS (Saura and Torné 2009). The outputs from such exercises are usually represented through green infrastructure network maps that provide a planning tool for protecting existing blue-green spaces and opportunity maps for identifying priority areas for enhancing structural connectivity (Carlsen et al. 2011; Zhang et al. 2019). Participatory processes are also possible using internet-based public participation GIS (PPGIS) surveys to map functional aspects of urban blue-green space (Kahila-Tani et al. 2016; Brown et al 2018a; Brown et al. 2018b) and map underused/unmapped microspaces (Crowe et al. 2016). Functional connectivity is measured in relation to the ability of the landscape to support the movement of organisms through it (Peer et al. 2011). There has been a particular focus on functional connectivity in relation to urban biodiversity (Hess and Fischer 2001; Opdam 2006; Ahern 2007) because of the impact that fragmentation and the reduction in the number and area of natural habitats has on the ability of many species to persist (Fletcher et al. 2018).

The predominance of grey infrastructure in urban areas can represent a physical barrier to the movement of many species. These barriers can occur to the extent that urban development can exclude many species (McKinney 2006). Similarly to biodiversity, lack of blue-green space connectivity can also present a barrier to the movement of humans through urban areas (Ioja et al. 2014), particularly in relation to the use of active transport (Giles-Corti et al. 2010) and physical activity (Davison and Lawson 2006).

Thresholds for connectivity differ between different species/groups. For some, connectivity must represent linear physical connections, for other species, 'stepping stones' of suitable habitat over appropriate spatial scale represent sufficient functional connectivity (Vergnes et al. 2012). Similar patterns are also reported for human activities associated with blue-green space (Wineman et al. 2014; Peschardt et al. 2012). This means that, for both biodiversity and human functional connectivity, it is vital to have an understanding of the spatial dynamics of connectivity of relevance to your target group and activity (e.g., for humans - active transport; for biodiversity – foraging, colonisation, etc) in order to set threshold values.

Methods for measuring connectivity are therefore based on the spatial thresholds for the group and activity of interest. The most basic method to achieve this is to use Geographical Information Systems (GIS) to apply buffer areas to mapped blue-green spaces that are known to be suitable for the target group and activity.

A more complex, but potentially more realistic approach is to combine distance data with data on the spatially heterogeneous impedance of the landscape matrix (i.e., a measure recognising that some non-target landuse types might be more permeable than others) (Hargrove et al. 2004). By adopting such an approach, it is possible to measure potential connectivity corridors using least-cost path tools using GIS software combined with gravity models and graph theory (Kong et al. 2010).

Conefor software in ArcMap can be used to calculate the integral index of connectivity (IIC). This represents a method for combining the distance between patches with the threshold dispersal distance of a certain species (Saura and Torné, 2009). Such a tool enables evaluation of functional connectivity and provides a suitable metric for landscape conservation planning (Pascual-Hortal and Saura, 2006). Another example of a method for capturing functional connectivity is the use of habitat suitability models (HSM) utilising remote sensed vegetation data to map landcover composition and species distributions across cities (Bellamy et al. 2017).

In general, the biggest barrier to the delivery of such mapping tends to be a lack of understanding of the spatial dynamics (in relation to what constitutes functional connectivity) for the target groups (LaPoint et al. 2015). Applied methods to study the spatial dynamics of target groups, and to assess the permeability of different habitat types by direct observation, can strengthen the validity of mapped data.

Evaluation of blue-green space structural and functional connectivity can be used to:

- Underpin green infrastructure and biodiversity spatial planning;
- Prioritise sites for interventions;
- Assess that impacts of NBS projects on pre-existing green networks;
- Promote active transport initiatives.

Earth observation/remote sensing metric review:

One of the major impacts of urbanization is the fragmentation of open spaces into smaller and more isolated patches. Increased fragmentation of green in urbanized areas can reduce intra- and inter-species connectivity and lead to a loss of biodiversity (Kettunen et al., 2007). Fragmentation of green areas and distance between habitat patches is thus an important factor in determining biodiversity. A Green Infrastructure approach, linking parks and other green spaces, is therefore considered essential for the preservation of biodiversity and to counter further habitat fragmentation (EEA, 2010). Fragmentation and isolation of urban green spaces can be described by means of spatial metrics, i.e., quantitative measures of spatial pattern that were originally developed by landscape ecologists to examine the link between the spatial patterning of ecosystem types in natural landscapes and ecological processes (Turner, 1989, 1990). Many metrics have been developed for characterizing patterns in landscapes and were later implemented in the spatial analysis program FRAGSTATS by McGarigal and Marks (1995), which today is a commonly used quantitative tool in the field of landscape ecology.

For instance, in the study of Van de Voorde et al. (2010) various spatial metrics available in FRAGSTATS were calculated to describe fragmentation and isolation of open and dense vegetation patches in the Brussels Capital Region, mapped from high resolution Quickbird data. Fragmentation can be described by the total number of patches and by summary statistics characterizing the frequency distribution of patch size (expressed in hectares), including mean patch size, median patch size, standard deviation of patch size and coefficient of variation. Isolation of open and dense patches can be described by two indicators: the Euclidean nearest neighbor distance of a patch to other patches of the same type, and the proximity index.

Satellite imagery is the fastest method for data collection for urban planning. Since the first development of satellite imagery, many studies have investigated extracting various types of vegetation information. Johansen & Phinn (2006) combined IKONOS and Landsat ETM+ data in order to map structural parameters and the species composition of vegetation. Dennison et al. (2010) used GeoEye-1 high spatial resolution satellite data to map canopy mortality caused by a pine beetle outbreak. Gašparović et al. (2018) used WorldView-2, RapidEye, and PlanetScope data to detect urban vegetation based on land cover classification. Kranjčić et al. (2018, 2019) used Sentinel-2 data to visualize bark-beetle-damaged forests in Croatia, and Wessel et al. (2018) tested object-based and pixel-based methods on Sentinel-2 imagery for two forest sites in Germany. They stated that Sentinel-2 data had high potential for applied forestry and vegetation analysis. Friedel et al. (2017) used unsupervised machine learning to map landscape soils and vegetation components from satellite imagery. Tsai et al. (2018) used machine learning classification in order to map vegetation and land use types. As seen from the abovementioned literature, a lot of work has been done with remote sensing and machine learning to extract vegetation information and measure the potential for green or blue areas to amplify the connectivity and multifunctionality of other urban green/blue areas.

Many studies highlighted landscape fragmentation which was caused by rapid urbanization and has resulted in an immense amount of damage to the ecological system. Taking city districts as study areas, Guo et al. (2018) distinguished the vital patches and corridors for landscape connectivity maintenance through morphological spatial pattern analysis (MSPA), the probability of connectivity (PC), and the least-cost path analysis. These methods are mostly adopted and combined from the existing research about landscape modeling and can be divided into two parameters: the resistance value and the distance threshold. In order to get a species-specific result, some focal species should be selected whose biological characteristics and habitat types are assumed to represent most of the habitats in the city being studied (umbrella species). The result of such studying can show the different habitats and corridors for such species.

Then, the results of simulated scenarios can be used to obtain the final landscape pattern. Based on this study, one can propose a paradigm of ecological network identification of multiple species, which may contribute to landscape modeling and greenspace planning.

Landscape connectivity, the opposite of landscape fragmentation, describes the facilitating or impeding effect of the landscape on the dispersal of species among habitats. It is used to evaluate the ecological service function of a certain landscape by quantifying landscape patterns from a macro point of view. In recent decades, an interdisciplinary field called landscape ecology has proposed new methods to understand how landscape patterns influence ecological processes, for instance, biodiversity and the warmer microclimate-heat island effect.

The high-resolution remote sensing images (RS-images) can be used to extract land cover information. Image processing should be performed using ENVI (Harris Geospatial, Boulder, CO, USA) and eCognition (Trimble, Westminster, CA, USA), which can extract meaningful information from remote sensing image. Before classification, images have to be segmented. The scale parameter refers to the threshold of the heterogeneity variation allowed in the segmentation process (Dekavalla & Argialas, 2018). Scale parameter will affect the accuracy and efficiency of the extraction process. Multiscale segmentation was used to fix this problem. It is the foundation procedure of object-based image analysis (OBIA) to convert discrete pixels of RS-images into a homogeneous image object. Depending on the required land-cover categories (green space, agriculture land, built-up area, transportation area, and water), the segmentation scale parameter and the hierarchical relationship were identified according to their characteristics after several attempts to obtain a satisfactory result.

Difficulties in pixel-based classification caused by increasing satellite resolution led to the development of OBIA (Blaschke 2010). By identifying spectral and spatial information (the normalized difference vegetation index, geometry, brightness, texture, neighborhood attributes), adjacent pixels are grouped into multipixel objects (Aplin et al. 1999). For this reason, the K-nearest neighbor method can be adopted in order to obtain the land-cover categories by creating the following spectral characteristics: normalized difference vegetation index, standard deviation, maximum difference, brightness, length/width, roundness, and aspect ratio.

Landscape metrics, for example, the L-Z complexity method (Li et al. 2009) and mean patch shape fragmentation index can be developed to quantify landscape fragmentation. Landscape fragmentation processes can be classified into perforation, subdivision, shrinkage, and attribution, which can also be measured. However, these studies evaluate the overall landscape fragmentation without locating where fragmentation is taking place. According to the definition of landscape fragmentation, fragmentation will bring two results: one is the decrease in patch area, and the other is the increase in patch number. In other words, the mean patch area will decrease. Therefore, the mean patch area can be used to quantify the fragmentation. The RS-image can be clipped into grids (size = 1 km × 1 km) using the Fishnet tool in ArcGIS. The area and number of patches in each grid can be summarized, then the mean patch area can be calculated to indicate its landscape fragmentation.

Table 1. Remote-sensing based indices for the effectiveness and health of green (Wellmann et al., 2018)

Type of Index	Index Name	Abbreviation	Reference
Vegetation Indices	Vegetation fractions	Frac	(Haase et al., 2019)
	Normalized difference vegetation index	NDVI	(Tucker, 1979)
	Green NDVI	gNDVI	(Gitelson et al., 1996)
	Red edge normalized difference vegetation index	reNDVI	(Gitelson and Merzlyak, 1994)
	Vegetation health index	VHI	(Lausch et al., 2018)
			(Kogan, 1990, 1997)
	Vegetation condition index	VCI	(Kogan, 1995)
	Temperature condition index	TCI	(Singh et al. 2003)
Combination of methods	satellite remote sensing with on-the-ground observations	-	(Lotze-Campen and Lucht, 2001)
			(Haase et al., 2019)
Statistical Indices	Principal component analysis	1st component	(Jolliffe, 2002)
		2nd component	
		1st and 2nd component	

Note: No single approach is sufficient to monitor the complexity and multidimensionality of health of green and VH over the short to long term and on local to global scales (as stated by Haase et al., 2019; Lausch et al., 2018; Wellmann et al., 2017). Rather, every approach has its pros and cons, making it all the more necessary to link approaches. It is possible to realize within the frameworks proposed in the above mentioned publications and by reflecting crucial requirements for coupling approaches and integrating additional monitoring elements to form a multisource vegetation health monitoring network (MUSO-VH-MN) as suggested by Lausch et al. 2018. Thereby it is important to have in mind, that when it comes to linking the different approaches, data, information, models or platforms in a MUSO-VH-MN, big data with its complexity and syntactic and semantic heterogeneity and the lack of standardized approaches and VH protocols pose the greatest challenge. Therefore, Data Science with the elements of (a) digitalization, (b) semantification, (c) ontologization, (d) standardization, (e) Open Science, as well as (f) open and easy analyzing tools for assessing VH are important requirements for monitoring, linking, analyzing, and forecasting complex and multidimensional changes in health of green and VH.

Table 2. Statistical indicators that have been tested for the quantification of spectral plant trait variations (Wellmann et al., 2017).

Type	Name	Formula	Reference
GLCM *Stats group*	GLCM mean	$\mu_i = \sum_{i,j=0}^{N-1} i(P_{i,j})$	(Haralick et al., 1973)
	GLCM variance	$\sigma_i^2 = \sum_{i,j=0}^{N-1} P_{i,j}(i-\mu_i)^2$	(Haralick et al., 1973)
	GLCM correlation	$\sum_{i,j=0}^{N-1} P_{i,j}\left[\frac{(i-\mu_i)(j-\mu_j)}{\sqrt{(\sigma_i^2)(\sigma_j^2)}}\right]$	(Haralick et al., 1973)
GLCM *Contrast group*	GLCM homogeneity	$\sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2}$	(Haralick et al., 1973)
	GLCM contrast	$\sum_{i,j=0}^{N-1} P_{i,j}(i-j)^2$	(Haralick et al., 1973)
	GLCM dissimilarity	$\sum_{i,j=0}^{N-1} P_{i,j}\lvert i-j\rvert$	(Haralick et al., 1973)
GLCM *Orderliness group*	GLCM entropy	$\sum_{i,j=0}^{N-1} P_{i,j}(-\ln P_{i,j})$	(Haralick et al., 1973)
	GLCM angular second moment	$\sum_{i,j=0}^{N-1} P_{i,j}^2$	(Haralick et al., 1973)
Spatial Autocorrelation	Geary's *C*	$C = \frac{n-1}{2*\left(\sum_i\sum_j w_{ij}\right)} * \frac{\sum_i\sum_j w_{ij}(x_i-x_j)^2}{\sum_i (x_i-\bar{x})^2}$	(Geary, 1954)
	Moran's *I*	$I = \frac{n*\sum_i\sum_j w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\left(\sum_i\sum_j w_{ij}\right)*\sum_i (x_i-x)^2}$	(Moran, 1950)
Descriptive Statistics	Standard Deviation	$\sigma = \sqrt{\frac{\sum(x-\overline{x})^2}{N}}$	
	Coefficient of Variation	$CV = \frac{\sigma}{\mu}$	(Datt, 1998)

Further details and hyperlinks on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Environmental Indicator Metrics Review Report

Scale of measurement	**Applied methods**: Analysis is generally performed on a city-wide or regional scale. Local connectivity analysis is also possible. **Earth observation / Remote sensing methods**: Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change at various geographical scales. However, the higher resolution required, the more expensive would be the RS data needed. In some cases, it would be better to use images provided by drones, but in this case permissions for survey mapping will be required and depends on the local and national/government regulations.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Level of expertise required	**Applied methods**: Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing. **Earth observation / Remote sensing methods**: The measure of the physical connectedness of the vegetation across a landscape, sometimes referred to as the 'structural vegetation connectivity' will typically be measured using remote sensing methods. It differs from 'ecological connectivity' which will usually be measured through on-ground observations and analysis. "Hyperspectral" sensors can have more than 200 bands and can provide a wealth of information to help, for example, identify specific species. Processing such datasets requires special expertise and satellite-based hyperspectral sensors are not yet common.
Synergies with other indicators	Remote sensing is generally most useful when combined with in situ observations, and these are usually required for calibration and for assessing RS accuracy. RS can provide excellent spatial and temporal coverage, for example, though its usefulness may be limited by pixel size which may be too coarse for some applications. On the other hand, in situ measurements are made at very fine spatial scales but tend to be sparse and infrequent, as well as difficult and relatively expensive to collect. Combining RS and in situ observations takes advantage of their complementary features. As such,

	synergies exist with other indicators that use greenspace mapping as a foundation for analysis
Connection with SDGs	Links with SDGs 3, 4, 8, to 11 and 13 to 17: Links to better accessibility; Links to environmental education; Job creation; More connected infrastructure; Social equality in relation to greenspace; Sustainable urban development; Climate change adaptation; Potential co-benefits related to more sustainable water management; Potential habitat creation/habitat connectivity; Environmental Justice in relation to high-quality greenspace; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods**: Opportunities are available for participation. This can be in the form of mapping greenspaces using internet-based public participation GIS (PPGIS), assessing habitat suitability for target species and activities, or surveying for presence/absence/movement of species. **Earth observation/Remote sensing methods**: Participatory processes can be used to support data analysis. For details see Applied above.
Additional information	
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9.1.1 *Structural connectivity of green space*

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Structural connectivity	**Biodiversity**
Description and justification	Biodiversity is the measure of biological variety in the environment and it has an important role in functioning ecosystems services and health of environment and society. Biodiversity is an aspect of natural environment that is most directly affected by anthropogenic influence. City biodiversity is seen as an important aspect of sustainable and resilient urban development. The fragmentation of natural environments is a major threat to biodiversity as scattered and non-connected natural areas are much less efficient in preserving biodiversity than large and connected areas.
Definition	Degree of physical ("structural") connectivity between natural environments within a defined urban area
Strengths and weaknesses	+ Relatively easy to evaluate - Estimation about connections
Measurement procedure and tool	To estimate fragmentation, natural areas are defined and then an estimation is made about their connections. A mesh indicator value is calculated. Natural areas are categorized into separate interconnected patches. The area of each patch is summed, squared and these squares are summed and divided by the total area of natural areas. $$Mesh\ indicator = \left(\frac{A_1^2 + A_2^2 + \cdots + A_n^2}{A_1 + A_2 + \cdots A_n}\right)$$ This index (in hectares) is a metric - mesh indicator - used in the indicator value.
Scale of measurement	District to region scale
Data source	

Required data	Data on zones in natural or naturalized condition in the urban area of interest from, e.g., government agencies, municipalities, nature groups, universities, etc.
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Moderate
Synergies with other indicators	Related to *Reclamation of contaminated land* and *Ratio of open spaces to built form* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	
Additional information	
References	Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

9.1.2 Functional connectivity of urban green and blue spaces

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Hanski Connectivity Index	**Biodiversity**
Description and justification	Indicators of Green Infrastructure sub-criterion will assess the landscape connectivity and the mosaic diversity.
Definition	The index *CIi* can be calculated by measuring edge-to-edge distances between study site (separately for large and small study sites) and all other habitat patches within the 2-km radius of each landscape.
Strengths and weaknesses	

Measurement procedure and tool	GIS/Survey
Scale of measurement	ha of potential habitat
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	3; 15
Opportunities for participatory data collection	
Additional information	
References	Bruckmann S.V., Krauss J., Steffan-Dewenter I. (2010). Butterfly and plant specialists suffer from reduced connectivity in fragmented landscapes. Journal of Applied Ecology, 47, 799-809. DOI: 10.1111/j.1365-2664.2010.01828 Hanski I. (1999). Habitat connectivity, habitat continuity, and metapopulations in dynamic landscapes, Biology, 87,2, 209-219. DOI: 10.2307/3546736

9.2 Number of native species

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Number of native animal species	**Biodiversity**
Description and justification	The total number of native species within a defined area (site/neighbourhood/region/city). This can compromise one or more of the following taxonomic groups (it should be specified which groups are covered): a. Plants

	b. Birds c. Butterflies d. Invertebrates e. Mammals
Definition	Provides an overview of the species diversity, with distinctions able to be made across taxonomic groups if multiple groups can be covered. Defined species can also serve as an indirect "indicator" for the habitat quality.
Strengths and weaknesses	Results can support the evaluation of the original aims of a nature-based solution scheme and can monitor performance against these aims over time. Classification of native can be complicated by naturalised species and there is much debate over the role of non-native species in conservation biology, particularly in urban areas.
Measurement procedure and tool	The sum for each taxonomic group is calculated using field survey. It should be clarified whether this is the exact number or an estimation.
Scale of measurement	Number of species in a defined area
Data source	
Required data	Survey data
Data input type	Quantitative
Data collection frequency	Typically annual, but can be less frequent if resources are stretched.
Level of expertise required	High expertise is typically required for species identification. This requirement can be reduced if an index of easily identifiable species is created as a proxy
Synergies with other indicators	Synergies with non-native and invasive species indicators
Connection with SDGs	SDGs 14, 15.
Opportunities for participatory data collection	Surveying represents an excellent opportunity for widening participation.
Additional information	

References	Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to the EEA. Also: CBI Indicator 3: https://www.nparks.gov.sg/biodiversity/urban-biodiversity/the-singapore-index-on-cities-biodiversity European Capital of Biodiversity Indicators 4-9: https://www.capital-biodiversity.eu/uploads/media/Indicators_on_urban_biodiversity_-_LIST_-_European_Capitals_of_Biodiversity.pdf Federal Capital of Biodiversity Indicators 2-7

9.3 Number of non-native species introduced

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Number of non-native animal species	**Biodiversity**
Description and justification	Proportion of non-native animal and/or plant species introduced within an area as part of a nature-based solution scheme
Definition	Non-native species are those that have been transported to regions beyond their natural range. In terms of biodiversity objectives, these species can: • create a risk of harm if they become invasive; • provide biodiversity benefits (e.g., complementing native species provision to extend flowering seasons for nectar and pollen collecting insects) • reduce the number of native species within a scheme
Strengths and weaknesses	Results can support the evaluation of the original aims of a nature-based solution scheme and can monitor performance against these aims over time. Classification of native and non-native can be complicated by naturalised and invasive species.
Measurement procedure and tool	Proportion is calculated on the basis of the number of non-native species divided by the total number of species (i.e., the number of non-native species plus the total number of native species).
Scale of measurement	% of species in a defined area
Data source	

Required data	Survey data
Data input type	Quantitative
Data collection frequency	Typically annual, but can be less frequent if resources are stretched.
Level of expertise required	High expertise is typically required for species identification. This requirement can be reduced if an index of easily identifiable species is created as a proxy
Synergies with other indicators	Builds from number of native species indicator
Connection with SDGs	Strongest link to SDGs 14 & 15. However there are links to all SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	Surveying represents an excellent opportunity for widening participation.
Additional information	
References	Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to the EEA.

9.3.1 Number of invasive alien species

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Number of Invasive Alien Species	**Biodiversity**
Description and justification	Proportion of invasive alien species within an area
Definition	Provides an overview of the prevalence of potentially harmful species within a defined area (site/neighbourhood/region/city)
Strengths and weaknesses	If monitored over time, this provides strong evidence of the status of invasive alien species in terms of increasing or decreasing. It is only as strong as the current list of invasive species, as such there may be need for new baselines as new invasive alien species are discovered.
Measurement procedure and tool	Proportion is calculated on the basis of the number of invasive alien species divided by the total number of species (i.e., the number of invasive alien species plus the total number of native species).
Scale of measurement	% of species in a defined area
Data source	
Required data	Survey data
Data input type	Quantitative
Data collection frequency	Typically annual, but can be less frequent if resources are stretched.
Level of expertise required	High expertise is typically required for species identification. This requirement can be reduced if an index of easily identifiable species is created as a proxy
Synergies with other indicators	Builds from number of native species indicator
Connection with SDGs	SDGs 14, 15. Also SDG 2 if alien species are a threat to food production
Opportunities for participatory	Surveying represents an excellent opportunity for widening participation.

data collection	
Additional information	
References	Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to the EEA: Also: CBI Indicator 10: https://www.nparks.gov.sg/biodiversity/urban-biodiversity/the-singapore-index-on-cities-biodiversity European Capital of Biodiversity Indicators 10: https://www.capital-biodiversity.eu/uploads/media/Indicators_on_urban_biodiversity_-_LIST_-_European_Capitals_of_Biodiversity.pdf

9.4 Species diversity within defined area per Shannon Diversity Index

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Francesca Martelli[1], Chiara Ferracini[1], Federica Paradiso[1], Monica Vercelli[1], Simona Bonelli[1]

[1] *Università degli Studi di Torino, Turin, Italy*

Shannon Diversity Index	**Biodiversity**
Description and justification	The Shannon Diversity is a very common index used in ecology to quantify diversity in a community. The index provides more information about the fauna and flora composition than simply area richness. It takes into consideration both the number of different species observed and their relative abundances
Definition	Shannon Diversity Index it is calculated as follows: $H = -\sum_{i=1}^{s} p_i \ln p_i$ P_i is the proportion of total number of individuals of i^{th} species, divided by total number of individuals of all species recorded.
Strengths and weaknesses	Strengths • applicable to different taxonomic groups • easy to apply and very plastic, in fact we can use it for flora and fauna • repeatable and standardized • cheaper data collecting Weaknesses • high staff specialization • high sampling efforts
Measurement	Shannon Diversity Index needs semiquantitative data. In our case, data must be collected through linear transects (linear paths with

procedure and tool	fixed length), in which experts record number of specimens for each species
Scale of measurement	Interval scale
Data source	
Required data	Number of individuals for each species recorded
Data input type	Number of individuals for each species recorded
Data collection frequency	Butterflies survey: at least once a month from April to September Bees survey: at least once a month from April to September Plants survey: at least once a month from April to September
Level of expertise required	Shannon Diversity Index is easy to apply but data collection requires a high level of taxonomic knowledge, in order to recognise the correct species, for each target taxon.
Synergies with other indicators	Shannon Diversity Index is in synergy with "Global Warming Potential" indicator, because our target taxa (bees, butterflies and vegetation) are very sensitive to Global Warming and so we can see remarkable change in the community composition. This index has also a connection with "Equivalent used soil", indeed we know that soil with a high degree of naturalness hosts a greater biodiversity. This indicator could also be interrelated with "Greenness" and "Walkability" indicators, since number of pollinator species is high in open meadows.
Connection with SDGs	Shannon Diversity Index is in connection with 15th SDGS that aims to protect and preserve a suitable use of terrestrial ecosystem. Indeed, this index could be a scientific evaluation of change in biodiversity richness and can guide political choices in land management
Opportunities for participatory data collection	It is possible to involve citizens in butterfly surveys, through Citizen Science projects. It is necessary to provide proper volunteer training to enable correct recognition of butterfly species and to learn transect sampling method.
Additional information	
References	https://ec.europa.eu/eurostat/statisticsexplained/index.php/Glossary:Shannon_evenness_index_(SEI) https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=File:Shannon_Diversity_Index_and_Shannon_Evenness_Index,_2009.PNG Mårtensson, R. (2016). Species and Biological Diversity-Choices of Diversity Indices and their Potential Consequences for Nature Conservation

9.5 Number of species within defined area per Shannon Evenness Index

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Francesca Martelli[1], Chiara Ferracini[1], Federica Paradiso[1], Monica Vercelli[1], Simona Bonelli[1]

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Shannon Evenness Index	**Biodiversity**
Description and justification	The Shannon Evenness Index provides information about area comparison and species richness. It gives information about homogeneity of individual distribution between species in the community
Definition	Shannon Evenness Index it is calculated as Shannon Diversity Index dived by its maximum. It varies between 0 and 1, heterogeneous vs homogeneous
Strengths and weaknesses	Strengths • applicable to different taxonomic group • easy to interpret • easy to apply and very plastic, in fact we can use it for flora and fauna • repeatable and standardized • cheaper data collecting Weaknesses • high staff specialization • high sampling efforts
Measurement procedure and tool	Shannon Evenness Index needs semiquantitative data. In this case, data must be collected through linear transect (linear paths with fixed length), in which experts record number of specimens for each species
Scale of measurement	Interval scale
Data source	
Required data	Number of individuals for each species recorded
Data input type	Number of individuals for each species recorded
Data collection	Butterfly survey: at least once a month from April to September Bee survey: at least once a month from April to September Plant survey: at least once a month from April to September

frequency	
Level of expertise required	Shannon Evenness Index is easy to apply but data collection required high level of taxonomic knowledge, in order to recognise the correct species
Synergies with other indicators	Shannon Evenness Index is in synergy with “Global Warming Potential” indicator, because our target taxa (bees, butterflies and vegetation) are very sensitive to Global Warming and so we can see remarkable change in the community composition. This index has also a connection with “Equivalent used soil”, indeed we know that soil with a high degree of naturalness hosts a greater biodiversity. This indicator could also affect “Greenness” and “Walkability” indicator since the number of pollinator species is highest in open meadow environments
Connection with SDGs	Shannon Evenness Index is in connection with 15th SDGS that aims to protect and preserve a suitable use of terrestrial ecosystem. Indeed this index could be a scientific evaluation of change in biodiversity richness, and can guide political choices in land management
Opportunities for participatory data collection	It is possible to involve citizens in butterfly surveys, through Citizen Science projects. It is necessary a proper volunteer training that allow them to recognise butterfly species and to learn transect sampling methods.
Additional information	
References	https://ec.europa.eu/eurostat/statisticsexplained/index.php/Glossary:Shannon_evenness_index_(SEI) https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=File:Shannon_Diversity_Index_and_Shannon_Evenness_Index,_2009.PNG Mårtensson, R. (2016). Species and Biological Diversity-Choices of Diversity Indices and their Potential Consequences for Nature Conservation

10 Additional Indicators of Biodiversity Enhancement

10.1 Proportion of natural areas within a defined urban zone

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

[1] *VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland*

[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Proportion of natural area	Biodiversity
Description and justification	Biodiversity is the measure of biological variety in the environment and it has an important role in functioning ecosystems services and health of environment and society. Biodiversity is an aspect of natural environment that is most directly affected by anthropogenic influence. City biodiversity is seen as an important aspect of sustainable and resilient urban development. Natural areas are defined as ecosystems, which are not significantly influenced by human actions and comprise mainly of native species in natural environments. Such environments are important in preserving biodiversity as natural areas typically harbour much larger biodiversity than urban or constructed green spaces.
Definition	Proportion of natural areas within a defined urban zone (fraction or %)
Strengths and weaknesses	+ Simple and easy to assess - Does not imply the intactness of biodiversity but provides a measure for habitat evaluation
Measurement procedure and tool	The area can be calculated using mapping tools, including satellite images from Google Maps. Calculate the share of the sum of natural and naturalized areas to the total area to get the indicator value. Natural areas include forests, swamps, streams, lakes, etc., but exclude parks and green infrastructure. Re-naturalized areas can be included.
Scale of measurement	District to region scale
Data source	
Required data	Data on zones in natural or naturalized condition in the urban area of interest from, e.g., government agencies, municipalities, nature groups, universities, etc.
Data input type	Quantitative

Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Partly related to *Reclamation of contaminated land* indicator
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

10.2 Area of habitats restored

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Area of habitats restored	**Biodiversity**
Description and justification	When NBS delivery is associated with the restoration of target habitats (e.g., Article 17 habitats, national priority habitats, or local priority habitats), quantification of the extent of restored habitats can function as an indicator of success.
Definition	Extent of habitat as a proportion of total area, or total area of a specific habitat type (e.g., proportion of amenity grassland restored to wildflower meadow.
Strengths and weaknesses	A simple and effective measure of habitat change, but this must be updated regularly and combined with condition assessment surveys to be sure that habitat restoration is successfully conserved

Measurement procedure and tool	This indicator uses standard terrestrial habitat mapping approaches (EEA 2014) to quantify changes in habitat area. In urban areas, where habitat parcels are smaller, higher-resolution data and or ground-truthing may be necessary to establish spatial extent.
Scale of measurement	Measurement is typically carried out over a city or regional scale. Smaller scales (e.g., site scales can also be relevant)
Data source	
Required data	Typically, aerial photo and/or satellite data is used as a interrogation layer in GIS with landcover data as a background map. Data on extent of target restoration habitat areas can also be required if such interpretation is not straightforward from aerial images.
Data input type	Spatial & Quantitative
Data collection frequency	Typically, annual, but can be less frequent if resources are stretched.
Level of expertise required	Expertise is typically required either for habitat identification or interrogation of satellite imagery. This requirement can be reduced if low resolution land cover maps are used for calculations.
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators.
Connection with SDGs	Strongest link to SDGs 14 & 15. However there are links to all SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	Surveying habitats represents an excellent opportunity for widening participation, this includes survey of habitat condition change over time. Alternatively, participatory GIS portals can be used to ground-truth satellite imagery.
Additional information	

References	EEA (2014) Terrestrial habitat mapping in Europe: an overview: Joint MNHN-EEA Technical report No 1/2014: https://www.eea.europa.eu/publications/terrestrial-habitat-mapping-in-europe/at_download/file

10.3 Shannon Diversity Index of habitats

Project Name: Nature4Cities (Grant agreement: No. 730468)

Author/s and affiliations: Flora Szkordilisz[1], Federico Silvestri[2], Barnabás Körmöndi[1]

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[2] *Colouree, Genova, Italy*

Shannon Diversity Index of Habitats	**Green Space Management Biodiversity**
Description and justification	This indicator is defined as the simple ratio of the natural areas (An) per the total area (Ac). The objective is to determine if the NBS solution increases or maintains the proportion of areas supporting biodiversity in the city or neighbourhood.
Definition	Indicates the proportion of bare turf and sparse vegetation, grassland and herbs, shrubs, trees and of built environment to the total area.
Strengths and weaknesses	+ standardizable, which makes the comparison with other cities easier
Measurement procedure and tool	- spreadsheet methods - or GIS-based models (spatial resolution of 1 meter) - calculation method: $D = -\sum_{i=1}^{5} (p_i \log_2 p_i)$ Where pi corresponds to the proportion of each of the five kind of habitat
Scale of measurement	Object and neighbourhood scale
Data source	
Required data	- Proportion of each class of habitat
Data input type	quantitative
Data collection frequency	Before and after the NBS implementation

Level of expertise required	It is relatively easy to calculate, but field data is required.
Synergies with other indicators	Shannon Index and Biotope Area Factor are also based on landcover data and assess the vegetation coverage and their quantities comparing to the total surveyed area.
Connection with SDGs	SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	-
Additional information	
References	Cornelis, Johnny, and Martin Hermy. "Biodiversity Relationships in Urban and Suburban Parks in Flanders." Landscape and Urban Planning 69, no. 4 (October 30, 2004): 385–401. doi:10.1016/j.landurbplan.2003.10.038. Nagendra, H. (2002). Opposite trends in response for the Shannon and Simpson indices of landscape diversity. Applied Geography, 22(2), 175-186. Whitford, V., A. R. Ennos, and J. F. Handley. "'City Form and Natural Process'—indicators for the Ecological Performance of Urban Areas and Their Application to Merseyside, UK." Landscape and Urban Planning 57, no. 2 (November 20, 2001): 91–103. doi:10.1016/S0169-2046(01)00192-X Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

10.3.1 Abundance of ecotones/Shannon diversity

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Abundance of Ecotones/Shannon Diversity	Biodiversity
Description and justification	The indicators assess the landscape connectivity and the mosaic diversity.
Definition	Biodiversity is one of the primary interests of ecologists; nevertheless, quantifying the species diversity of ecological communities is complicated. The Shannon Diversity index (Barnes et al. 1998) was developed from information theory and is based on measuring uncertainty. The degree of uncertainty of predicting the species of a random sample is related to the diversity of a community. If a community has low diversity (dominated by one species), the uncertainty of prediction is low; a randomly sampled species is most likely going to be the dominant species. However, if diversity is high, uncertainty is high.
Strengths and weaknesses	The index inclusion of both components of biodiversity can be seen as both a strength and a weakness. It is a strength because it provides a simple, synthetic summary. On the other hand, it may be viewed as a weakness because it makes it difficult to compare communities that differ greatly in richness. Data used for biodiversity richness indicators can be used for the estimation of Shannon Index.
Measurement procedure and tool	The Shannon diversity index *H'* is calculated as: $$H' = \sum_i p_i \cdot ln(p_i)$$ where *pi* is the proportion of individuals found in species *i* For a well-sampled community, we can estimate the proportion as: $$p_i = \frac{n_i}{N}$$ where *ni* is the number of individuals in species *i* and *N* is the total number of individuals in the community.

	The Shannon index increases as both the richness and the evenness of the community increase.
Scale of measurement	Dimensionless Typical values are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4.
Data source	
Required data	Number of individuals of different species in the study area
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	Related to indicators estimating the richness of a certain species (e.g., species richness indicator, bird richness indicator).
Connection with SDGs	3; 15
Opportunities for participatory data collection	Local stakeholders can be involved in the individuals survey
Additional information	
References	Barnes, B. V., Zak, D. R., Denton, S., Spurr, S. (1998), Forest ecology. John Wiley and Sons, INC. Magurran, A.E. (2004), Meausuring Biological Diversity. Blackwell

10.4 Length of ecotones

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Length of ecotones	**Biodiversity**
Description and justification	Measurement of the length of ecotones can be a proxy for quantifying the extent of transition habitats. This can represent an important aspect of habitat characterisation and quality that is often overlooked.
Definition	Ecotones are transition areas dividing ecological communities or ecosystems. They occur in both terrestrial

	and aquatic systems. Ecotones can occur at multiple spatial scales. They included both natural boundaries and human-generated ecotones. They are typically areas of high species richness and abundance that can be overlooked when using traditional habitat mapping or land use indicators. Monitoring the contribution of nature-based solutions to the creation of ecotones can support their evaluation in terms of meeting biodiversity-related key performance indicators.
Strengths and weaknesses	A key indicator related to the biodiversity value of spaces. Evaluation can, however, require specific ecological knowledge and, can also require ground-truthing to support evaluation outcomes of remote sensing data.
Measurement procedure and tool	Ecotone length can be measured by ground-truthed survey (using GPS to map ecotones). Carrying out such a process can be combined with ecological characterisation of identified ecotones. However, such methods can be very resource intensive in terms of person-hours. An alternative established method is the use of GIS (Johnston& Bonde 1989; Johnston, Pastor & Pinay 1992). Raster images can be analysed to measure the boundary associations at the edges fo land cover patches. This can provide information about the association of different cover types in the landscape.
Scale of measurement	Measurement can be carried out over a city or regional scale, however, application to smaller scales (e.g., site scales can also be relevant) can also be relevant when assessing performance against specific project targets.
Data source	
Required data	Satellite or aerial photo imagery is typically used. This can vary from low-resolution data (e.g., MODIS, moderate-resolution Landsat) to high-resolution data (WorldView and aerial orthophotos).
Data input type	Spatial & Quantitative
Data collection frequency	Typically, annual, but can be less frequent if resources are stretched.
Level of expertise required	Expertise is typically required either for habitat identification or interrogation of satellite imagery. If statistics of landscape pattern are used to infer ecological process at an ecotone level, there is a requirement to understand both ecotone ecology and the specific sensitivities of statistics to ecotone characteristics.
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators.

Connection with SDGs	Strongest link to SDGs 14 & 15. However there are links to all SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	Surveying habitats represents an excellent opportunity for widening participation, this includes survey of habitat condition change over time. Alternatively, participatory GIS portals can be used to ground-truth satellite imagery.
Additional information	
References	Chhetri, P.K., Thai, E. (2019) Remote sensing and geographic information systems techniques in studies on treeline ecotone dynamics. J. For. Res. 30, 1543–1553. Johnston C.A., Pastor J., Pinay G. (1992) Quantitative Methods for Studying Landscape Boundaries. In: Hansen A.J., di Castri F. (eds) Landscape Boundaries. Ecological Studies (Analysis and Synthesis), vol 92. Springer, New York, NY Johnston CA, Bonde JP (1989) Quantitative analysis of ecotones using a geographic information system. Photogrammetric Eng and Remote Sensing 55:1643–1647

10.5 Publicly accessible green space connectivity

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Publicly accessible green space connectivity	Biodiversity
Description and justification	The extent and spatial arrangement of accessible green space within each sub-demo area may have an important

	influence on public health and wellbeing; as well as having the potential to increase biodiversity. Vegetated areas provide cooling on hot days through evapotranspiration; and trees reduce radiant heat by shading, making public space and travelling routes more comfortable for people on days when temperatures in urban areas are high. This KPI will focus on public accessible greenspace, therefore residential gardens will not be considered here.
Definition	This environmental (biological) indicator evaluates the increases of connectivity related to existing green infrastructures.
Strengths and weaknesses	This KPI requires specific software (GIS software).
Measurement procedure and tool	Typology map data representing areas of GI both before and after NBS GI interventions will be analysed using a Geographic Information System (GIS) to calculate change in each sub-demo area in a) the proportion of the sub-demo area represented by GI, b) distance between areas of GI, and c) the number of street trees Use of GIS to calculate % change in the following parameters in each sub-demo area following NBS GI interventions: • The extent of accessible GI. Calculate the proportion of the sub-demo area occupied by GI (select all GI types in typology layer except residential gardens) pre- and post- GI interventions. • The distance between each accessible GI patch and its nearest accessible GI neighbour within the sub-demo area. If d is the nearest-neighbour (Euclidean) distance from accessible GI patch i to accessible GI patch j; calculate the mean nearest-neighbour distance over all patches, both pre- and post-intervention (FRAGSTATS, 2015) • The distance to the nearest accessible green infrastructure everywhere (for every raster cell) calculated using a raster nearest neighbour approach • the number of street trees
Scale of measurement	City
Data source	
Required data	This KPI (Key Performance Indicator) can be measured throughout specific software, such as GIS software and spreadsheet software. QGIS is the GIS software proposed to be used, due to it being an open source and

	multiplatform software and it is distributed under Creative Commons Attribution-Share Alike 3.0 licence (CC BY-SA).
Data input type	GIS data (vectorial, raster)
Data collection frequency	Pre and post intervention.
Level of expertise required	Technical/expert
Synergies with other indicators	This KPI is related with KPI Accessibility: distribution, configuration and diversity of green space and land use changes (multi-scale, green spaces quantity), and Perceptions of citizens on urban nature – green spaces quality.
Connection with SDGs	This KPI is directly related with SDG 11 and SDG 3.
Opportunities for participatory data collection	This is not a KPI open to participatory collaboration.
Additional information	
References	URBAN GreenUP KPI: Increased connectivity to existing green infrastructure URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Data processing software: https://www.qgis.org/en/site/forusers/download.html# https://docs.qgis.org/2.18/en/docs/user_manual/ ://plugins.qgis.org/plugins/LecoS/ http://www.umass.edu/landeco/research/fragstats/fragstats.html.

10.6 Ecological integrity

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Ecological Integrity	**Biodiversity**
Description and justification	Ecological integrity is an emerging concept that is in some ways analogous with human health in terms of defining normal boundaries for a 'healthy' condition and categorising traits that are 'desirable' and 'sustainable'. However, for the concept of ecological integrity, 'health' refers to the complexity of interactions between numerous species, and both living and non-living components of ecosystems, and evaluates them in relation to the state of the ecosystem being considered. This state refers to both the biodiversity value and the ecosystem service provision. As such, this measure brings together several indicators into a single metric in relation to ecosystem 'health'.
Definition	Ecological Integrity is a holistic measure of ecological value and refers to an ecosystem's capacity to support and maintain ecological processes and diverse communities of organisms. It is typically quantified in terms of a measure of 'Intactness (% score or Index).
Strengths and weaknesses	A strength relates to the ability to bring together numerous characteristics of the health of an ecosystem into a single measure. For example: • Physical stress • Wildfire • Pollution • Thermal stress • Biological stress • Resiliency and resistance • Biodiversity • Complexity of structure and function • Controlled nutrient cycling • Efficient energy use and transfer • Ability to maintain natural ecological values Weaknesses relate to: • the emerging nature of this concept, and thus lack of consensus on a precise definition. • the complexity of quantifying these values into a single measure, in particular to ecosystems where understanding is still evolving.

	• the methodology relies on proxy variables that include data on landscape characteristics such as patch size, abiotic factors such as hydrology, and some features of vegetation structure and composition. It has been argued that these proxy values can lead to imprecise results due to the distillation of complex systems into simple values (Brown and Williams 2016). • the scale that this evaluation tends to be implemented means that it is more suitable for large/landscape-scale areas that small-scale NBS interventions
Measurement procedure and tool	An ecological integrity assessment is a multi-metric index that assigns ranked ecological scores to a variety of spatial and ecological parameters (Brown and Williams 2016). It assesses ecological integrity using data based on remotely sensed landscape characteristics such as patch size and surrounding land use, some abiotic factors such as hydrology, and some attributes of vegetation structure and composition. The methodology relies almost entirely on proxy variables, such as structure of vegetation or the species richness of vascular plants as a proxy for diversity of a range of taxa (Faber-Langendoen et al. 2012a; 2012b). Faber-Langendoen et al. (2012a; 2012b) present a comprehensive methodology for ecological integrity assessment. Beyer et al. (2020) also present a method that uses nine categories of intactness to capture global habitat loss, quality and fragmentation patterns at a 1km x 1km resolution. Forestry integrity mapping has also been carried out that could be used as a baseline for future evaluation of large-scale nature-based solution change in forestry management https://www.forestintegrity.com/. Details of methods used are presented in the Grantham et al. (2020) publication pre-print.
Scale of measurement	Landscape scale assigning Intactness scores to large land parcels. This indicator is typically used across rural landscapes rather than in small urban land parcels.
Data source	
Required data	Multiple remote sensed datasets are combined to create an index of ecological integrity. Data sources depend upon methodology. See Faber-Langendoen et al. (2012a; 2012b) for a standard methodology

Data input type	Quantitative Spatial data on a range habitat characteristics.
Data collection frequency	Evaluation frequency would typically be carried out to correspond with update of the various datasets required for the consolidated assessment. Ideally this would be an annual process, but update over periods of up to five years may also be feasible. Longer-time frames than this may miss critical tipping points in terms of habitat change.
Level of expertise required	This evaluation indicator requires expertise in both remote sensing methodologies and ecological understanding.
Synergies with other indicators	Strong synergies with other biodiversity indicators, particularly as some of the component datasets for this indicator might also be relevant across several biodiversity indicators. Also, synergies with greenspace mapping indicators.
Connection with SDGs	Strongest link to SDG 15. However there are links to all SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	Low opportunity for participatory involvement in the Evaluation Indicator itself. However, several of the component spatial datasets provide opportunity for citizen-science type opportunities in relation to data generation and/or ground-truthing of datasets. Similarly, output Ecological Integrity maps can also be ground-truthed through participatory processes.
Additional information	
References	Beyer, HL, Venter, O, Grantham, HS and Watson, JEM (2020) Substantial losses in ecoregion intactness highlight urgency of globally coordinated action. Conservation Letters 13(2), e12692, https://doi.org/10.1111/conl.12692. Brown, E.D., Williams, B.K. (2016) Ecological integrity assessment as a metric of biodiversity: are we measuring what we say we are?. Biodiversity Conservation 25, 1011–1035.

	Faber-Langendoen D, Hedge C, Kost M, Thomas S, Smart L, Smyth R, Drake J, Menard S (2012a) Assessment of wetland ecosystem condition across landscape regions: a multi-metric approach. Part A. Ecological integrity assessment overview and field study in Michigan and Indiana. U.S. Environmental Protection Agency report EPA/600/R-12/021a, Washington, DC. Faber-Langendoen D, Rocchio J, Thomas S, Kost M, Hedge C, Nichols B, Walz K, Kittel G, Menard S, Drake J, Muldavin E (2012) Assessment of wetland ecosystem condition across landscape regions: a multi-metric approach. Part B. Ecological integrity assessment protocols for rapid field methods (L2). U.S. Environmental Protection Agency report EPA/600/R-12/021b, Washington, DC. Grantham, HS, Duncan, A, Evans, TD et al. (2020) Modification of forests by people means only 40% of remaining forests have high ecosystem integrity. bioRxiv 2020.03.05.978858; Pre-print DOI: https://doi.org/10.1101/2020.03.05.978858

10.7 Proportion of protected areas

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

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Proportion of protected areas	Biodiversity
Description and justification	Proportion of a specific area (typically a Formal Urban Area) which fall under special protection by the Natura 2000 directive, and this includes a variety of different biodiversity-rich and sensitive habitats. This represents a proxy measure for the contribution that an area is making to biodiversity conservation strategies.
Definition	There are a range of restrictions to agricultural and forestry related activities within these areas which contribute to foster the development and recovery of rare species.
Strengths and weaknesses	A key indicator related to the biodiversity value of spaces. Relatively straightforward, but does not consider any sites that do not fall under the Natura 2000 directive. This can, therefore, miss many sites of value to nature conservation including designated sites, particularly in urban areas.
Measurement procedure and tool	Proportion (%) of a designated area (e.g., Formal Urban Area) belonging to Natura 2000 network per grid cell. Typically, using a GIS programme (e.g.ArcGIS, QGIS) a Natura 2000 shapefile is clipped to a target area polygon,

	with remaining sites dissolved to avoid site overlaps. The proportion of the total area covered by Natura 2000 sites is calculated.
Scale of measurement	Measurement can be carried out over a city or regional scale. Smaller scales are not typically relevant due to the scale of Natura 2000 sites.
Data source	
Required data	Pre-existing Natura 2000 shapefiles are used. If these are not available, it might be necessary to generate them.
Data input type	Spatial & Quantitative
Data collection frequency	Typically, before and after implementation of NBS that has impacted Natura 2000 site areas or designation. Following this regular data collection is advised to coincide with updating of Natura 2000 shapefiles.
Level of expertise required	Expertise is typically required either for habitat identification or interrogation of satellite imagery. If statistics of landscape pattern are used to infer ecological process at an ecotone level, there is a requirement to understand both ecotone ecology and the specific sensitivities of statistics to ecotone characteristics.
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators.
Connection with SDGs	Strongest link to SDGs 14 & 15. However there are links to all SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	Limited opportunity for participatory data collection, unless combined with some type of condition assessment of sites.
Additional information	
References	Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to

	the EEA: https://www.eionet.europa.eu/etcs/etc-bd/products/etc-bd-reports/eubi_cities_biodiversity_indicator/@@download/file/EUBI_cities_biodiversity_indicator.pdf Urban Atlas 2012: https://www.eea.europa.eu/data-and-maps/data/urban-atlas Natura 2000 End 2016 database: https://www.eea.europa.eu/data-and-maps/data/natura-9

10.7.1 Sites of community importance and special protection areas

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Sites of Community Importance (SCI) and Special Protection Areas	**Biodiversity**
Description and justification	These indicators assess whether the study area is classified as a protected area or is within a protected area belonging to Natura 2000 network.
Definition	The Indicator describes the extension, measured in hectares, of Site of Community Importance (SCI) and/or Special Protection Areas (SPA) in the study area.
Strengths and weaknesses	This indicator allows at evaluating the effects of NBS on habitat creation/reduction. The Indicator hardly changes in the design and long-term scenario, even if it could be assessed if the NBS implementation have produced such a beneficial impact on biodiversity to activate EU procedures in order to enlarge SCI and/or SPA perimeter.
Measurement procedure and tool	The indicator is easily calculated using a simple GIS routine, as follows: 1) The intersection between the shapefile of the SCI and SPA and the shapefile of the study area is achieved using the geoprocessing tool “Intersect”; 2) The spatial extension of the output of the previous step, i.e., the portion of SCI and SPA falling within the study area, is calculated using the “calculate geometry” tool.

Scale of measurement	Ha
Data source	
Required data	Information on spatial distribution of SCI and SPA. Each EU Member has a Natura 2000 webpage, where the SCI and SPA maps can be consulted and, in some cases, downloaded. Considering that areas eligible as SCI are proposed to the Commission by the State Members, information from local authorities are needed.
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Medium
Synergies with other indicators	Related to indicators measuring the extension of habitat and areas and to indicators measuring the maintenance or restoration at a favourable conservation status of a natural habitat type or of a species.
Connection with SDGs	15
Opportunities for participatory data collection	Environmental stakeholders can be involved into the indicator measurement and can be interested in proposing areas to local authorities to be elected as SCI and SPA.
Additional information	
References	Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (art 1 k).

10.7.2 Article17 habitat richness

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Article 17 habitat richness	**Biodiversity**
Description and justification	Habitat richness is a crucial component of biodiversity and habitat density describes how many bird habitats are encountered within a Functional Urban Area. This can be calculated using a count of Article 17 habitat types per hexagonal grid cell, derived from modified Article 17 dataset.

Definition	Measure of habitat richness of Article 17 habitats using bird habitat density as a habitat richness proxy as defined in The European Urban Biodiversity Index (EUBI).
Strengths and weaknesses	
Measurement procedure and tool	Method taken from The European Urban Biodiversity Index (EUBI): “The process involves several steps to obtain the Article 17 habitat count per hexagonal cell. At first a hexagonal grid with a unique identifier for each grid cell is created. This grid is merged with UA polygons which have been assigned towards specific MAES habitats with a crosswalk using the GIS Tool “Union”. In a second step the Article 17 GIS- data is clipped to the FUA Boundary and also merged with the grid. Through this process the created datasets obtain a common identifier within the hexagonal grid, which is the basis for further processing steps. The data is imported into a database system (MS-SQL) for further processing and cleaning operation. Article 17 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database. The data is then joined using the common identifier assigned within the hexagonal grid as well as the MAES habitat. This enables the filtering out of habitats which may cover a grid cell, but which are not assigned to a MAES habitat within the cell and thus are unlikely to occur at that location.”
Scale of measurement	Functional Urban Area (city perimeter)
Data source	
Required data	Landcover, city perimeter and MAES habitats data
Data input type	Quantitative
Data collection frequency	Typically annual, but can be less frequent if resources are stretched.
Level of expertise required	Expertise is typically required either for habitat identification or interrogation of satellite imagery. This requirement can be reduced if low resolution land cover maps are used for calculations
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators, particularly Article 17 listed species.

Connection with SDGs	SDGs 14, 15.
Opportunities for participatory data collection	Surveying habitats represents an excellent opportunity for widening participation. Alternatively, participatory GIS portals can be used to ground-truth satellite imagery.
Additional information	
References	Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to the EEA. Reporting under Art. 17 Habitats Directive – Database: https://www.eea.europa.eu/data-and-maps/data/article-17-database-habitats-directive-92-43-eec-1 Reporting under Art. 17 Habitats Directive – GIS Data: https://www.eea.europa.eu/data-and-maps/data/article-17-database-habitats-directive-92-43-eec-1#tab-gis-data Urban Atlas (2012), Art. 17, WISE WFD reference spatial data sets – Surface Water Body (2016), Linkages of species and habitat types to MAES ecosystems

10.8 Number of veteran trees per unit area

Project Name: CONNECTING Nature (Grant Agreement no. 730222)
Author/s and affiliations: Stuart Connop
Sustainability Research Institute, University of East London, UK

Number of veteran trees per unit area	Biodiversity
Description and justification	In addition to the multifunctional benefits that are provided by trees, veteran trees play a crucial role in the conservation of biodiversity. An effective measure of conservation of veteran trees is the number of such trees within a unit area (e.g., Formal Urban Area).
Definition	Although not as old as ancient trees provide holes, cavities and crevices which are especially important for wildlife. In particular, trees with decay containing cavities are important habitats for many saproxylic invertebrate species. As such, targets and measures of number of veteran trees in a landscape can contribute the biodiversity conservation objectives and strategies. Whilst provision of nature-based solutions rarely created new veteran trees (due to long time-sales involved in veteran tree development), nature-based solutions can

	protect veteran trees, deliver veteranisation of young trees, or cause the loss of veteran trees. As such, this represents a valuable biodiversity indicator.
Strengths and weaknesses	The strength of evidence relates to the direct count methodology which retains an absolute total of veteran trees. It does not, however, include an assessment of the value of individual trees in terms of presence/absence of habitat features associated with the highest biodiversity value veteran trees, nor any assessment of the quality of biodiversity assemblages supported by the veteran trees. This can also be a resource intensive survey process for large target areas, unless veteran tree mapping has already been carried out and merely need to be updated based on presence/absence, which can be done using remote sensing methodologies.
Measurement procedure and tool	Standard veteran tree identification and mapping protocols have been developed. An example of this from the UK was developed by Treeworks (1996). This protocol supports the identification, characterisation and mapping of veteran tree networks. The protocol is based on field survey and subsequent mapping.
Scale of measurement	Site, region, or city-wide (e.g., Functional Urban Area)
Data source	
Required data	Background maps (e.g., Ordnance Survey Maps) and ground-truthed GPS point source data to represent each individual veteran tree
Data input type	Quantitative and spatial
Data collection frequency	Once a baseline spatial dataset of canopy cover has been established, it may be possible to update the regularly using satellite imagery. This is particularly to case for individual trees in urban/pasture settings. Veteran trees as part of woodland canopies would require ground truthing surveys which, due to their resource intensity, are generally carried out less frequently. Under such a scenario surveys should be repeated at 5 yearly intervals or less.
Level of expertise required	Expertise is typically required either for veteran tree identification and mapping. However, surveying methods can be adapted to surveyor expertise. GIS expertise is required for creation of maps and any subsequent remote sensing evaluation.
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators, particularly Article 17 listed species.

Connection with SDGs	SDG 15.
Opportunities for participatory data collection	Surveying habitats represents an excellent opportunity for widening participation. Alternatively, participatory GIS portals can be used to ground-truth satellite imagery.
Additional information	
References	Treeworks (1996) Veteran Trees Initiative Specialist Survey Method. Report produced by English Nature. Available from: http://www.treeworks.co.uk/downloads/SSM_HandBook.pdf

10.9 Quantity of dead wood per unit area

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

Sustainability Research Institute, University of East London, UK

Quantity of dead wood per unit area	Biodiversity
Description and justification	Deadwood plays a key role in within ecosystems. Evaluating the quantity of deadwood associated with nature-based solution delivery can represent a proxy for quantification of biodiversity value. It can also be used to establish a baseline to ensure that deadwood provision is considered in future land management change decisions.
Definition	Deadwood encompasses all non-living woody biomass not contained in litter, either standing, lying on the ground, or in the soil (FAO, 2004). Deadwood provision is a key consideration in biodiversity conservation due to its value in terms of providing microhabitats for other species, providing a structural/functional role in stabilizing steep slopes and stream channels, and contributing to carbon, nitrogen and phosphorus cycles (Paletto et al 2012).
Strengths and weaknesses	If quantity is defined as presence/absence, this can be a relatively straightforward survey process (as long as a categorisation of 'deadwood' can be agreed upon). Such a method, however, misses critical data on deadwood volume and condition. If a more detailed quantification is desirable, defining and identifying deadwood can be more challenging as a standardised method has not been agreed upon in scientific literature. Moreover, the indicator represents a measure of habitat quality rather than biodiversity value as it does not include an assessment of organisms associated with deadwood (e.g., the many scarce and

	threatened species associated with this habitat). There is also no consensus on a threshold for a target amount of deadwood within a habitat, so the indicator tends to be focused on no net-loss, rather than informed thresholds.
Measurement procedure and tool	Calculation of the volume of standing and lying deadwood, typically in forests and other wooded land, classified by forest type (Forest Europe et al. 2011). Deadwood is typically classified according to type (standing, lying, decay state) in a defined area (tonnes/hectare or cubic metre/ha). Classification is typically defined nationally, with common examples including Length >/= 2 m. and diameter mean 10 cm (EEA 2020).
Scale of measurement	Possibly most relevant on a site/project scale. Could also be applied on a region or city-wide (e.g., Functional Urban Area) scale.
Data source	
Required data	Background maps (e.g., Ordnance Survey Maps) and ground-truthed GPS point source data to represent each individual deadwood feature.
Data input type	Quantitative and spatial
Data collection frequency	Surveys can be repeated regularly to keep mapping updated as deadwood removal can occur regularly through decomposition and or 'tidying' management. Surveys should be repeated at a maximum of 5 yearly intervals.
Level of expertise required	Some expertise is required for surveying deadwood on the ground. If surveys are to combine deadwood counts with characteristics/features (e.g., characterising veteran and ancient trees), then a greater level of expertise is required (see veteran tree indicator).
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators, particularly Article 17 listed species and veteran tree surveys
Connection with SDGs	SDG 15
Opportunities for participatory data collection	Surveying habitats represents an excellent opportunity for widening participation. This can also be supplemented by the use of participatory GIS portals for 'citizen scientists' to upload observations.
Additional information	
References	EEA (2020) Forest deadwood indicator Assessment. Available from: https://www.eea.europa.eu/data-and-maps/indicators/ forest-deadwood-1/assessment-1 FAO, (2004). Global Forest Resources Assessment Update 2005: Terms and Definitions. Rome: Working Papers 83/E, Forest Resources Assessment Programme.

	Forest Europe, UNECE and FAO (2011), State of Europe's forests 2011. Status and Trends in Sustainable Forest Management in Europe. Available at: www.foresteurope.org/documentos/State_of_Europes_Forests_2011_Report_Revised_November_2011.pdf Paletto, A, Ferretti, F, De Meo, I, Cantiani, P and Focacci, M. (2012) Ecological and Environmental Role of Deadwood in Managed and Unmanaged Forests. 10.5772/24894.

10.10 Forest habitat fragmentation – Effective Mesh Density

Project Name: PHUSICOS (Grant Agreement no. 776681)

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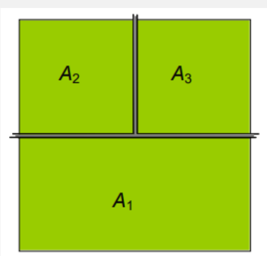
Effective Mesh Density	Biodiversity
Description and justification	This indicator evaluates whether the Design scenarios ensure the removal of physical barriers obstructing forest habitat connectivity.
Definition	Effective mesh density quantifies the degree to which wildlife movement is interrupted by barriers in the environment. It expresses the degree of fragmentation of a landscape and measure the effective number of patches (forest areas) per 1 km^2 (EEA).
Strengths and weaknesses	+ It easily expresses how much the forest habitats are fragmented; in a long-term scenario, these indicators could be re-assessed, monitoring, through a direct survey, if the NBS implementation has produced impact on forest habitat fragmentation. - A detailed identification of forest patches localization should require a field and/or aerial survey and time-consuming data post-processing.
Measurement procedure and tool	It can be calculated using the following expression: $$s_{eff} = {}^{1}/_{m_{eff}}$$ given:

	$$m_{eff} = \frac{1}{A_{tot}} \cdot (A_1{}^2 + A_2{}^2 + \cdots + A_i{}^2 + \cdots A_n{}^2)$$ where: *n* is the number of patches; A_{tot} is the total area of the study area; A_i is the size of patch *i* (*i* = *1,…, n*)
Scale of measurement	1 / ha
Data source	
Required data	Spatial data concerning forest patches in the study area.
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	15
Opportunities for participatory data collection	Local stakeholders could provide information about
Additional information	
References	Jaeger, J.A. (2000), *Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation*. Landscape Ecology 15, 115–130 https://doi.org/10.1023/A:1008129329289

Example: A forest is fragmented by streets into three patches.



A_{TOT} = 4 ha

A_1 = 2 ha

A_2 = 1 ha

A_3 = 1 ha

$$m_{eff} = \frac{1}{A_{tot}} \cdot \left(A_1{}^2 + A_2{}^2 + A_3{}^2\right) = \frac{1}{4} \cdot \left(2^2 + 1^2 + 1^2\right) = \frac{6}{4} = 1,5\ ha$$

so

$$s_{eff} = {}^{1}/_{m_{eff}}\ {}^{1}/_{1,5} = 0,67$$

10.11 Extent of habitat for native pollinator species

Project Name: CONNECTING Nature (Grant Agreement no. 730222)
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Extent of habitat for native pollinator species	Biodiversity
Description and justification	Pollinators play a key role in ecosystems, supporting crop production and pollinating trees and wildflowers necessary for supporting other ecosystem functions. Global declines mean that provision of habitat for supporting these species has been identified as a critical conservation target internationally. Evaluation of extent of habitat for native pollinator species is a proxy measure of the health of pollinators and the ecosystems and crops they support.
Definition	Pollinators are organisms that facilitate the transfer of pollen from a male part of a plant to a female part of a plant, supporting fertilisation and seed production. This includes many groups of insect and some birds, and bats. In order to support pollination, it is vital that habitats suitable for supporting pollinators is retained. This can include such diverse provisions as pesticide free zones, wildflower-rich areas, and bare ground for nesting. The critical first step of defining extent of habitat for native pollinator species is to define the target habitats that are being quantified. Typically, this comprises an assessment of wildflower areas, or nectar and pollen-rich flowering areas. However, more detailed characterisation of pollinator habitat needs and associated habitat characteristics provides a more effective measure of biodiversity value.

Strengths and weaknesses	Surveys including evaluation of habitats that provide a diversity of resources to support all the life cycle requirements of pollinators can provide an effective measure of the biodiversity value of landscapes to pollinators. Such approaches tend to require surveys to be carried out in the field and can be resource intensive if repeated regularly. This can represent an excellent opportunity for community participation though as training in the recognition of habitat features can be delivered relatively easily. Remote sensing-based methodologies tend to be focused on single habitat types (e.g., availability of wildflowers) and thus tends to provide less information on the nuances of pollinator habitat requirements. For example, diversity of forage, duration and timing of forage, and habitats associated with other life cycle requirements (e.g., nesting, hibernation, etc).
Measurement procedure and tool	A variety of measurement procedures are available depending upon the level of characterisation of pollinator habitats. For pollen and nectar-rich habitats at a field survey level, surveys can comprise a simple count of flower-rich habitats using established habitat classification methods (EEA 2014), or a quantification of the flora available to pollinators (Carvell et al. 2004). Habitat Maps can also be developed from the interrogation of vegetation maps, land use maps and Earth Observation data (e.g., NDVI) analysis (Corbane et al. 2015; Alleaume et al. 2018). UAVs also provide opportunities for mapping habitat areas (Alvarez-Vanhard et al. 2020). However, this can be more challenging in urban areas due to flight restrictions. All methodologies characterise pollinator habitat extent in terms of a proportion of the total area (e.g., % or m^2/ha).
Scale of measurement	Dependent upon the method of evaluation. For field-based survey, scale can be determined by effort required. As such, this tends to be better suited for site and neighbourhood scales. Remote sensing methods are typically more appropriate for larger regional or city-wide (e.g., Functional Urban Area) scales
Data source	
Required data	Landscape data, such as aerial photos and Ordnance Survey maps are useful to act as a foundation for both field

	survey and remote sensing techniques. Beyond that, data is generated either by interrogation of aerial images or field survey.
Data input type	Both ground survey and remote sensing methodologies generate spatial records of habitat type. These are either recorded using GPS for subsequent transfer to GIS mapping, or directly so for Remote Sensing methodologies. In addition to habitat extent, this if measures of habitat quality are included, quantitative data is also generated
Data collection frequency	Data collection frequency is typically defined by the area of interest and the availability of resources. For site and neighbourhood scale evaluation, annual or even seasonal survey is recommended. For more substantial areas, frequency may have to be reduced dependent upon resources.
Level of expertise required	Dependent upon the level of complexity of habitat classification, level of expertise required can be quite varied. For remote sensing approaches, basic GIS data processing expertise is required. For field survey, it might be possible to train a team of citizen scientists with low level of expertise.
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators, particularly Article 17 listed species.
Connection with SDGs	Strongest links to SDGs 2& 15. However there are links to all SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	Surveying habitats represents an excellent opportunity for widening participation. Alternatively, participatory GIS portals can be used to ground-truth satellite imagery.
Additional information	
References	Alleaume, S., Dusseux, P., Thierion, V. Commagnac, L., Laventure, S., Lang, M., Féret, J-B., Hubert-Moy, L and Luque, S (2018) A generic remote sensing approach to derive operational

	essential biodiversity variables (EBVs) for conservation planning Methods Ecol. Evol. 9, 1822-1836. Alvarez-Vanhard, E., Houet, T, Mony, C, Lecoq, L and Corpetti, T (2020) Can UAVs fill the gap between in situ surveys and satellites for habitat mapping? Remote Sensing of Environment 243, 111780. Carvell, C., Meek, W.R., Pywell, R.F. and Nowakowski, M. (2004) The response of foraging bumblebees to successional change in newly created arable field margins. Biological Conservation 118, 327-339. Corbane, C, Lang, S, Pipkins, K, Alleaume, S, Deshayes, M., García Millán, VE., Strasser, T, Vanden Borre, J., Toon, S. and Michael, F (2015) Remote sensing for mapping natural habitats and their conservation status – New opportunities and challenges. International Journal of Applied Earth Observation and Geoinformation 37, 7-16. European Environment Agency (2014) Terrestrial habitat mapping in Europe: an overview. Joint MNHN-EEA report, ISSN 1725-2237

10.12 Polluted soils

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Polluted Soils	**Biodiversity**
Description and justification	This indicator evaluates whether the project scenarios enhance the ability of a soil to resist or recover their healthy state in response to destabilising influences.
Definition	This Indicator describes the quantity of soils in the study area, measured in hectares, used for highly polluting industries, brownfields, drosscapes, mines, dumps, construction sites. It provides a quick evaluation of soil quality since the less polluted a soil is, the higher its overall quality.
Strengths and weaknesses	+ In a long-term scenario, the Indicator could be re-assessed, monitoring, through a direct survey, if the NBS implementation has produced impact on soil resilience.

	- It doesn't take into account polluted soils within natural areas.
Measurement procedure and tool	The final formula of Polluted Soils (*PS*) results as: $$PS = \sum_i A_i^{PS}$$ where: A_i^{PS} is the estension of the i-th polluted area (e.g., highly polluting industries, brownfields, drosscapes, mines, dumps, construction sites) [ha] The indicator is easily calculated in a GIS environment using simple GIS geoprocessing tools.
Scale of measurement	ha
Data source	
Required data	Detailed land use data
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Medium
Synergies with other indicators	Related to indicators concerning land use cover.
Connection with SDGs	3
Opportunities for participatory data collection	Environmental stakeholders can be involved into the indicator measurement and can be interested in proposing areas to local authorities to be elected as SCI and SPA.
Additional information	
References	

10.13 Soil food web stability

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Soil Food Web Stability	**Biodiversity**
Description and justification	This indicator assesses the stability of the soil communities and derived environmental services.
Definition	The community of organisms living wholly or partially within the soil. It describes a complex living system in the soil and how it interacts with the environment, plants, and animals.
Strengths and weaknesses	+ In a long-term scenario, the Indicator could be re-assessed, monitoring, through a direct survey, if the NBS implementation has produced impact on soil web stability. - It is quite difficult to collect the data needed for its complex calculation.
Measurement procedure and tool	To determine food web stability, Jacobian matrices, or interaction strength matrices (May 1972), are built from the system of generalized Lotka-Volterra differential equations that describe the dynamics of each food web (de Ruiter et al., 1995; Neutel et al., 2007). The off-diagonal elements, a_{ij}, or the interspecific interaction strengths, represent the per capita effects of species *j* (i.e., trophic group j) on species *i*. The effects of consumers *j* on resources *i* are given by $\alpha_{ij} = -\frac{F_{ij}}{B_j}$, and the effects of resources *i* on consumers *j* are given by $\alpha_{ji} = \frac{e_j F_{ij}}{B_i}$. The diagonal element, α_{ii}, quantifies the food web stability (Neutel et al., 2002). They are defined as: $\alpha_{ii} = -sd_i$, where *s* is the fraction of deaths caused by density dependence (Neutel et al. 2002). *s* could be used as a measure for stability, defined by Neutel et al. (2002) as the minimum value needed for the interaction strength matrix to be stable, i.e., it is the value where the maximum real part of all eigenvalues is equal to zero. The lower the value of *s*, the ‘more stable’ the food web means that the food web requires less self-damping to remain stable (van Altena et al., 2016)

Scale of measurement	-
Data source	
Required data	Ecological data
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	2
Opportunities for participatory data collection	
Additional information	
References	de Ruiter PC, Neutel AM, Moore JC (1995), *Energetics, patterns of interaction strengths, and stability in real ecosystems*. Science 269(5228):1257–1260. doi:10.1126/science.269.5228.1257 May RM (1972), *Will a large complex system be stable*. Nature 238(5364):413. doi:10.1038/238413a0 Neutel AM, Heesterbeek JAP, de Ruiter PC (2002), *Stability in real food webs: weak links in long loops*. Science 296(5570):1120–1123. doi:10.1126/science.1068326 Neutel A-M, Heesterbeek JAP, van de Koppel J, Hoenderboom G, Vos A, Kaldeway C, Berendse F, de Ruiter PC (2007), *Reconciling complexity with stability in naturally assembling food webs*. Nature 449(7162):599–U511. doi:10.1038/nature06154 van Altena, C., Hemerik, L. & de Ruiter, P.C. (2016), *Food web stability and weighted connectance: the complexity-stability debate revisited*. Theor Ecol 9, 49–58. https://doi.org/10.1007/s12080-015-0291-7

10.14 Modelled C and N cycling in soil

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Modelled C and N Cycling	Biodiversity
Description and justification	This indicator assessed the soil fertility, in terms of nutrients, structure and *C* and *N* cycling.
Definition	Nutrient cycling is one of the most important processes of nutrients that occur in an ecosystem: their use, movement, and recycling in the environment. Valuable nutrients like carbon, oxygen, hydrogen, phosphorus, and nitrogen are recycled in the ecosystem to allow the life of organisms. Nutrient cycles are inclusive of both living and non-living components and involve biological, geological, and chemical processes, which is the reason that these nutrient circuits are known as biogeochemical cycles. Carbon cycling is essential to all life as it is the main constituent of living organisms. It serves as the backbone component for all organic polymers, including carbohydrates, proteins, and lipids. Carbon compounds, such as carbon dioxide (CO2) and methane (CH4), circulate in the atmosphere and influence global climates. Nitrogen cycling is a necessary component of biological molecules. Some of these molecules include amino acids and nucleic acids.
Strengths and weaknesses	- Soil sample collecting could be time and money consuming.
Measurement procedure and tool	This Indicator must be measured in the field so that laboratory analyses for soil organic matter and nutrient content can be better related to actual field conditions at time of sampling. C and N cycling can be achieved from soil respiration that depends from soil temperature and water-filled pore space (WFPS), which serves as an excellent integrator of physical, chemical and biological soil properties and aeration dependent microbial processes important to C and N cycling in soil (Parkin et al., 1996).
Scale of measurement	t/ha/year
Data source	

Required data	Soil samples
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	Indicators related to soil fertility (soil available nutrients, texture and structure)
Connection with SDGs	2
Opportunities for participatory data collection	
Additional information	
References	https://www.thoughtco.com/all-about-the-nutrient-cycle-373411 Parkin, T.B., Doran, J.W. and Franco-Vizcaino, E. (1996) Field and laboratory tests of soil respiration. in: Doran, J.W. and Jones, A.J. (eds) Methods for Assessing Soil Quality, Soil Science Society of America, Special Publication no. 49, Madison, Wisconsin. Pankhurst C., Gupta V.V.S.R. (1997), *Biological Indicators of Soil Health*. CAB International

10.15 Equivalent used soil

Project Name: proGIreg (Grant Agreement no. 776528)

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Equivalent used soil	**Biodiversity**
Description and justification	This is an indicator of the amount of soil (mainly peat) saved thanks to the soil produced by the NBS. Peat is the main constituent of organic substrates typically used for ornamental plat cultivation. In recent years, due to a recognition of the ecosystem service provision potential of peatlands, the supply of peat has reduced. The NBS, producing suitable soil for cultivating ornamental plant, will go in the direction to find new materials to replace peat.

Definition	Total amount of peat saved by using the soil regeneration procedures proposed within the NBS
Strengths and weaknesses	A strength of this indicator is that it obtains important information by simply using a substitutional approach. On the other hand, a strong limitation is that it will be case specific.
Measurement procedure and tool	The indicator is obtained using a substitutional approach: amount of m^3 soil produced by NBS equal amount of m^3 peat saved.
Scale of measurement	NBS Level
Data source	
Required data	Records of the amount of soil produced
Data input type	Discrete variables
Data collection frequency	During all the implementation, in order to have a final total value of the amount of soil produced
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators of environmental benefit
Connection with SDGs	Sustainable consumption and production: The implementation of nature-based solutions contributes to “doing more and better with less,” net welfare gains from economic activities can increase by reducing resource use, degradation and pollution along the whole life cycle.
Opportunities for participatory data collection	
Additional information	
References	Chapman, Steve, et al. "Exploitation of northern peatlands and biodiversity maintenance: a conflict between economy and ecology." Frontiers in Ecology and the Environment 1.10 (2003): 525-532.

10.16 Number/proportion of conservation priority species

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

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Number/proportion of conservation priority species	Biodiversity
Description and justification	Biodiversity generates a wide range of benefits to society (ecosystem services) therefore its conservation is essential to achieving Sustainable Development Goals (SDGs) and to meet the United Nations Convention on Biodiversity (CBD) Aichi Biodiversity Targets. Measuring net changes to biodiversity to monitor gains or losses as a consequence of NBS can be undertaken using various methodologies, involving either primary observations of species or assessments of habitat extent/quality as a proxy for biodiversity value. Conservation priority species are those species that are seen as keystone species, umbrella species, or species at particular risk locally, regionally or globally. Evaluation of the number/proportion of conservation priority species in a survey area can represent an effective proxy for overall habitat quality. Conservation priority species can include Article 17 species, European Red Data Book Species, national Red Data Book Species, National Biodiversity Action Plan Species, and local Red Data Book Species Key drivers include: • Assisting local authorities to evaluate their progress in urban biodiversity conservation objectives (for example against Aichi/national/local biodiversity targets); • Ensuring NBS contributes positively to biodiversity conservation; • Serving as a public platform upon which biodiversity awareness raising exercises can be launched.
Definition	Measure net change in individual conservation priority species numbers or proportion of overall sample in an area affected by NBS.
Strengths and weaknesses	+ Very good representation of biodiversity value of habitats for species groups considered in conservation action plans. Fairly good proxy for groups not considered.

	- Can be resource intensive dependent upon level of scale of survey and/or availability of existing survey protocols.
Measurement procedure and tool	Methods tend to focus on more applied/participatory methods rather than earth observation/remote sensing methods as, whilst some conservation priority species have been identified and counted from remote sensed data, inventories of conservation priority species and proportional surveys of conservation priority species amongst all background species represent more of a challenge. Nevertheless, if remote sensing methods are a priority, see methods details in Species Diversity Indicator. For applied/participatory methods, standard presence absence or population count surveys can be carried out for target conservation priority species. Carrying out standardised surveys before NBS implementation can provide a baseline from which comparisons can be made. Similarly, surveys of groups of species or species inventories can provide an intuitive biodiversity metric of proportion of conservation priority species. Such survey methodologies can have public resonance and the data can be used to populate indicators and measure progress towards conservation policy targets. UK Common Standards Monitoring using PANTHEON represents an effective way of quantifying habitat value in relation to conservation priority species. Invertebrate surveys are carried out following the Common Standards Methodology reported in Drake et al., (2007). Subsequent species lists are processed through the online PANTHEON portal (https://www.brc.ac.uk/pantheon/) to identify conservation priority statuses, traits and habitat associations. The resulting dataset can be used to present the number of conservation priority species, the proportion of conservation priority species, or an indices of conservation values that combines species inventories with conservation priority status to generate a Species Quality Index or SQI. An example of this is the Saproxylic Quality Index (Fowles et al. 1999; Alexander 2004). Whilst national standardised evaluation processes such as this are a useful aim, it is also possible to make more bespoke approaches on a site-by-site or city-wide scale based on local, regional, national, or international priority species.

Scale of measurement	**Applied methods**: Typically, more local or project scale but can be used to capture data at city scale. Scale is typically related to recorded networks and their scale. **Earth observation / Remote sensing methods**: at various geographical scales. Satellite remote sensing technology in the last decade has empowered interdisciplinary research at regional and local scale with high temporal resolution in order to provide information about changes in species distribution.
Data source	
Required data	Presence/absence and or numerical data on target species or inventories of species. This data will be associated with a spatial attribute and, often, combined with mapping data.
Data input type	Quantitative numerical data, spatially referenced
Data collection frequency	Ideally annual. If resources do not permit this, longer-time periods might be feasible (max 5-yearly)
Level of expertise required	Expertise level is dependent upon level of difficultly of identification required. For a single easily identifiable target species, level of expertise required can be low. More comprehensive/inventory surveys typically require a greater level of expertise. For some species, eDNA methods might be possible (Thomsen and Willerslev 2015). For further details see Metagenomic mapping indicator.
Synergies with other indicators	Synergies with other biodiversity indicators, particularly Article 17 species and broader biodiversity measures. Also with landuse change, greenspace area and accessibility to greenspace (wildlife areas).
Connection with SDGs	Strongest link to SDG 15. However there are links to all SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.

Opportunities for participatory data collection	Such monitoring schemes offer great opportunities for citizen participation. This can be a mechanism to increase the scale and extent of the monitoring, and to increase community engagement with, and awareness of, urban biodiversity.
Additional information	
References	Alexander, K.N.A. 2004. Revision of the Index of Ecological Continuity as used for saproxylic beetles. English Nature Research Reports. 574. Drake C.M., Lott, D.A., Alexander, K.N.A. and Webb, J. (2007) Surveying Terrestrial and Freshwater Invertebrates for Conservation Evaluation. Natural England Research Report NERR005. Natural England, Sheffield: http://publications.naturalengland.org.uk/publication/36002 Fowles, A.P., Alexander, K.N.A. & Key, R.S. 1999. The Saproxylic Quality Index: evaluating wooded habitats for the conservation of dead-wood Coleoptera. The Coleopterist, 8: 121-141 Thomsen, PF and Willerslev, E (2015) Environmental DNA – An emerging tool in conservation for monitoring past and present biodiversity, Biological Conservation 183, 4-18.

10.17 Article17 species richness

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Stuart Connop

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Article 17 species richness	**Biodiversity**
Description and justification	Species richness is a crucial component of biodiversity and species density describes how many Art.17 species are encountered within a defined area (e.g., Functional Urban Area). This can be calculated using a count of species listed under Art. 17 per hexagonal grid cell.
Definition	Count of Art. 17 species per hexagonal grid cell, derived from modified Art. 17 dataset.
Strengths and weaknesses	+ uses a standardised EU-wide survey protocol so that data is comparable - data is only as precise as the survey methods employed and might not pick up changes related to smaller scale implementation of nature-based solutions in urban areas.

Measurement procedure and tool	The method follows that recommended in The European Urban Biodiversity Index (EUBI) and is specific to Article 17 species: The process involves several steps to obtain the Article 17 species count per hexagonal cell. At first a hexagonal grid with a unique identifier for each grid cell is created. This grid is merged with urban area polygons which have been assigned towards specific MAES habitats with a crosswalk using the GIS Tool "Union". In a second step, the Article 17 GIS- data is clipped to the Formal Urban Area Boundary and also merged with the grid. Through this process the created datasets obtain a common identifier within the hexagonal grid, which is the basis for further processing steps. The data is imported into a database system (MS-SQL) for further processing and cleaning operation. Art. 17 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database. The data are then joined using the common identifier assigned within the hexagonal grid as well as the MAES habitat. This allows the filtering out species which may cover a grid cell, but which are not assigned to a habitat within the cell and thus are unlikely to occur at that location. *Based on Ruf et al (2018)*
Scale of measurement	Functional Urban Area (city perimeter)
Data source	
Required data	Landcover, city perimeter and MAES species-habitats data
Data input type	Quantitative
Data collection frequency	Typically annual, but can be less frequent if resources are stretched.
Level of expertise required	Expertise is typically required either for interrogation of satellite imagery. This requirement can be reduced if low resolution land cover maps are used for calculations
Synergies with other indicators	Synergies with other greenspace mapping indicators and protected habitats and species indicators, particularly Article 17 listed habitats.
Connection with SDGs	SDGs 14, 15.

Opportunities for participatory data collection	Surveying habitats represents an excellent opportunity for widening participation. Alternatively, participatory GIS portals can be used to ground-truth satellite imagery.
Additional information	
References	Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to the EEA. Urban Atlas (2012), Art. 17, WISE WFD reference spatial data sets Surface Water Body (2016), Linkages of species and habitat types to MAES ecosystems.

10.18 Number of native bird species within a defied urban area

Project Name: UNaLab (Grant Agreement no. 730052)

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Number of native bird species within an urban area	**Biodiversity**
Description and justification	Biodiversity is the measure of biological variety in the environment and it has an important role in functioning ecosystems services and health of environment and society. Biodiversity is an aspect of natural environment that is most directly affected by anthropogenic influence. City biodiversity is seen as an important aspect of sustainable and resilient urban development. Bird species numbers act as an indicator about changes in the diversity of the urban environment.
Definition	Number of different native species of birds within a defined urban area (number/ha)
Strengths and weaknesses	+ Birds are relatively easy to detect and monitor - While considered a universally good indicator of biodiversity change, the data can be difficult to obtain, it has high variability and requires long timescales to show significant trends
Measurement procedure and tool	Total native bird species detected in built areas are counted. The number of species acts as the indicator value.

Scale of measurement	District to region scale
Data source	
Required data	Total native bird species detected in built areas. The count census numbers can be obtained from city council archives or bird watch organizations.
Data input type	Quantitative or semi-quantitative
Data collection frequency	Annually
Level of expertise required	Low to Moderate – for the identification of the taxonomic groups
Synergies with other indicators	Related to *Reclamation of contaminated land* and *Ratio of open spaces to built form* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection is feasible via citizen science with appropriate training of the volunteers
Additional information	
References	Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

10.19 Species diversity – general

Project Name: CONNECTING Nature (Grant Agreement no. 730222) and RECONECT (Grant Agreement no. 776866)

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Species diversity - general	**Biodiversity**
Description and justification	It is important to foster research and monitoring of biodiversity to determine the best assemblages of species to achieve the most efficient NBS, including the optimization of multiple economic, ecological and social benefits and exploration of trade-offs created by NBS. This can be achieved

	by collection of new data in the field and the use of remote sensing to gather comprehensive data on additional benefits, to complement existing data and observation. Species diversity refers to the number of individual species per area. It can be useful in detecting colonisation of a given area or response of species to a given management action. Counts for species or groups of species can provide an intuitive biodiversity metric which also has public resonance and the data can be used to populate indicators and measure progress towards conservation policy targets. Whilst survey of individual target conservation species and/or umbrella species can be of value in relation to specific conservation objectives, quantification of biodiversity indices can also have value in providing a more holistic insight into overall biodiversity and greater representation of a range of taxa. Key drivers for such biodiversity monitoring include: - Assisting local authorities to evaluate their progress in urban biodiversity conservation (for example against Aichi/national/local biodiversity targets); - Ensuring NBS contribute positively to biodiversity conservation; - Creating a foundation for development of Local Biodiversity Strategies/Action Plans (see example of Lisbon, Portugal in MAES reference below) Serving as a public platform upon which biodiversity awareness raising exercises can be launched.
Definition	Changes in overall number of species/species diversity/biodiversity indices within area affected by NBS.
Strengths and weaknesses	+ Count of species is relatively easy to monitor - Sensitive to area and site specific – extrapolation to larger area overestimates species density due to the non-even species distribution. Mobile species counts require taking into consideration their different relation to the studied habitat/area (e.g., migrants, breeding – resting species). **Applied methods:** Strength of indicator depends of the quality of the data used and the representativeness of the index selected to overall biodiversity patterns. Raw data can characterise species spatial and temporal distributions but are generally limited because of the time/costs involved in the detailed level of data collection needed to accurately detect change.

	Earth observation / Remote sensing methods: Remote sensing has been increasingly contributing to timely, accurate, and cost-effective assessment of biodiversity-related characteristics and functions during the last years. Various studies have demonstrated how satellite remote sensing can be used to infer species richness. However, most relevant studies constitute individual research efforts, rarely related with the extraction of widely adopted Convention on Biological Diversity (CBD) biodiversity indicators (Petrou et al., 2015). Furthermore, systematic operational use of remote sensing data by managing authorities remains limited. The monitoring with CBD related indicators can be facilitated by remote sensing. Numerous studies using RS data to measure biodiversity-related properties are presented in the literature, covering a broad range of applications, study areas, data and methods. However, most studies are rarely explicitly connected to any widely adopted biodiversity indicator that could be extracted through them directly or indirectly. Instead, various indicators have been used by individual studies, resulting in numerous incompatible monitoring systems (Feld et al. 2009). Furthermore, despite the increasing availability of RS data, the connection between variables measured by RS and indicators required by the biodiversity and policy-making community is still poor (Secades et al. 2014). Thus, a link of RS approaches to a common set of indicators would be highly beneficial.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. **Applied / Participatory Methods**: Use species or groups of species count methods (e.g., plot (quadrat) count, point count and line transect methods) to calculate species density expressed in units of species per specified area. The City Biodiversity Index (CBI) (Chan et al 2014), was proposed to engage cities in the implementation of the Convention on Biodiversity's strategic plan for biodiversity. The CBI was intended to provide a benchmark of biodiversity conservation efforts of cities, it provides a self-assessment tool to monitor the progress of biodiversity conservation efforts against a city's baseline. The first part of the framework involves a profile of the city, then 23 indicators are proposed that comprise 3 core

	components: 1) native biodiversity, 2) ES provided by biodiversity, and 3) governance and management of biodiversity. This framework could be used to undertake a full CBI self-assessment. Alternatively, those indicators that directly measure biodiversity could be used, for example Indicator 3: native biodiversity in built-up areas (bird species), or Indicators 4-8 which include three 'core indicator' groups that are most surveyed worldwide – plants, birds and butterflies. Cities can select two additional taxonomic groups (for instance those where data is already held or target groups of local importance/conservation interest). The data from the first year of implementing the Index provides the baseline for future monitoring. It is recommended that application of the Index take place every 3 years to allow sufficient time for the results of biodiversity conservation efforts (e.g., NBS implementation) to materialise. Example units of calculation are: number/abundance of native bird species per hectare. The net change in number of native species from the previous survey to the most recent survey is calculated as: total increase in number of species (as a result of re-introduction or restoration efforts, new species found, etc.) minus number of species that have gone extinct. Possible sources of data include agencies in charge of nature conservation/biodiversity (Wildlife Trusts, etc), city municipalities and urban planning agencies, biological records centres, nature groups, universities, etc. The Urban Biodiversity Inventory Framework (UBIF 2017) offers an alternative 3 track methodology to collect species diversity information as follows: Track 1 - collating data from partners/stakeholders; Track 2 - presence/absence of surrogate species; Track 3 - relative abundance estimates of surrogate species. Track 1 requires the least additional resources but with limited scope for summary statistics, whereas Tracks 2 and 3 require increasing resources but generate increasingly detailed data e.g., comparing changes at a site over time. The CBD agreed a set of 26 specific biodiversity indicators (2010 Biodiversity Indicators Partnership 2010), some of which reflect measures in the CBI (above) and others that could be extrapolated for use under this indicator: • Trends in the abundance/distribution of selected species (e.g., birds/butterflies) • Change in status of threatened and/or protected species (Red List species/species of European interest) • Change in extent of habitats (e.g., vulnerable habitats/habitats of conservation importance)

	• Coverage of protected areas (loss/gain of nationally/locally designated areas/sites) Additional specific examples of general biodiversity measures typically undertaken by professional ecologists include: The Defra Biodiversity Metric 0.2 (Natural England 2018) was developed to as a means of assessing changes in biodiversity value as a consequence of development or land-use change, primarily with the aim of quantifying biodiversity net-gain. It uses habitat as a proxy to measure biodiversity which is converted into measurable 'biodiversity units' according to the area of each habitat type. The metrics score different habitat types (e.g., woodland, grassland) according to their relative biodiversity value and adjusts this according to the condition and location of the habitat. Where new habitat is created or existing habitat is enhanced, then the associated risks of doing so are factored into the metric. It can be used to calculate losses and gains in biodiversity from actions. The metric sites within the 'mitigation hierarchy'. To apply the metric a site should be surveyed, mapped and divided into parcels of distinct habitat types present using a recognised habitat classification system. The biodiversity 'value' of a habitat parcel is evaluated on the basis of its area and the relative 'quality' of its habitat (distinctiveness, condition, strategic significance, habitat connectivity). The calculation uses the scores and the area of the habitat to give a number of biodiversity units that represent the biodiversity value of that habitat parcel. The relative value in biodiversity units 'post development' is then deducted from the 'baseline' to give a value for the extent of change e.g., 'Net Gain'. Net loss would require improvement to development proposal to improve the number of biodiversity units obtained or, if there is no scope for additional on-site compensation or enhancement, off-site measures will need to be considered. BREEAM UK Strategic Ecology Framework (SEF) is a new framework for evaluating, protecting and enhancing ecology in the built environment (Yates, Abdul & Buchanan, 2016). BREEAM credits for ecology (BREEAM 2014) provides a scoring system for assessing the ecological value of a site before and after development (Land Use and Ecology LE01 – LE06). Both protocols start with a Preliminary Ecological Appraisal (PEA) and evaluate and monitor how proposed schemes will benefit biodiversity. The credit system awards high scores to schemes that deliver ecological enhancement. **Earth Observation / Remote Sensing**:

	There are a number of recent remote sensing approaches able to extract related properties that exist for each headline indicator. Methods cover a wide range of fields, including: habitat extent and condition monitoring; species distribution; pressures from unsustainable management, pollution and climate change; ecosystem service monitoring; and conservation status assessment of protected areas. There are some advantages and limitations of different remote sensing data and algorithms. By virtue of the large spatial coverage, information-rich character, and high temporal resolution, remote sensing technology has been widely used in UGS research (Chen et al., 2018). At the end of the 20th century, low/medium spatial resolution remote sensing products began to be applied to the identification of vegetation types (Mucina, 2010). Recent developments in remote sensors offer an excellent opportunity to explore various aspects of different vegetation types. With the many advantages of new remote sensors, combining the advantages of different sensors optimized for vegetation features has attracted a significant amount of research interest and has enabled researchers to propose many promising new techniques for the identification of various vegetation types. For example, using high temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types (Yan et al. 2018; Senf et al. 2015). Utilizing the 3D structures provided by LiDAR imagery in combination with the hundreds of narrow spectral bands provided by hyperspectral (HS) imagery can enable the identification of more vegetation types (Xia et al. 2018; Alonzo et al. 2014) However, although there has been much research that involved combining multi-source data sets or adopting better classification methods, these are still unable to identify different social function types of UGS. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects see the Connecting Nature Environmental Indicator Metrics Review Report.
Scale of measurement	**Applied methods:** Can be used to measure change over a range of scales from city level down to a borough/neighbourhood/site/plot/defined habitat level. **Earth observation/Remote sensing methods:** at various geographical scales. Satellite remote sensing technology in the last decade has empowered interdisciplinary research at regional and local scale with high temporal resolution in order to provide information about changes in species distribution, habitat degradation and fine-scale disturbances of forests.

Data source	
Required data	Typically, total species/group count detected in the area. However, required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data input type	Typically Quantitative, However, data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data collection frequency	Annually is a good frequency target. However, data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Level of expertise required	Medium to high: **Applied methods**: Expertise needed for accurate monitoring of some species groups. Relatively straightforward data analysis based on the CBI calculation for example. **Earth observation/Remote sensing methods**: Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing. Typical “multi-spectral” sensors with 4 to 20 carefully selected and well-calibrated bands provide a great deal of information, and adding more bands can help with specific issues. “Hyperspectral” sensors can have more than 200 bands and can provide a wealth of information to help, for example, identify specific species. Processing such datasets requires special expertise and satellite-based hyperspectral sensors are not yet common. Other sensor types include radar and lidar which actively emit electromagnetic energy and measure the amount that is reflected—these sensors are useful for measuring surface height as well as tree canopy characteristics and surface roughness. Lidar is generally more precise than radar and ideal for measuring tree height. Radar is particularly useful where cloud cover is a problem (for instance, in the biodiversity-rich tropical rainforests) because it penetrates clouds.
Synergies with other indicators	The significance of urban land-system synergies and spatial governance are increasingly emerging towards sustainable targets (also regarding the biodiversity conservation) and liveable environments in cities. Satellite remote sensing, process-based models and big data are playing pivotal roles for obtaining spatially explicit knowledge for the purpose of biodiversity conservation and better planning for managing

	cities. Thus, synergy will be provided through the integration of governance with remote sensing, modelling and big data. Direct measures of supporting/increasing biodiversity could have synergies with landuse change, greenspace area and accessibility to greenspace (wildlife areas).
Connection with SDGs	All SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodveristy and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; Potential co-benefits related to more sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods** Data capture could include public participation and citizen science data collection. Such practices are widespread including using volunteer recording groups for particular species groups. **Earth observation / Remote sensing methods**: It is today possible to integrate remote sensing data and in situ observations to monitor several essential biodiversity variables such as habitat structure and phenology. In this context, municipalities should explore the possibilities of launching citizen science projects and consider the possibility in general that within cities, local knowledge on biodiversity and ecosystem services may reside in many different groups within civic society. Here, we can face the challenges related to scaling, boundaries, locally adapted indicators and scoring which can be met by each municipality developing their interpretation of what scale and what boundary is the most appropriate, what definitions to use, and what set of sub-indicators may best reflect the local ecological and cultural context. However, there are some challenges that are not easily addressed at the municipal level and need input from the research community.
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10.19.1 City Biodiversity Index

Project Name: UNaLab (Grant Agreement no. 730052)

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City Biodiversity Index	**Biodiversity**
Description and justification	The definition of biodiversity is the presence of different species of different taxonomic groups. The net change in the number of species in a municipality is an indication of biological diversity loss or gain. A more comprehensive sample of the biodiversity in an area can be obtained through a census of species in different groups. Vascular plants, birds, and butterflies have been defined in the City Biodiversity Index as core taxonomic groups to be followed in all cities. On top of these, cities are encouraged to select two supplementary taxonomical groups chosen to best reflect local biodiversity. The supplementary taxonomical groups can include, e.g., bryophytes, fungi, amphibians, reptiles, fish, beetles, spiders, seagrasses or others.
Definition	The number of native species detected in the urban area, compared to a baseline number of species
Strengths and weaknesses	+ Encourage reintroduction of lost native species to urban areas through active development or protection - The data can be difficult to obtain, it has high variability and requires long timescales to show significant trends
Measurement procedure and tool	Counts of animal and plant species found on the whole urban area of interest are used. As focus in this metric is increasing biodiversity and reintroducing broader array of natural species, it can be sufficient to select a certain biotypes or areas and a selection of species for monitoring. The indicator value is the number of new native species detected in the urban area, compared to a baseline species number. The first part of the framework involves a profile of the city, then 23 indicators are proposed that comprise 3 core components: 1) native biodiversity, 2) ES provided by biodiversity, and 3) governance and management of biodiversity. This framework could be used to undertake a full CBI self-assessment. Alternatively, those indicators that directly measure biodiversity could be used, for example Indicator 3: native biodiversity in built-up areas (bird

	species), or Indicators 4-8 which include three 'core indicator' groups that are most surveyed worldwide – plants, birds and butterflies. Cities can select two additional taxonomic groups (for instance those where data is already held or target groups of local importance/conservation interest). The data from the first year of implementing the Index provides the baseline for future monitoring. It is recommended that application of the Index take place every 3 years to allow sufficient time for the results of biodiversity conservation efforts (e.g., NBS implementation) to materialise. Example units of calculation are: number/abundance of native bird species per hectare. The net change in number of native species from the previous survey to the most recent survey is calculated as: total increase in number of species (as a result of re-introduction or restoration efforts, new species found, etc.) minus number of species that have gone extinct. Possible sources of data include agencies in charge of nature conservation/biodiversity (Wildlife Trusts, etc), city municipalities and urban planning agencies, biological records centres, nature groups, universities, etc.
Scale of measurement	District to region scale
Data source	
Required data	Data on counts of animal and plant species found on the whole urban area of interest. These can be available through municipalities, government agencies, environmental organizations, bird watch organizations or universities.
Data input type	Quantitative or semi-quantitative
Data collection frequency	Annually
Level of expertise required	Low to Moderate – for the identification of the taxonomic groups
Synergies with other indicators	Related to *Reclamation of contaminated land* and *Ratio of open spaces to built form* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection is feasible via citizen science with appropriate training of the volunteers
Additional information	
References	Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore

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10.20 Bird species richness

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Bird Species Richness	Biodiversity
Description and justification	Based on the European Urban Biodiversity Index (EUBI) metric, this indicator uses bird species richness as a proxy for habitat quality in urban areas. Species richness is a crucial component of biodiversity and species density describes how many bird species are encountered within the Formal Urban Area. The concept is based on the idea of umbrella species, whereby bird species richness is considered to be indirectly linked to the conservation and protection of other species within their ecosystem.
Definition	Count of bird species per hexagonal grid cell, derived from modified Article12 datasets from the EU Birds Directive (Number of species per hexagonal grid cell).
Strengths and weaknesses	+ can be aligned with Birds Directive reporting - can represent a substantial amount of survey work, if such a survey protocol is not already established. - the value of the outcomes are proportional to the effort of the survey - whilst birds can represent a good indication of habitat quality, they are not an accurate proxy for all biodiversity.
Measurement procedure and tool	Based on the EUBI metric: C06 Art. 12 Bird species richness The process involves several steps to obtain the Article 12 species count per hexagonal cell. At first a hexagonal grid with a unique identifier for each grid cell is created. This grid is merged with Urban Area polygons which have been assigned towards specific MAES habitats with a crosswalk using the GIS Tool "Union". In a second step, the Article 12 GIS- data is clipped to the Formal Urban Area Boundary and also merged with the grid. Through this process the created datasets obtain a

	common identifier within the hexagonal grid, which is the basis for further processing steps. The data is imported into a database system (MS-SQL) for further processing and cleaning operation. Article 12 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database. The data is then joined using the common identifier assigned, as well as by the MAES habitat. This enables filtering out of species which may cover a grid cell, but which are not assigned to a habitat within the cell and thus are unlikely to occur at that location.
Scale of measurement	Number of species in a defined area
Data source	
Required data	Survey data and GIS mapping data
Data input type	Quantitative and Spatial
Data collection frequency	Ideally annual. Can be less frequent if resources do not permit this (e.g., 6-yearly to coincide with Birds Directive reporting).
Level of expertise required	Expertise is typically required for species identification if survey is part of the metric. If using existing survey data, then methodology only requires basic GIS skills for data analysis.
Synergies with other indicators	Synergies with other biodiversity indicators and greenspace mapping indicators
Connection with SDGs	SDG 15.
Opportunities for participatory data collection	Surveying represents an excellent opportunity for widening participation.
Additional information	
References	Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to the EEA. Urban Atlas (2012), Art. 12, WISE WFD reference spatial data sets – Surface Water Body (2016), Linkages of species and habitat types to MAES ecosystems

10.21 Animal species potentially at risk

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Domestic and Wild Fauna at Risk	**Natural and Climate Hazards Biodiversity**
Description and justification	This indicator assesses the potential animal species exposed to risk.
Definition	Livestock and protected species.
Strengths and weaknesses	+ It helps to highlight the density of fauna at risk under current, design and/long-term scenarios (e.g., NBS implementation); the Indicator could significantly change in the design and long-term scenario, if the NBS implementation could produce the removal of hazard affecting local fauna habitats. - It could be difficult to obtain the statistical data needed to calculate the Indicator.
Measurement procedure and tool	The final formula of Domestic and Wild Fauna at Risk (*DWFR*), for each specie *i* and habitat type *k* results as: $$DWFR = \frac{\sum_i \sum_j \delta_i \cdot h_j + L}{A}$$ where: δ_i is the density of the i-th specie living in the habitats in the study area exposed to risk [nr/ha] h_j is the extension of the j-th habitat in the study area exposed to risk [ha] *L* is the number of head of livestock living in the study area exposed to risk [nr] A is the extension of the study area [ha]
Scale of measurement	nr/ha
Data source	
Required data	The density of species could be obtained from literature data. The extension of habitats is easily calculated using a simple GIS routine, as follows:

	1) The intersection between the shapefile of the habitats, obtainable from the Corine Land Cover Project, and the shapefile of the hazardous area is achieved using the geoprocessing tool "Intersect"; 2) The spatial extension of the output of the previous step, i.e., the portion of habitats falling within the hazardous area, is calculated using the "calculate geometry" tool.
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Related to indicators measuring the extension of areas exposed to risk and to indicators describing land uses and land use transformation.
Connection with SDGs	15
Opportunities for participatory data collection	Economic stakeholders can be involved into the indicator measurement, as regards the estimation of number of head of livestock living in the study area exposed to risk
Additional information	
References	Gaston K. J., Blackburn T. M. and Goldewijk K. K. (2003), Habitat conversion and global avian biodiversity loss. Proc. R. Soc. Lond. B.270 1293–1300 http://doi.org/10.1098/rspb.2002.2303 Gaston, K.J., Blackburn, T.M. (1997), How many birds are there?. Biodiversity and Conservation 6, 615–625 https://doi.org/10.1023/A:1018341530497 Smil V. (2015), Harvesting the Biosphere: What We Have Taken from Nature, MIT Press Matheny, G., Chan, K.M.A. (2005), Human Diets and Animal Welfare: the Illogic of the Larder. J Agric Environ Ethics 18, 579–594. https://doi.org/10.1007/s10806-005-1805-x

10.22 Typical vegetation species cover

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Typical Vegetation Species Cover	Biodiversity
Description and justification	This indicator assesses the effects of project scenarios on the promotion and the development of typical and local vegetation species.
Definition	It expresses the percentage of natural soil covered by assemblage of typical vegetation species. The higher the value of the indicator, the greater the cover by native vegetation species.
Strengths and weaknesses	+ It helps highlight how much the area, in the baseline, design and/long-term scenarios is covered by local vegetation species; the Indicator could significantly change in the design and long-term scenario, if the NBS implementation could mainly occur through the use of native vegetation species. - A detailed identification of typical vegetation species localization should require a field and/or aerial survey and time-consuming data post-processing.
Measurement procedure and tool	The final formula of Typical Vegetation Species Cover (*TVSC*), for each specie *i* results as: $$TVSC = \frac{\sum_i C_j}{A}$$ where: C_i is the area of the i-th typical vegetation specie cover in the portion of the study area covered by vegetation [ha] A is the extension of the portion of the study area covered by vegetation [ha] The indicator is easily calculated in a GIS environment using a simple geoprocessing tools.
Scale of measurement	%
Data source	
Required data	Spatial data concerning typical vegetation species cover and the whole vegetation cover in the study area.

Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	Related to indicators estimating the richness of a certain species (e.g., species richness indicator) or to indicators concerning land use cover.
Connection with SDGs	15
Opportunities for participatory data collection	Local stakeholders can be involved into the indicator measurement, as regards the acknowledgement and survey of typical vegetation species cover
Additional information	
References	

10.23 Pollinator species presence

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Pollinator Species Presence	**Biodiversity**
Description and justification	The presence of pollinating insects such as bees, hoverflies, butterflies and moths visiting flowers is indicative of pollination (ecosystem service). Increased habitat for pollinators in NBS GI may contribute to increased abundance of pollinators in the wider urban area and provide stepping stones or corridors of habitat from a source site such as an urban park to another urban GI site. Flying pollinating insects are an appropriate indicator of pollination and biodiversity in new NBS GI as these taxa are likely to be already present in source sites such as urban parks within normal foraging range of the new NBS. Flying pollinating insects are highly-mobile, and therefore, considered to have the potential to reach the NBS sites within the project monitoring period.
Definition	This environmental (biological) indicator evaluates if new GI/NBS can attract pollinators species.

Strengths and weaknesses	This KPI requires field surveys and it requires high personnel costs.
Measurement procedure and tool	Measures will be carried out by visual direct counting of species in a given area (limited square) and during a concrete space of time. This method will be repeated periodically in a given area.
Scale of measurement	NBS and surrounding area
Data source	
Required data	Field surveys.
Data input type	Dataforms.
Data collection frequency	Specific surveying calendar (weekly, monthly, etc). Survey take place with the period of the flowering of the autochthonous species of each zone or area, since this determines the period in which the insects carry out their activity.
Level of expertise required	Technical/basic
Synergies with other indicators	This KPI is related with KPI Production of food, KPI Accessibility: configuration and diversity of green space and land use changes, KPI Perceptions of citizens on urban nature, and KPI green intelligence awareness.
Connection with SDGs	This KPI is directly related with SDG 13 and 15.
Opportunities for participatory data collection	Citizens can be involved in these measures as a part of engagement activities. However, data needs to be collected by a trained staff, following a specific schedule.
Additional information	
References	URBAN GreenUP KPI: Pollinator species increase URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl

10.24 Biodiversity Conservation

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Biodiversity conservation (Applied and EO/RS combined)		**Biodiversity**
Description and justification	Biodiversity generates a wide range of benefits to society (ecosystem services) therefore its conservation is essential to achieving Sustainable Development Goals (SDGs) and to meet the United Nations Convention on Biodiversity (CBD) Aichi Biodiversity Targets. Measuring net changes to biodiversity to monitor gains or losses as a consequence of NBS can be undertaken using various methodologies, involving either primary observations of species or assessments of habitat extent/quality as a proxy for biodiversity value. Key drivers include: • Assisting local authorities to evaluate their progress in urban biodiversity conservation (for example against Aichi/national/local biodiversity targets); • Ensuring NBS contributes positively to biodiversity conservation; • Serving as a public platform upon which biodiversity awareness raising exercises can be launched.	
Definition	Measure net change in individual (native) species numbers, functional richness, vegetation cover, conservation priority species in area affected by NBS using more applied and participatory methods or earth observation/remote sensing methods.	
Strengths and weaknesses	**Applied methods**: Ad-hoc, unstructured recording can restrict scientific value but can catalyse community engagement. Structured, systematic monitoring programmes, including citizen science, can be an important mechanism for ascertaining population trends over time. **Earth observation/Remote sensing methods**: Remote sensing has been increasingly contributing to timely,	

	accurate, and cost-effective assessment of biodiversity-related characteristics and functions during the last years. Various studies have demonstrated how satellite remote sensing can be used to infer species richness. However, most relevant studies constitute individual research efforts, rarely related with the extraction of widely adopted Convention on Biological Diversity (CBD) biodiversity indicators (Petrou et al., 2015).
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. **Applied participatory methods**: Counts of species (species richness) have commonly been used as a surrogate for measuring biodiversity for conservation at local and broader scales, and taxa are often categorized according to rarity/local conservation concern (see The Royal Society, 2003 for a framework for measuring biodiversity for conservation). Measurements of population sizes of individual species (abundance), particularly umbrella species (Roberge and Angelstam 2004) (species which if protected, indirectly protect many other species comprising the ecological community of their habitat), can be a more sensitive indicator of change. However, collecting the data on the population dynamics of single species can be resource intensive. Adopting participatory/citizen science approaches can provide a mechanism to reduce resource intensity but can, typically, only be applied to relatively easy to identify species. Selecting appropriate metrics will depend on the objectives of the study, and whether direct measurement is required, or whether a proxy/surrogate measurement may be sufficient. Typically, extrapolations are made from collecting a stratified random sample. Repeat surveys must be undertaken to monitor change against a baseline survey. Analytical techniques will be related to sampling strategies (i.e., diversity or species quality indices, multivariate modelling, etc). Pocock et al. (2015) have developed a checklist of priority attributes for developing a biodiversity monitoring programme that includes 25 attributes that range from elemental to aspirational. This can be used as a checklist to clarify objectives and justify investment in resources and provides an excellent resource for local authorities or city stakeholders wanting to establish monitoring programes. The National Biodiversity Network (James, 2007) has an

	online handbook which provides comprehensive guidance on running a biological recording scheme that could potentially be used for site assessment, land-use planning and environmental policy development. The Natural History Museum (NHM) has a guide for specifically developing citizen science recording schemes (Tweddle, 2012). The Wildlife Trust Biodiversity Benchmark provides a framework to achieve continual biodiversity enhancement and protection on landholdings by developing an action plan, recording the baseline (PEA - habitats & species), and conducting periodic monitoring to assess performance against targets. Examples of citizen science projects that could be applied to NBS projects: Glasgow's buzzing - community bee recording project in partnership with Buglife, creating and enhancing wildflower meadows across the City, carrying out invertebrate surveys (sweep nets of parks before/after meadow creation/enhancement) and raising community awareness of biodiversity (Bairner, 2016) Urban butterfly project - recording butterflies in urban greenspaces 3 times during spring/summer to measure species/abundance using iRecord Butterflies app RSPB Big Garden Birdwatch/Big Schools Birdwatch – annual snapshot of bird diversity NHM Bioblitz – community Bioblitz, typically a 24 hour census, recording as many species as possible. This is typically also associated with use of citizen science recording methods (e.g iNaturalist https://www.inaturalist.org/) When selecting species to target for evaluation of benefits, there are generally two strategies: selecting species that are local, national or international conservation priority species, and selecting representative umbrella species that are indicators of high biodiversity. When selecting umbrella species, it is generally advisable to select a range of species that are representative of a range of taxa (Sattler et al. 2014) and ensure that there is a local focus to this selection in terms of species associated with site of high biodiversity (Caro 2010).

Earth Observation / Remote Sensing methods:

It is important to foster research and monitoring of biodiversity to determine the best assemblages of species to achieve the most efficient NBS, including the optimization of multiple economic, ecological and social benefits and exploration of trade-offs created by NBS. This can be achieved by collection of new data in the field and the use of remote sensing to gather comprehensive data on additional benefits, to complement existing data and observation.

Biodiversity includes multiscalar and multitemporal structures and processes, with different levels of functional organization, from genetic to ecosystemic levels. One of the most widely used methods to infer biodiversity is based on taxonomic approaches and community ecology theories. However, gathering extensive data in the field is difficult due to logistic problems, especially when aiming at modelling biodiversity changes in space and time, which assumes statistically sound sampling schemes. In this context, airborne or satellite remote sensing allows information to be gathered over wide areas in a reasonable time. Most of the biodiversity maps obtained from remote sensing have been based on the inference of species richness by regression analysis. Estimating compositional turnover (β-diversity) might add crucial information related to relative abundance of different species instead of just richness. Presently, few studies have addressed the measurement of species compositional turnover from space. There are novel techniques to measure β-diversity from airborne or satellite remote sensing proposed by Roccini et al. (2017), mainly based on:

- multivariate statistical analysis,
- the spectral species concept,
- self-organizing feature maps,
- multidimensional distance matrices,
- Rao's Q diversity.

Each of these measures addresses one or several issues related to turnover measurement.

High temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types. Yan et al. (2018) integrated object-based classification data with vegetation phenological information derived from multi-temporal WorldView-2 images to identify grass and tree types. Senf et al. (2015) found that adding phenological patterns captured by multi-seasonal Landsat imagery can better discriminate shrublands and woodlands that would otherwise be a challenging task in single-date Landsat imagery. Moreover, utilizing the 3D structures provided by LiDAR imagery in combination with the hundreds of narrow spectral bands provided by hyperspectral (HS) imagery can enable the identification of more vegetation types. Xia et al. (2018) constructed an ensemble classifier to integrate HS and LiDAR data, and used it to identify several tree types and three grass types. Alonzo et al. (2014) used a crown-level integration of HS and LiDAR data to identify 29 common tree species in urban regions

Drone mapping is described as a tool for monitoring ecosystem restoration. Plant communities with different plant cover and species composition reflect spectral bands in different rates and this information reflects state and disturbances of mire ecosystems (peatlands). Usage of drones gives higher resolution data compared to other remote sensing options, and is suitable for plant community level monitoring, but at the same time there is a trade-off between spatial resolution and mapping area.

Various indicators are used to assess the status and trends of components of biodiversity, measure pressures, and quantify biodiversity loss at the level of genes, populations, species, and ecosystems, at various scales (Butchart et al. 2010; EEA 2012; Petrou et al. 2015). Several sets of such indicators have been proposed by organizations, scientists, and policy makers (EEA 2012; Feld et al. 2009; Petrou et al., 2015; Strand et al. 2007).

They can be either directly measured or calculated using statistical models and may have a global, regional, or national applicability. Among the most widely adopted sets are the ones proposed by the United Nations (UN) Convention on Biological Diversity (CBD), aiming at monitoring the progress towards the achievement of the defined targets at global scale (AHTEG 2011). Further efforts include the definition of more directly measured variables, to enhance indicator extraction, such as the Essential Biodiversity Variables (EBV) proposed by the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Pereira et al. 2013).

Although in-situ campaigns are the most accurate way of measuring certain aspects of biodiversity, such as the distribution and population of plant and animal species, in many cases, they have proven particularly costly, time demanding, or impossible (Buchanan et al. 2009; Gillespie et al. 2008). Alternatively, remote sensing (RS) data from airborne or satellite sensors are increasingly being employed in biodiversity monitoring studies (Nagendra et al. 2013; Bergen et al. 2009). Offering repetitive and cost-efficient monitoring of large areas, RS data can provide precious information nearly impossible to be acquired by field assessment alone (Nagendra et al. 2001, 2013).

Recently, essential biodiversity variables (EBVs) were identified (Pereira et al., 2013) (Table 1) and defined as variables, or a group of linked variables, that allows quantification of the rate and direction of change in one aspect of the state of biodiversity over time and across space (Pettorelli et al., 2018). EBVs are planned to harmonise assessment of biodiversity monitoring at any scales, and to support the aims of the Convention on Biological Diversity and IPBES. From the start, satellite remote sensing has been expected to be an important methodology for the derivation of EBVs, and indeed, satellite remote sensing EBVs (SRS-EBVs) have been conceptualised as the subset of EBVs whose monitoring relies largely or wholly on the use of satellite-based data (Luque S et al. 2018).

Table 2 gives a summary of the different types of remote sensing data that is useful in biodiversity monitoring.

Table 1. Essential biodiversity variables and use of RS (based on Walters et al., 2013)

ESSENTIAL BIODIVERSITY VARIABLES	SPATIAL RESOLUTION SATELLITE IMAGERY WITH TYPE OF MEASUREMENT SCALES (INCLUDING AVAILABLE REMOTE SENSING SENSORS)	RELEVANCE AND RELATED INFORMATION FOR BIODIVERSITY
TEMPORAL PHENOLOGY METRICS	Low/coarser spatial resolution (Global Scale) (MODIS, AVHRR etc.)	Phenology types, Forest / Non Forest, Deforestation and Biomass burning.
HABITAT STRUCTURE, ECOSYSTEM EXTENT AND FRAGMENTATION	Medium spatial resolution (Regional Scale) (Landsat, IRS, SPOT etc.)	Forest type distribution and agricultural expansion
HABITAT TYPES AND STRUCTURES, AND ECOSYSTEM COMPOSITION BY FUNCTIONAL TYPE	High spatial resolution (Local scale) (IKONOS, QuickBird, Rapid Eye historic GeoEye, WorldView-2 etc.)	Species-level distribution, canopy diameters, stand-level analysis, individual tree detection, to differentiate species at a finer scale.
HABITAT TYPES AND STRUCTURES	Active remote sensing data	Habitat degradation monitoring by generation of 3D structures

Table 2. Remote Sensing Data Useful for Biodiversity Monitoring

REMOTE SENSING DATA	BIODIVERSITY MONITORING
COARSE SPATIAL RESOLUTION (MODIS, AVHRR)	Forest / Non Forest, Biomass burning studies at global scale.
MEDIUM SPATIAL RESOLUTION (LANDSAT, IRS, SPOT)	Indicators of overall species richness and diversity at regional scales, forest type distribution and agricultural expansion
HIGH TEMPORAL RESOLUTION DATA (MULTI SEASON DATA OR IMAGES CORRESPONDING TO SPECIFIC SEASONS)	Information on invasion species and other species of interest (e.g. using images acquired corresponding to critical phonological stages of flowering or leaf senescence

For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Environmental Indicator Metrics Review Report

Scale of measurement	**Applied methods**: Typically more local or project scale but can be used to capture data at city scale. Scale is typically related to recorded networks and their scale. **Earth observation / Remote sensing methods**: at various geographical scales. Satellite remote sensing technology in the last decade has empowered interdisciplinary research at regional and local scale with high temporal resolution in order to provide information about changes in species distribution, habitat degradation and fine-scale disturbances of forests
Data source	

Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Level of expertise required	**Applied methods**: Professional ecological consultants and scientific/ecological expertise are needed to design and implement and/or support citizen scientists monitoring schemes and data analysis (depending on the scheme or whether an existing scheme is adopted). If identification of target species is not straightforward, expertise can be required for the monitoring also. **Earth observation/Remote sensing methods**: Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing. Typical "multi-spectral" sensors with 4 to 20 carefully selected and well-calibrated bands provide a great deal of information, and adding more bands can help with specific issues. "Hyperspectral" sensors can have more than 200 bands and can provide a wealth of information to help, for example, identify specific species. Processing such datasets requires special expertise and satellite-based hyperspectral sensors are not yet common. Other sensor types include radar and lidar which actively emit electromagnetic energy and measure the amount that is reflected—these sensors are useful for measuring surface height as well as tree canopy characteristics and surface roughness. Lidar is generally more precise than radar and ideal for measuring tree height. Radar is particularly useful where cloud cover is a problem (for instance, in the biodiversity-rich tropical rainforests) because it penetrates clouds.
Synergies with other indicators	The significance of urban land-system synergies and spatial governance are increasingly emerging towards sustainable targets (also regarding the biodiversity conservation) and liveable environments in cities. Satellite remote sensing, process-based models and big data are playing pivotal roles for obtaining spatially explicit knowledge for the purpose of biodiversity conservation and better planning for managing cities. Thus, synergy will be provided through

	the integration of governance with remote sensing, modelling and big data. In relation to direct measures of supporting/increasing biodiversity, there could be synergies with landuse change, greenspace area and accessibility to greenspace (wildlife areas).
Connection with SDGs	All except SDGs 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodiversity and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; More sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working
Opportunities for participatory data collection	**Applied methods**: Such monitoring schemes offer great opportunities for citizen participation. This can be a mechanism to increase the scale and extent of the monitoring, and to increase community engagement with, and awareness of, urban biodiversity. **Earth observation/Remote sensing methods**: It is today possible to integrate remote sensing data and in situ observations to monitor several essential biodiversity variables such as habitat structure and phenology. In this context, municipalities should explore the possibilities of launching citizen science projects and consider the possibility in general that within cities, local knowledge on biodiversity and ecosystem services may reside in many different groups within civic society. Here, we can face the challenges related to scaling, boundaries, locally adapted indicators and scoring which can be met by each municipality developing their interpretation of what scale and what boundary is the most appropriate, what definitions to use, and what set of sub-indicators may best reflect the local ecological and cultural context. However, there are some challenges that are not easily addressed at the municipal level and need input from the research community.
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10.25 Metagenomic mapping

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Metagenomic Mapping	Biodiversity
Description and justification	This indicator assesses the plant soil genetic diversity of microbial and invertebrate (metagenomic map), soil functional diversity of microbial and invertebrate (abundance of functional groups), plant functional diversity (diversity of functional groups) and animal functional diversity (diversity of functional groups).
Definition	Metagenomics is the study of genetic material recovered directly from environmental samples. The broad field may also be referred to as environmental genomics, ecogenomics or community genomics.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Model
Scale of measurement	-
Data source	
Required data	
Data input type	Qualitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	15
Opportunities for participatory data collection	
Additional information	

References	

10.25.1 Abundance of functional groups

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Abundance of Functional Groups	Biodiversity
Description and justification	This indicator assesses the plant soil genetic diversity of microbial and invertebrate (metagenomic map), soil functional diversity of microbial and invertebrate (abundance of functional groups), plant functional diversity (diversity of functional groups) and animal functional diversity (diversity of functional groups).
Definition	A functional group is merely a set of species, or collection of organisms, that share alike characteristics within a community. The abundance of a functional group is the probability that a random organism of the community belongs to the i-th functional group.
Strengths and weaknesses	+ Relative abundances of functional groups, in addition to the number of species, contribute to defining the degree of diversity of an ecosystem. - Samples collection could be time and money consuming; it could be difficult to obtain than information on functional group memberships.
Measurement procedure and tool	Given a sample of organism belonging to a community (it is supposed that the sample was correctly collected, without giving priority to a particular zone of the ecosystem), a group of *N* organisms classified in *S* functional groups. The abundance of a functional group is given by: $$p_i = \frac{N_i}{N}$$ where: p_i is the abundance of the i-th functional group, i.e., the probability that a random organism of the community belongs to the i-th functional group N_i is the number of organisms belonging to the i-th functional group

	N is the number of organisms that were classified in S functional groups The maximum diversity occurs in that state where all the elements are equal; i.e., when $p_a = p_b = \cdots = p_i = \cdots = p_s = {}^{1}/_{S}$, where p_i is the relative abundance of the i-th functional group and S is the number of functional groups.
Scale of measurement	-
Data source	
Required data	Samples of soil collected in the study area
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	The Indicator can be further processed with conventional species diversity indices (Functional Group Richness, Shannon Index, Simpson Diversity Index, etc.)
Connection with SDGs	15
Opportunities for participatory data collection	
Additional information	
References	Borics G.,Tothmérész B., Lukacs B. A., Varbiro G. (2012), *Functional groups of phytoplankton shaping diversity of shallow lake ecosystems*, Hydrobiologia doi: 10.1007/s10750-012-1129-6 Schleuter, D., Daufresne, M., Massol, F., and Argillier, C. (2010), *A User's guide to functional diversity indices*, Ecological Monographs, vol. 80, n. 3, 469-484. doi: 10.1890/08-2225.1

10.25.2 Diversity of functional groups (plants)

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Diversity of Functional Groups (Plants)	**Biodiversity**
Description and justification	This indicator assesses the plant soil genetic diversity of microbial and invertebrate (metagenomic map), soil functional diversity of microbial and invertebrate (abundance of functional groups), plant functional diversity (diversity of functional groups) and animal functional diversity (diversity of functional groups).
Definition	The Indicator is a quantitative measure reflecting how many different functional groups of plants are present in a community (study area) and is expressed by the Shannon Diversity Index, which quantifies the uncertainty in predicting the functional group identity of an individual randomly selected from the study area.
Strengths and weaknesses	The index property of incorporating both components of biodiversity can be seen as both a strength and a weakness. It is a strength because it provides a simple, synthetic summary; on the oither hand it van be seen as a weakness because it makes it difficult to compare communities that differ greatly in richness. Data used for biodiversity richness indicators can be used for the estimation of Shannon Index.
Measurement procedure and tool	The Diversity of Functional Groups (Plants) is calculated, like the Shannon diversity index *H'*, as: $$H' = \sum_i p_i \cdot ln(p_i)$$ where p_i is the proportion of individuals found in functional groups *i* For a well-sampled community, we can estimate the proportion as: $$p_i = \frac{n_i}{N}$$ where

	n_i is the number of individuals in functional group *i* and *N* is the total number of individuals in the community.
Scale of measurement	Dimensionless
Data source	
Required data	Number of individuals (plants) of different functional groups in the study area
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	Related to indicators concerning functional groups in the study area (diversity of animals functional groups, abundance of functional groups).
Connection with SDGs	15
Opportunities for participatory data collection	It is possible to involve local stakeholders in plant surveys, although proper volunteer training may be necessary to allow them to recognise plant species.
Additional information	
References	Barnes, B. V., Zak, D. R., Denton, S., Spurr, S. (1998), Forest ecology. John Wiley and Sons, INC. Magurran, A.E. (2004), Measuring Biological Diversity. Blackwell

10.25.3 Diversity of functional groups (animals)

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Diversity of Functional Groups (Animals)	**Biodiversity**
Description and justification	This indicator assesses the plant soil genetic diversity of microbial and invertebrate (metagenomic map), soil functional diversity of microbial and invertebrate

	(abundance of functional groups), plant functional diversity (diversity of functional groups) and animal functional diversity (diversity of functional groups).
Definition	The Indicator is a quantitative measure that reflects how many different functional groups of animals there are in a community (study area) and is expressed by the Shannon Diversity Index, which quantifies the uncertainty in predicting the functional group identity of an individual that is taken at random from the study area.
Strengths and weaknesses	The fact that the index incorporates both components of biodiversity can be seen as both a strength and a weakness. It is a strength because it provides a simple, synthetic summary, but it is a weakness because it makes it difficult to compare communities that differ greatly in richness. Data used for biodiversity richness indicators can be used for the estimation of Shannon Index.
Measurement procedure and tool	The Diversity of Functional Groups (Plants) is calculated, like the Shannon diversity index *H'*, as: $$H' = \sum_i p_i \cdot ln(p_i)$$ where p_i is the proportion of individuals found in functional groups *i* For a well-sampled community, the rate can be estimated as: $$p_i = \frac{n_i}{N}$$ where n_i is the number of individuals in functional group *i* and *N* is the total number of individuals in the community.
Scale of measurement	Dimensionless
Data source	
Required data	Number of individuals (animals) of different functional groups in the study area
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	High

Synergies with other indicators	Related to indicators concerning functional groups in the study area (diversity of plants functional groups, abundance of functional groups).
Connection with SDGs	15
Opportunities for participatory data collection	It is possible to involve local stakeholders in plant surveys, although proper volunteer training may be necessary to allow them to recognise plant species.
Additional information	
References	Barnes, B. V., Zak, D. R., Denton, S., Spurr, S. (1998), Forest ecology. John Wiley and Sons, INC. Magurran, A.E. (2004), Measuring Biological Diversity. Blackwell

AIR QUALITY

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11 RECOMMENDED INDICATORS OF AIR QUALITY

11.1 Number of days during which air quality parameters exceed threshold values

Project Name: UNaLab (Grant Agreement no. 730052) and URBAN GreenUP (Grant Agreement no. 730426)

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Number of days during which air quality parameters (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3 and PAHs) in ambient air exceed threshold values	**Air Quality**
Description and justification	Air pollution is considered the single largest environmental health risk in the world, causing an estimated 2-6 million or more yearly deaths globally (Health Effects Institute [HEI], 2018; World Health Organisation [WHO], 2016). An important focus of research has been on the role of urban vegetation in the formation and removal of air pollutants in cities (e.g., Miranda et al., 2017) and the associated impacts of air pollution on morbidity, mortality and life-expectancy (e.g., Costa et al., 2014). The most relevant air pollutants are particulate matter of different sizes (PM2.5, PM10),

	ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), benzene (C_6H_6) and toxic metals (As, Cd, Ni, Pb and Hg) (EEA, 2018b).
Definition	Number of documented exceedances to the limit value established in the Air Quality Framework Directive (Directive 2008/50/EC) for $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, ground-level O_3 and PAHs (as indicated by benzo[a]pyrene).
Strengths and weaknesses	+ Accurate results with automated measurements - Some of the measurement systems can be expensive and require continual management and upkeep
Measurement procedure and tool	Air pollution concentrations for regulatory compliance are based on measured pollutant concentrations (PM_{10} and $PM_{2.5}$, O_3, NO_2, SO_2, CO and PAHs) in ambient air. To assess differences in air quality as a result of NBS implementation, air quality monitoring should be conducted in close proximity to the NBS of interest and at an analogous reference site. ***Particulate matter (PM_{10} and $PM_{2.5}$) concentration:*** The reference method for the sampling and measurement of $PM_{2.5}$ and PM_{10} is described in EN12341:2014 "*Ambient Air — standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2,5}$ mass concentration of suspended particulate matter*". Briefly, particulate matter is measured using an air sampler that draws ambient air at a constant flow rate through a specially shaped inlet onto a filter that is weighed periodically to measure the accumulated particle load. The inlet defines the particle size cut-off (2.5 or 10 µm). A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of particulate matter using standardized air sampler equipment is undertaken. The limit concentration for $PM_{2.5}$ is 25 µg/m^3 averaged over one calendar year. Similarly, the limit concentration for PM_{10} is 40 µg/m^3 averaged over one year. To obtain these values, daily $PM_{2.5}$ and PM_{10} averages are averaged over a year to reach a yearly average, which acts as the indicator (ISO, 2018). There is an additional daily average limit value for PM_{10} of 50 µg/m^3, which cannot be exceeded more than 35 times in a calendar year. ***Nitrogen dioxide (NO_2) concentration:*** The reference method for the measurement of nitrogen dioxide and oxides of nitrogen is that described in EN 14211:2012 "*Ambient air — Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence*". To quantify nitrogen dioxide, a stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of nitrogen dioxide is undertaken using standardized chemiluminescence detection equipment. An average of hourly averages is used to calculate a daily average. Daily

averages are then used to calculate a yearly average (ISO, 2018). The limit concentration for NO_2 is 200 µg/m^3 in any one-hour time period, and 40 µg/m^3 averaged over one year.

Sulfur dioxide (SO_2) concentration:
The reference method for the measurement of sulphur dioxide is described in EN 14212:2012 "*Ambient air — Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence*". To quantify sulfur dioxide, a stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of nitrogen dioxide is undertaken using ultraviolet fluorescence detection equipment. An average of hourly averages is used to calculate a daily average. Daily averages are used to calculate a yearly average (ISO, 2018). The limit concentration for SO_2 is 350 µg/m^3 in any one-hour time period and 125 µg/m^3 averaged over one day.

Ground-level ozone (O_3) concentration:
The reference method for the measurement of ozone is described in EN 14625:2012 "*Ambient air — Standard method for the measurement of the concentration of ozone by ultraviolet photometry*". A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of ozone by ultraviolet photometry using standardized equipment is undertaken. The convention for ozone measurement is to calculate a daily maximum 8-hour mean (ISO, 2018). The limit concentration for maximum daily 8-hour mean ground-level O_3 is 120 µg/m^3.

Carbon monoxide (CO) concentration:
The reference method for the measurement of carbon monoxide is described in EN 14626:2012 "*Ambient air — Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy*". A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of CO using non-dispersive infrared spectroscopy equipment is undertaken. Like O_3, the convention for CO measurement is to calculate a daily maximum 8-hour mean (ISO, 2018). The limit concentration for maximum daily 8-hour mean CO is 10 µg/m^3.

Polycyclic aromatic hydrocarbon (PAH) concentration:
The reference method for the sampling of polycyclic aromatic hydrocarbons in ambient air is described in EN 12341:2014. The PAH benzo(a)pyrene (BaP) serves as an analogue for all PAHs in the European air quality regulations. To assess the contribution of BaP in ambient air, the Ambient Air Quality Directive (2004/107/EC) outlines an obligation for Member States to monitor other relevant PAHs at a limited number of measurement sites including at least: benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, and dibenz(a,h)anthracene. The reference method for the measurement

of benzo(a)pyrene in ambient air is described in EN 15549:2008 "*Air quality — Standard method for the measurement of concentration of benzo[a]pyrene in ambient air*". Briefly, benzo(a)pyrene (BaP) is analysed as part of the captured PM_{10} matter. BaP samples are extracted from captured PM_{10} then analysed by high performance liquid chromatography (HPLC) with fluorescence detection (FLD) or by gas chromatography with mass spectrometric detection (GC/MS). The target value for BaP is 1 ng/m^3 averaged over one calendar year

Summary list of ambient air quality pollutants and limit concentrations.

Pollutant	**Units**	**Limit concentration**	**Averaging period**
$PM_{2.5}$	µg/m^3	25 µg/m^3	1 year
PM_{10}	µg/m^3	50 µg/m^3	24 hours
PM_{10}	µg/m^3	40 µg/m^3	1 year
NO_2	µg/m^3	200 µg/m^3	1 hour
NO_2	µg/m^3	40 µg/m^3	1 year
SO_2	µg/m^3	350 µg/m^3	1 hour
SO_2	µg/m^3	125 µg/m^3	24 hours
CO	mg/m^3	10 mg/m^3	Maximum daily 8-hour mean
O_3	µg/m^3	120 µg/m^3	Maximum daily 8-hour mean
PAHs	ng BaP/m^3	1 ng/m^3	1 year

Scale of measurement	District to region scale
Data source	
Required data	Pollutant measurement data from municipalities and regional, national and European authorities
Data input type	Quantitative
Data collection frequency	Continuous measurements with hourly, daily, monthly, and yearly averages
Level of expertise required	Moderate
Synergies with other indicators	Directly related to the *European Air Quality Index* indicator and the other indicators of the *Air Quality* group.
Connection with SDGs	SDG 3 Good health and well-being; SDG 11 Sustainable cities and communities; SDG 15 Life on land

Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Directive 2015/1480 of 28 August 2015 amending several annexes to Directives 2004/107/EC and 2008/50/EC of the European Parliament and of the Council laying down the rules concerning reference methods, data validation and location of sampling points for the assessment of ambient air quality Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., … Teixeira, J.P. (2014). Integrating Health on Air Quality Assessment - Review Report on Health Risks of Two Major European Outdoor Air Pollutants: PM and NO_2. Journal of Toxicology and Environmental Health - Part B Critical Reviews, 17(6), 307-340. European Environment Agency. (2018b). Air quality in Europe – 2018 report. EEA Report No. 12/2018. Luxembourg: Publications Office of the European Union. https://www.eea.europa.eu/publications/ air-quality-in-europe-2018 Health Effects Institute (HEI). (2018). State of Global Air 2018. Special Report. Boston, MA: Health Effects Institute. International Organization for Standardization (ISO). (2018). Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018). https://www.iso.org/standard/68498.html Miranda, A.I., Martins, H., Valente, J., Amorim, J.H., Borrego, C., Tavares, R., … Alonso, R. (2017). Case Studies: modeling the atmospheric benefits of urban greening, In D. Pearlmutter, C. Calfapietra, R. Samson, L. O'Brien,S. Ostoic, G. Sanesi, R. Alonso (Eds.), The Urban Forest. Cultivating Green Infrastructures for People and the Environment (pp. 89-99). New York: Springer International Publishing. National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/ World Health Organization (WHO). (2016). Ambient air pollution: A global assessment of exposure and burden of disease. Geneva: World Health Organization. https://www.who.int/phe/publications/air-pollution-global-assessment/en/

11.2 Proportion of population exposed to ambient air pollution

Project Names: URBAN GreenUP (Grant Agreement no. 730426) and UNaLab (Grant Agreement no. 730052)

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Proportion of population exposed to ambient air pollution	Air Quality
Description and justification	High population densities in urban areas and related economic activities result in increased emissions of air pollutants, which in turn lead to higher ambient concentrations of these pollutants and higher rates of human exposure. Urban areas across the European Union (EU) arehome to more than 70% of the population of the EU-28 (Eurostat, 2014b). The latest World Health Organization (WHO) review of the health effects of air pollution (WHO, 2013) concluded that particulate matter (PM), ozone (O_3) and nitrogen dioxide (NO_2) observed at levels commonly present in Europe have adverse health effects of. A 2013 assessment by the WHO's International Agency for Research on Cancer (IARC) (D. Loomiset al., 2013) concluded that outdoor air pollution is carcinogenic to humans, with the particulate matter component of air pollution most closely associated with an increased incidence of cancer, especially lung cancer. This is in addition to the role air pollution plays in the development of heart and respiratory diseases, including acute respiratory infections and chronic obstructive pulmonary diseases. This indicator focuses on the air pollutants that are more relevant in terms of their health effects and urban concentrations: PM — both PM_{10} (particles with a diameter of 10 micrometres or less) and fine PM, or $PM_{2.5}$ (particles with a diameter of 2.5 micrometres or less); O_3; NO_2; sulphur dioxide (SO_2); and benzo[a]pyrene (BaP). According to several WHO studies (WHO, 2000, 2006, 2013, 2014), exposure to PM can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias. It can also affect the central nervous system, the reproductive system and cause cancer. Exposure to high O_3 concentrations can cause breathing problems, trigger asthma, reduce lung function and cause lung diseases. Exposure to NO_2 increases symptoms of bronchitis in asthmatic children and reduces lung function growth. SO_2 can affect the respiratory system and the

	functioning of the lungs, and causes irritation of the eyes. Finally, BaP is carcinogenic and is used as an indicator of the carcinogenic effect of the total polycyclic aromatic hydrocarbons (PAHs). This indicator can be used to assess the impact of the NBS implantation using data before and after the implementation or to compare data in cities with different level of NBS or GI implantation.
Definition	Urban population exposed to air pollutant concentrations above EU standards and WHO air quality guidelines The following units are used in this indicator: **Concentration**: micrograms (mg) of pollutant per cubic metre for $PM_{2.5}$, PM_{10}, O_3, NO_2 and SO_2. Nanograms (ng) of pollutant per cubic metre for BaP. **Urban population** (POP): number of inhabitants in the 'core city' and, from 2016 on, 'greater city' of the Urban Audit cities represented by the urban stations taken into account in the calculations. **Percentage of the urban population**.
Strengths and weaknesses	+ Accurate results with automated measurements + Based on the reported monitoring data by Member States - Some of the measurement systems can be expensive and require continual management and upkeep - Methodological uncertainty, data uncertainty and rationale uncertainty
Measurement procedure and tool	**Urban population exposure** Information on cities is obtained from the Urban Audit (UA) data (Eurostat, 2014c). The urban population considered is the total number of people represented by any of the urban monitoring stations in the 'core city' and, from 2016, the 'greater city' of the UA cities taking part in the calculations. Initially, stations in the EEA air-quality database are spatially joined with UA core and, from 2016, greater cities in a geographical information system in order to select those stations that fall within the boundaries of the cities included in the UA collection. The selected stations include station types classified as 'urban traffic', 'suburban traffic', 'urban background' and 'suburban background'. According to a study for the European Commission by Entec UK Limited (EC, 2006), in Europe, on average, 5% of the city population lives closer than 100 m from major routes and is therefore potentially exposed to concentrations measured at traffic stations. The remaining 95% of the city population is assumed to be exposed to urban and suburban background concentrations. These percentages vary among jurisdictions.

To calculate the percentages of persons living closer than 100 m to major traffic routes, national data on the population living closer than 100 m from major roads can been taken from Appendix D (EC, 2006).

For PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2, only stations with at least 75% of valid data per calendar year are used. For BaP, the minimum data time coverage accepted is 14% (51 days), according to the data quality objectives related to indicative measurements in the Directive 2004/107/EU (EU, 2004).

For each year, each city (i) in country (j), and every pollutant, the total number of urban or suburban traffic stations (nit) and the total number of urban or suburban background stations (nib) are obtained. A percentage (Ptj %) of the total population of the city (Popi) is proportionally assigned to each of the traffic stations and Pbj % of Popi is proportionally assigned to each of the background stations. Thus, every traffic station has an allocated population equal to ((Ptj / 100) * Popi / nit) and every background station has an allocated population equal to ((Pbj /100) *Popi / nib).

EU LIMIT AND TARGET VALUES

Fine particulate matter ($PM_{2.5}$)

The annual mean concentration is calculated for each of the selected stations fulfilling the valid data criteria. Depending on the mean concentration, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (less than or equal to the target value (25 $\mu g/m^3$), or greater than the target value).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each concentration class by the sum of the population assigned to each station.

Coarse particulate matter (PM_{10})

For each selected station that fulfils the valid data criteria, the 90.4 percentile (P90.4) of the daily mean concentration series is calculated. P90.4 represents, in a complete series of 365 elements, the 36th highest value. When P90.4 is less than or equal to 50 $\mu g/m^3$, it indicates that the daily limit value (DLV) was not exceeded on more than 35 days.

Depending on the value of P90.4, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (P90.4 > 50 $\mu g/m^3$, i.e., greater than the DLV and P90.4 ≤ 50 $\mu g/m^3$, i.e., less than the DLV).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each individual concentration class by the sum of the population assigned to each station.

Ozone (O_3)

For each selected station fulfilling the valid data criteria, the 93.2 percentile (P93.2) of the daily maximum 8-hourly mean concentration series is calculated. P93.2 represents, in a complete series of 365 elements, the 26th highest value. When P93.2 is less than or equal to 120 µg/m^3, it indicates that the long term objective was not exceeded on more than 25 days.

Depending on the value of P93.2, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (P93.2 >120 µg/m^3, i.e., exceedance of the long term objective on more than 25 days, and P93.2 ≤120 µg/m^3, i.e., exceedance of the long term objective on fewer than or equal to 25 days).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each individual concentration class by the sum of the population assigned to each station.

Nitrogen dioxide (NO_2)

The annual mean concentration is calculated for each of the selected stations that fulfills the valid data criteria.

Depending on the annual mean concentration, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (less than or equal to the limit value (40 µg/m^3), or greater than the limit value).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each concentration class by the sum of the population assigned to each station.

Benzo[a]pyrene (BaP)

The annual mean concentration is calculated for each of the selected stations fulfilling the valid data criteria.

Depending on the mean concentration, each station (and its allocated population) is then classified uniquely in one of the two concentration classes (less than or equal to the target value (1.0 ng/m^3), or greater than the target value).

The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each concentration class by the sum of the population assigned to each station.

	Sulfur dioxide (SO_2) For each selected station that fulfills the valid data criteria, the 99.2 percentile (P99.2) of the daily mean concentration series is calculated. P99.2 represents, in a complete series of 365 elements, the 4th highest value. When P99.2 is less than or equal to 125 µg/m^3, it indicates that the daily limit value would was not exceeded on more than three days. Depending on the value of P99.2, each station (and its allocated population) is then classified uniquely in one of these two concentration classes (P99.2 >125 µg/m^3, i.e., greater than the daily limit value and P99.2 ≤125 µg/m^3, i.e., less than the daily limit value). The percentage of the urban population allocated to these two concentration classes is calculated by dividing the population represented by the stations assigned to each individual concentration class by the sum of the population assigned to each station. *For a more detailed description of the indicator, please follow the link in the first reference listed below.*
Scale of measurement	At sampling points as indicated by the data resolution needed to quantify NBS impacts. EEA data are provided at district to region scale. Data regarding microclimatic impacts of NBS can be obtained by installation of specific sensors in close proximity to implemented NBS.
Data source	
Required data	• Air Quality e-Reporting (AQ e-Reporting) provided by European Commission (https://www.eea.europa.eu/ds_resolveuid/DAT-3-en) • AirBase - The European air quality database provided by European Environment Agency (EEA) (https://www.eea.europa.eu/ds_resolveuid/DAT-3-en) • Gisco - Urban Audit 2012 provided by Statistical Office of the European Union (Eurostat) (https://www.eea.europa.eu/data-and-maps/data/external/gisco-urban-audit) • City population provided by City Population (https://www.eea.europa.eu/data-and-maps/data/external/city-population)
Data input type	Quantitative
Data collection frequency	Annually

Level of expertise required	Moderate to High (Air quality expert and IT expert)
Synergies with other indicators	*Number of days during which air quality parameters exceed threshold* values, *European Air Quality Index* and the other indicators of the Air Quality group.
Connection with SDGs	SDG 3 Good health and well-being; SDG 11 Sustainable cities and communities; SDG 15 Life on land
Opportunities for participatory data collection	None identified
Additional information	
References	**Exceedance of air quality standards in urban areas EEA (2019).** https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit-3/assessment-5 Permalink: https://www.eea.europa.eu/ds_resolveuid/13c96efc7a1f44ee9337b2e2cdf077a9 EC, 2006 - Development of a methodology to assess the population exposed to high levels of noise and air pollution close to major transport infrastructure, prepared by Entec UK Limited (Appendix D). ETC/ACC, 2009 - Indicators on urban air quality. A review of current methodologies. ETC/ACC Technical paper 2009/8 (http://acm.eionet.europa.eu/reports/ETCACC_TP_2009_8_UrbanAQindicators) EU, 2004 - Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004L0107 Eurostat, 2014c - Urban Audit. (http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/urban-audit).https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit-3/assessment-5 https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit-3/assessment-5

11.3 European Air Quality Index

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Raúl Sánchez[1], Jose Fermoso[1], Silvia Gómez, María González[1], Jose María Sanz[1], Esther San José[1]

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European Air Quality Index	Air Quality
Description and justification	The European Air Quality Index allows users to understand more about air quality where they live, work or travel. Displaying up-to-date information for Europe, users can gain insights into the air quality in individual countries, regions and cities. The Index is based on concentration values for up to five key pollutants, including: ▪ Particulate matter (PM_{10}); ▪ Fine particulate matter ($PM_{2.5}$); ▪ Ozone (O_3); ▪ Nitrogen dioxide (NO_2); ▪ Sulphur dioxide (SO_2). It reflects the potential impact of air quality on health, driven by the pollutant for which concentrations are poorest due to associated health impacts. The index is calculated hourly for more than two thousand air quality monitoring stations across Europe, using up-to-date data reported by EEA member countries. These data are not formally verified by the countries. By default, the air quality index depicts the situation 3 hours ago. Users can then select any hour in the preceding 48 hours and view forecast values for the following 24 hours. The user can filter the selection by country and by station type. Stations are classified in relation to the predominant emission sources, including traffic, industry and background where the pollution level is dominated neither by traffic nor by industry. The user can view all stations, traffic stations only or non-traffic stations only (i.e., industrial, urban or regional background stations). European Union legislation sets air quality standards for both short-term (hourly or daily) and long-term (annual) air quality levels. Standards for long-term levels are stricter than for short-term levels, since serious health effects may occur from long-term exposure to pollutants. The Index indicates the short-term air quality situation. It does not reflect the long-term (annual) air quality situation, which may differ significantly.

	The air quality index is not a tool for checking compliance with air quality standards and cannot be used for this purpose.
Definition	European Air Quality Index
Strengths and weaknesses	+ Based on the reported monitoring data by Member States - Some of the measurement systems can be expensive and they need constant management and upkeep.
Measurement procedure and tool	The Index uses 'up-to-date' air quality data officially reported every hour by EEA member countries, complemented where necessary by modelled air quality data from the European Union's Copernicus Atmosphere Monitoring Service (CAMS). Additionally, can be complemented with local air quality data from equimpents installed in NBS locations. Concentrations values for up to five key pollutants determine the index level that reflects air quality at each monitoring station. The index corresponds to the poorest level for any of five pollutants, according to the table shown below. Circles on the map represent the locations of air quality monitoring stations. The colours reflect air quality at the given hour at that station. **Calculating the index for traffic stations** When calculating the index for traffic stations we only use data for NO_2 and PM (either $PM_{2.5}$, PM_{10} or both). This is because SO_2 concentrations can be high in localized areas and distort the picture of local air quality, while ozone levels are normally very low at traffic stations. **Calculating the index for industrial and background stations** At industrial and background stations, the index is calculated for those stations with data (either measured or modelled) for at least the three pollutants NO2, O3 and PM (either $PM_{2.5}$, PM_{10} or both). **Stations missing data for certain pollutants** To avoid leaving out stations that do not report data for all pollutants or for which missing data cannot be gap-filled, the index is calculated for all monitoring stations with data for at least one pollutant. Those stations that do not report data or for which data cannot be gap-filled for the minimum pollutants for that station type are depicted as transparent dots, indicating that the index is not calculated with the minimum range of pollutants. **Averaging time for pollutants**

	For NO_2, O_3 and SO_2, hourly concentrations are fed into the calculation of the index. For PM_{10} and $PM_{2.5}$, the 24-hour running means for the past 24 hours are fed into the calculation of the index. **Bands of concentrations and index levels** The bands are based on the relative risks associated to short-term exposure to $PM_{2.5}$, O_3 and NO_2, as defined by the World Health Organization in its report on the Health Risks of Air Pollution in Europe project (HRAPIE project report). The relative risk of exposure to $PM_{2.5}$ is taken as basis for driving the index, specifically the increase in the risk of mortality per 10 µg/m3 increase in the daily mean concentration of $PM_{2.5}$. Assuming linearity across the relative risks functions for O_3 and NO_2, we calculate the concentrations of these pollutants that pose an equivalent relative risk to a 10 µg/m3 increase in the daily mean of $PM_{2.5}$. For PM_{10} concentrations, a constant ratio between PM_{10} and $PM_{2.5}$ of 1:2 is assumed, in line with the World Health Organization´s air quality guidelines for Europe. For SO_2, the bands reflect the limit values set under the EU Air Quality Directive. **Health messages** The index bands are complemented by health related messages that provide recommendations for both the general population and sensitive populations. The latter includes both adults and children with respiratory problems and adults with heart conditions.

Pollutant	Index level (based on pollutant concentrations in µg/m3)					
	Good	Fair	Moderate	Poor	Very poor	Extremely poor
Particles less than 2.5 µm ($PM_{2.5}$)	0-10	10-20	20-25	25-50	50-75	75-800
Particles less than 10 µm (PM_{10})	0-20	20-40	40-50	50-100	100-150	150-1200
Nitrogen dioxide (NO_2)	0-40	40-90	90-120	120-230	230-340	340-1000
Ozone (O_3)	0-50	50-100	100-130	130-240	240-380	380-800
Sulphur dioxide (SO_2)	0-100	100-200	200-350	350-500	500-750	750-1250

AQ index	General population	Sensitive populations
Good	The air quality is good. Enjoy your usual outdoor activities.	The air quality is good. Enjoy your usual outdoor activities.
Fair	Enjoy your usual outdoor activities	Enjoy your usual outdoor activities
Moderate	Enjoy your usual outdoor activities	Consider reducing intense outdoor activities, if you experience symptoms.
Poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat	Consider reducing physical activities, particularly outdoors, especially if you experience symptoms.
Very poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat	Reduce physical activities, particularly outdoors, especially if you experience symptoms.
Extremely poor	Reduce physical activities outdoors.	Avoid physical activities outdoors.

Scale of measurement	District to region scale
Data source	
Required data	Pollutant measurement data from municipalities and regional, national and European authorities.
Data input type	Quantitative
Data collection frequency	Continuous measurements with hourly, daily, monthly, and yearly averages
Level of expertise required	Moderate
Synergies with other indicators	Number of days during which air quality parameters exceed threshold values and the other indicators of the Air Quality group.
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified

Additional information	
References	https://airindex.eea.europa.eu/Map/AQI/

12 ADDITIONAL INDICATORS OF AIR QUALITY

12.1 Removal of atmospheric pollutants by vegetation

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Raúl Sánchez[1], Jose Fermoso[1], Silvia Gómez, María González[1], Jose María Sanz[1], Esther San José[1]

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Removal of atmospheric pollutants by vegetation (leaves, stems and roots)	**Air Quality**
Description and justification	Air pollution is one of the main problems of urban areas. Many cities experience air pollution during months owing to the combustion of fossil fuels. The air pollutant removal capacity of trees is estimated based on dry deposition that is considered as the rate of air pollutants removed from the atmosphere (Lovett, 1994; McPherson et al., 1998; Scott et al., 1998). Pollutants are removed on leaf surfaces primarily through leaf stomata uptake of gaseous pollutants and leaf interception of particulate matter (Nowak et al., 2006). The first process leads to the diffusion of pollutant into the inner part of leaves. Gases may also be absorbed or react with plant surfaces, whereas removal through the latter process may be reduced by the suspension of intercepted particles from the leaf surfaces through wind action (Selmi et al., 2016). Air pollutant deposition on vegetation cover other than trees (such as shrubs, grass) and land cover types (like water bodies, and buildings) are not included in the calculation presented herein.
Definition	With this KPI the main aim is to calculate the pollutions removed by vegetation (in stem, leaves and roots) (kg ha^{-1} year^{-1}) using formulas and equations in order to assess the impact of the NBS.
Strengths and weaknesses	+ This method does not required field work. - Modelled method and specific software are required.
Measurement procedure and tool	The capacity of trees to attenuate air pollutants is calculated based on the formulas below (Baldocchi and Camara, 1987): The *pollutant flux* (F_i) is calculated as the product of the *deposition velocity* (V_d) and the *concentration of air pollutant i* (C_i), Eq.(1): $F_i = V_d \times C$ (1) *Total flux into urban trees of air pollutant i* (F_{it}) can be estimated by multiplying F_i by tree cover (A) across a time period (T), Eq.(2): $F_{it} = F_i \times A \times T\ C$ (2)

	The *quantity of air pollutants removed by trees* (F) can be quantified by Eq.(3); $F = \sum_{i=1}^{3} F_{it}$ (3) The land use-land cover map can be derived from satellite imagry using screen digitalizing in ArcGIS 10. The percentage of tree cover is calculated for each Demo Site separately in ArcGIS 10. The maps and models needed can easily be converted to an open platform such as QGIS.
Scale of measurement	Building to street scale
Data source	
Required data	Atmospheric pollutant concentration data from monitoring stations and tree cover data from (municipal) maps and models.
Data input type	
Data collection frequency	Annually
Level of expertise required	High
Synergies with other indicators	None identified
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	None identified.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl

	Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099. Mullaney, J., Lucke, T., Trueman, S.J., 2015. A review of benefits and challenges in growing street trees in paved urban environments. Landscape Urban Plan. 134, 157–166. doi:10.1016/j.landurbplan.2014.10.013. Baró, F., Haase, D., Gómez-Baggethun, E., Frantzeskaki, N., 2015. Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities. Ecol. Indic. 55, 146–158. doi:10.1016/j.ecolind.2015.03.013. SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf

12.2 Total particulate matter removed by NBS vegetation

Project Name: proGIreg (Grant Agreement no. 776528)

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[2] *Università degli Studi della Tuscia, Viterbo, Italy*

Particulate Matter Removed by NBS Vegetation	**Air Quality**
Description and justification	Particulate matter (PM) abatement, due to the green surface is a key indicator of the amelioration of the environmental quality due to the implementation of NBS in urban areas. Indeed, PM has become a serious environmental problem and harms human health.
Definition	The PM abatement is defined as the PM deposed on tree and shrub leaves.
Strengths and weaknesses	It allows to detect the abatement of PM at different particle size fraction. The limit is that the survey is discrete and not continuously during the time.

Measurement procedure and tool	PM deposed on the leaves will be studied by Scanning Electron Microscopy combined with Energy Dispersed X-Ray microanalysis, obtaining a quanti-qualitative characterization of the deposited particles, as a function of their size and elemental composition
Scale of measurement	NBS
Data source	
Required data	Leaf samples
Data input type	Discrete variables
Data collection frequency	Particulate matter abatement will be estimated twice during the project (at the NBS implementation and after 2 years: pre-post design)
Level of expertise required	High
Synergies with other indicators	Reduction of Pollutants
Connection with SDGs	Make cities inclusive, safe, resilient and sustainable Ensure healthy lives and promote well-being for all at all ages
Opportunities for participatory data collection	
Additional information	
References	Baldacchini, Sgrigna, Clarke, Tallis, Calfapietra, 2019. An ultra-spatially resolved method to quali-quantitative monitor particulate matter in urban environment Environ. Sci. Poll. Res. 26; 18719-18729 Baldacchini et al., 2017. How does the amount and composition of PM deposited on Platanus acerifolia leaves change across different cities in Europe? Environ. Sci. Technol. 51; 1147-1156. Sgrigna, Baldacchini, Esposito, Calandrelli, Tiwary, Calfapietra, 2016. Characterization of leaf–level particulate matter for an industrial city using electron microscopy and X-ray microanalysis, Sci. Tot. Environ. 548–549; 91– 99. 39

12.3 Modelled O_3, SO_2, NO_2 and CO capture/removal by vegetation

Project Name: UNaLab (Grant Agreement no. 730052)

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Modelled air pollutant capture/removal by vegetation	Air Quality
Description and justification	Vegetation can remove air pollutants (particles and gases) by the process of dry deposition. Deposition is the transport from a point in the air to a plant surface, which is mainly related to near-surface pollutant concentration, weather conditions and vegetation properties. Most plants have a large surface area per unit volume, increasing the probability of deposition compared with the smooth, manufactured surfaces present in urban areas. For example, 10-30 times faster deposition has been reported for sub-micrometre (<µm) particles on synthetic grass compared with glass and cement surfaces (Air Quality Expert Group [AQEG], 2013; Roupsard, Amielh, Maro, Coppalle, & Branger, 2013). To estimate the magnitude of this contribution models are commonly used.
Definition	Annual capture of O_3, SO_2, NO_2, CO and $PM_{2.5}$ by trees and shrubs and grass (all expressed in units of mass, report as kg/ha/y)
Strengths and weaknesses	+ Effective method for extensive analyses - Needs expert users and a lot of input data
Measurement procedure and tool	The chemical transport model WRF-Chem (National Oceanic and Atmospheric Administration [NOAA], n.d.) has a dry deposition model that can estimate the amount of pollutants removed by vegetation (O_3, NOX, VOC, PM_{10} and $PM_{2.5}$) with an hourly resolution per grid cell. As input data WRF-Chem requires: i) high resolution inventory of anthropogenic emissions; ii) biogenic emissions (MEGAN model; Guenther et al., 2006); iii) initial and boundary conditions (MOZART model; Emmons et al., 2010); and,

	iv) topography and land use (United States Geological Survey [USGS] 33 classes database; Pineda et al., 2004). These results can be used to calculate the annual amount of pollutants removed by vegetation at the grid, neighbourhood or city scale. The i-Tree Eco model (USDA Forest Service, 2019) can also be applied to estimate the air pollutants removed by vegetation. Although it does not provide spatial variability, it can calculate hourly amounts of pollutants removed by urban forests, as well as the associated percentage of air quality improvement throughout a year. Pollution removal is calculated for ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter ($PM_{2.5}$). To apply the i-Tree Eco model, the following data is required: i) extent of vegetation cover and characteristics (e.g., type, age and height); ii) land use; iii) air quality; and, iv) meteorology. Results can be used to calculate the annual amount of pollutants removed by vegetation at the local scale.
Scale of measurement	Street to metropolitan scale
Data source	
Required data	Various requirements based on the model type; see *Measurement procedure and tool*
Data input type	Qualitative and quantitative
Data collection frequency	Before and after the NBS implementation
Level of expertise required	Moderate to High – to apply models and evaluate the outcomes
Synergies with other indicators	Other indicators of the *Air Quality* group
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified

Additional information	
References	Air Quality Expert Group [AQEG]. (2018). Impacts of Vegetation on Urban Air Pollution. Prepared for Department for Environment, Food and Rural Affairs, Scottish Government, Welsh Government, and Department of the Environment in Northern Ireland. Carlisle, UK: Department for Environment, Food and Rural Affairs. Retrieved from https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1807251306_180509_Effects_of_vegetation_on_urban_air_pollution_v12_final.pdf. Emmons, L.K., Walters, S., Hess, P.G., Lamarque, J.-F-, Pfister, G.G., Fillmore, D. … Kloster, S. (2010). Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4). Geoscientific Model Development, 3, 43-67. Guenther, A., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P.I., & Geron, C. (2006). Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature). Atmospheric Chemistry and Physics, 6(11), 3181–3210. United States Department of Agriculture (USDA) Forest Service. (2019). i-Tree Eco Manual. Northern Research Station, USDA Forest Service. Retrieved from https://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6_UsersManual.pdf National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/ Pineda, N., Jorba, O., Jorge, J., & Baldasano, J.M. (2004). Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model. International Journal of Remote Sensing, 25(1), 129–143. Roupsard, P., Amielh, M., Maro, D., Coppalle, A., & Branger, H. (2013). Measurement in a wind tunnel of dry deposition velocities of submicron aerosol with associated turbulence onto rough and smooth urban surfaces. Journal of Aerosol Science, 55, 12-24.

12.3.1 Total Leaf Area

Project Name: Nature4Cities (Grant Agreement no. 730468)

Author/s and affiliations: Florian Kraus[1], Bernhard Scharf[1]

[1] *Green4Cities GmbH/GREENPASS GmbH*

Leaf Area (LA)	**Green Space Management Climate Resilience Air Quality**
Description and justification	The LA (Leaf Area) is a Key Performance Indicator of the GREENPASS® system. It expresses the sum of leaf area of NBS within project area. The Leaf Area is the operating surface of NBS and therefore decisive for climate regulation, carbon storage and air purification.
Definition	The LA (Leaf Area) describes the total amount of leaf area of all NBS in a project area.
Strengths and weaknesses	+ key performance indicator regarding biodiversity + easy for communication, understanding and decision-making + useful for design optimization + link the NBS performance to a single number - needs area analysis and calculation
Measurement procedure and tool	- NBS analysis of an area and calculation (eg with GREENPASS® system and tools) - numerical value in m^2
Scale of measurement	Object, neighbourhood and city scale
Data source	
Required data	- project area - NBS typologies and areas
Data input type	- numerical analysis of vegetation types incl. characteristics (eg LAI)
Data collection frequency	- one to several times in planning and optimization process
Level of expertise required	easy to understand – for planners and decision makers
Synergies with other indicators	-
Connection with SDGs	SDG 11 Sustainable Cities and Communities, SDG 13 Climate action

Opportunities for participatory data collection	-
Additional information	
References	Kraus, F.; Scharf, B. (2019): Management of urban climate adaptation with NBS and GREENPASS®. Geophysical Research Abstracts. Vol. 21, EGU2019-16221-1, 2019 EGU General Assembly 2019. Kraus, F.; Scharf, B. (2019): Climate-resilient urban planning and architecture with GREENPASS illustrated by the case study 'FLAIR in the City' in Vienna. OP Conf. Ser.: Earth Environ. Sci. 323 012087. Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions. Nature4Cities, D2.2 - Expert-modelling toolbox Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

12.4 NO_X and PM in gaseous releases

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Raúl Sánchez[1], Jose Fermoso[1], Silvia Gómez, María González[1], Jose María Sanz[1], Esther San José[1]

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NO_X and PM in gaseous releases	Air Quality
Description and justification	Other indicators are defined to assess general impacts of implemented NBS on air quality at building, district or city scale. In contrast, this indicator is focused on the impact of specific NBS on a polluted gaseous stream prior to release into the urban atmosphere. This indicator has been mainly defined for the Urban Garden BioFilter but in the future can be used for other NBS to be installed in outdoor pipes to capture pollutants. At laboratory scale, the impact of this NBS has been measured by a setup with air characterisation upstream

	and downstream of the filter. However, real world applications of interventions and measurements of air quality are relatively more complex. Inlet air can be measured by installing a sensor in the area where air is going to be extracted or inside of the inlet pipe. However, outlet air cannot be captured directly as the atmosphere is an open system. Thus, the ideal sensor configuration involves installation of two measuring points, one before and at least one after the BioFilter. One post-filter measuring point should be within the outdoor area in close proximity to the gas release point. A second, more distant post-filter measuring point (within the expected flow path of effluent gas) is recommended. These three measuring points are to be instrumented with $PM_{2.5}$ and NOx sensors.
Definition	Measure air concentrations of NO_2 and $PM_{2.5}$ (µg/m^3) at sampling points at a range of radii from NBS location both pre- and post-intervention. Compare these data to measurements taken at equivalent locations on equivalent stretches of street without NBS at a similar time of day on the same dates.
Strengths and weaknesses	- Specific Method for polluted air solutions. - PM monitoring device required.
Measurement procedure and tool	**<u>Data processing</u>** Calculation of (weekly, monthly and/or Annually) mean levels of NO_2, PM_{10} and $PM_{2.5}$ at each sampling location as the average value of the all the measurements done before and after of the interventions. Comparison of mean values for NBS intervention and control sample locations in the implementation area. Data comparison before and after of the intervention using the reference to assess possible meteorological or other factors influence. Calculations must be done using comparable periods of time before and after the interventions (i.e., if measurement period before of the intervention goes from nov18-oct19, measurement period must be at minimum from nov19-oct21 and processing can be done for either years or Annually). For this KPI, continuous records of air quality are available and, therefore, a different processing of the information will be applied to evaluate the impact of the NBS. **<u>Results</u>** The calculated values will be compared qualitatively and quantitatively for the periods before and after the interventions in the NBS and reference sections.

Quantitative assessment will be done by using the following expression:

$$\textbf{PM impact} = \left(\frac{NBS\ Measures\ average\ after\ intervent. - NBS\ Expected\ average\ a}{NBS\ Expected\ average\ after\ intervent.}\right) \times 100$$

Where *measures average after intervent.* is the average value of measurements after interventions and *Expected value after intervent.* (but supposing that interventions had not been done) is:

$$\textbf{NBS Expected average after intervent.} = \left(\frac{Ref.average\ after\ intervent.}{Ref.average\ before\ intervent.}\right) \times NBS\ Measures\ before\ intervent.$$

Positive or null NO_2, PM_{10} and $PM_{2.5}$ impact values indicates negative or no impact of the NBS on PM concentration for that implementation. Negative values indicates a positive impact of that NBS on NO_2, PM_{10} and $PM_{2.5}$ concentration.

The additional methodology (using continuous data) aims to find significant differences by comparing the normalized distributions of the difference between the sections with NBS and the reference sections.

First, the normalized distribution of the difference of the hourly values of the NBS location and the reference location is calculated. Then, the distributions of data before and after of the interventions are compared. If significant differences are found between the distributions before and after the implementation, then the impact of the NBS can be assessed.

If the centers of the histograms of both distributions (before and after the implementation) are separated by more than the sum of the standard deviations, σ (i.e., 2σ), then they will be considered as significantly different (with a 95% probability). If the center of the histogram of the situation after the implementation is lower than that of the previous situation (and the differences are significant) then it will be concluded that the impact of the NBS is appreciable. As an equation, this statement could be presented as follows:

$$Absolut\ value\left(Aver._{before} - Aver._{after}\right) > \sigma_{before} + \sigma_{after}\ Positive\ impact$$

$$Absolut\ value\ \left(Prom._{before} - Prom._{after}\right) < \sigma_{before} + \sigma_{after}\ Neglective\ impact$$

	This procedure is suitable for both $PM_{2.5}$ and NO_2.
Scale of measurement	street/Building
Data source	
Required data	Concentrations of NO_2 and airborne particulate matter are measured by recording PM mass per cubic metre of air ($PM_{2.5}$ and PM_{10}). PM - Micrograms (mcg) per cubic metre, µg/m^3. (Microgram (µg) One-millionth of a gram; a milligram (mg) = 1000 micrograms). NO_2 – ppb (parts per billion). Parts per billion (ppb) is the number of units of mass of a contaminant per 1000 million units of total mass.
Data input type	Continuous monitoring of NO2 and particulate matter.
Data collection frequency	Continuous monitoring in the selected points hourly.
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index

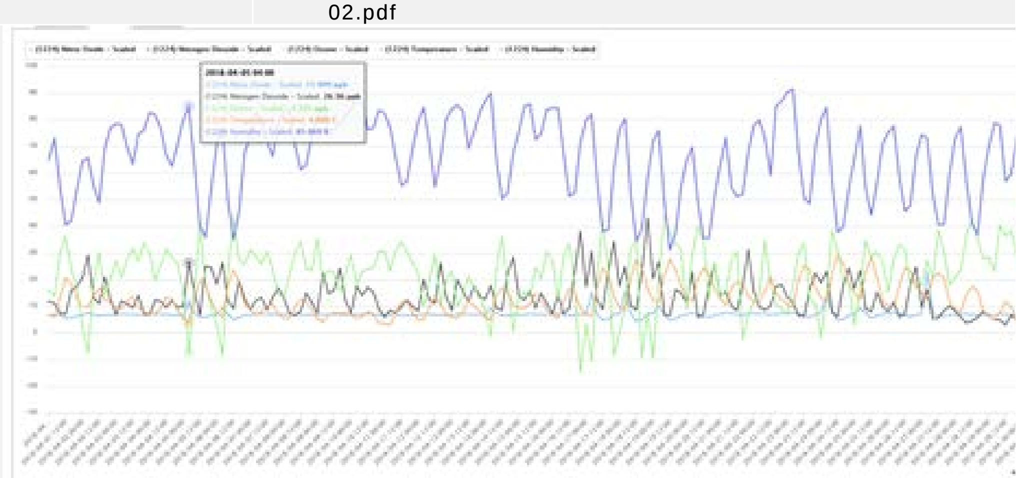
Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099.

Mullaney, J., Lucke, T., Trueman, S.J., 2015. A review of benefits and challenges in growing street trees in paved urban environments. Landscape Urban Plan. 134, 157–166. doi:10.1016/j.landurbplan.2014.10.013.

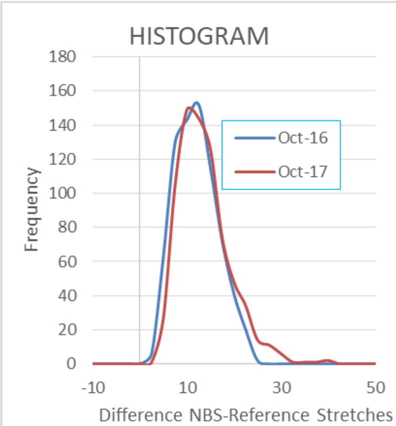
Baró, F., Haase, D., Gómez-Baggethun, E., Frantzeskaki, N., 2015. Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities. Ecol. Indic. 55, 146–158. doi:10.1016/j.ecolind.2015.03.013.

SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf

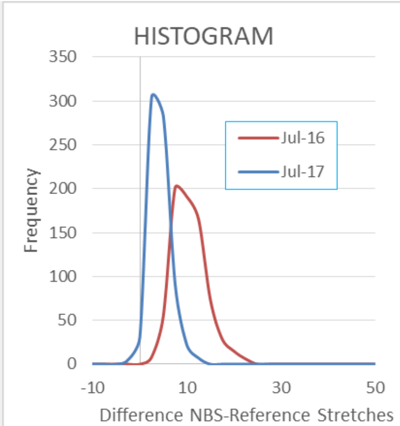
SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf



Data collection example.



No significant differences



Significant differences

	Oct-16	Oct-17		Oct-16	Oct-17
Average	10,8	12,4	**Average**	9,3	3,1
Stand. Desv.	4,5	5,4	**Stand. Desv.**	3,6	2,3

Example of data processing.

12.5 Ambient pollen concentration

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Ambient pollen concentration	**Green Space Management** **Air Quality**
Description and justification	Urban green spaces frequently have a limited number of plant species, including a higher proportion of non-native species in comparison with rural areas (McKinney, 2002). The low species diversity in many urban areas is directly linked to the formation of concentrated pollen emission sources. In particular, large-scale use of a small number of roadside tree species results in production of large quantities of a single species of pollen. Areas of concentrated pollen may not be readily dispersed by air currents. Some studies indicate that urban citizens are 20% more likely to suffer airborne pollen allergies than people living in rural areas, largely due to the uniformity of green spaces, where a small number of species that

	have proved highly suited to urban environmental conditions are overwhelmingly used, and the interaction of pollen with air pollutants (Cariñanos & Casares-Porcel, 2011).
Definition	Number of grains of pollen per cubic metre of air (pollen grains/m^3)
Strengths and weaknesses	+ The results are widely accepted and known to be consistent - The method of identifying and characterising trapped pollen and spores is time-consuming and requires considerable expertise
Measurement procedure and tool	The volumetric Hirst-type pollen and spore trap designed in 1952 remains one of the devices most commonly used for pollen and spore monitoring (Buters et al., 2018). The Hirst-type trap is standard in pollen monitoring networks in Europe. The Hirst-type pollen and spore trap uses a vacuum pump to continuously draw air at a known rate (e.g., 10 L/min). A wind vane attached to the sampler head ensures that the trap inlet is always facing the prevailing wind. Depending on the configuration of the trap, pollen and spores are captured on adhesive coated transparent plastic tape (Melinex) or on a microscope slide coated with an adhesive. Adhesive tapes are attached to a metal drum that rotates with time. Pollen traps can be fitted with a drum specific to a 24-h or a 7-day sampling period. At the conclusion of the sampling period, the tape with adhered pollen and spores is cut into pieces representing 24-h periods of time and mounted on a microscope slide. Where the pollen and spores are captured directly on a microscope slide, the slide must be changed every 24 h. These slides are examined by microscopy for counting and identification of pollen and spores.
Scale of measurement	Plot to neighbourhood scale
Data source	
Required data	Pollen measurement data
Data input type	Quantitative
Data collection frequency	Continuous collection with a 24 h or a 7-day sampling period
Level of expertise required	Moderate
Synergies with other indicators	Synergies with *Distribution of public green space*, *Accessibility of urban green spaces,* and *Proportion of*

	natural area, and *Availability and equitable distribution of blue-green space* indicators
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Buters, J.T.M., Antunes, C., Galveias, A., Bergmann, K.C., Thibaudon, M., Galán, C. … & Oteros, J. (2018). Pollen and spore monitoring in the world. Clinical and Translational Allergy, 8, 9. Cariñanos, P., & Casares-Porcel, M. (2011). Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. Landscape and Urban Planning, 101(3), 205-214. McKinney, M. (2002). Urbanization, Biodiversity, and Conservation: The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. BioScience, 52(10), 883-890.

12.6 Trends in NOx and SOx emissions

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Trends in Emissions of NOx and SOx	**Air Quality**
Description and justification	It is estimated that in the UK air pollution reduces overall life expectancy by seven to eight months, with estimated annual health costs of up to £20 billion. The impacts are higher on the most vulnerable, including lifelong impact on children. The predominant source of NOx in Europe is road transport and it is thought that half of emissions in Europe originate from this source; certainly the highest concentrations of NO_2 are generally found close to busy roads in urban areas In keeping with other local authorities across England and Wales, Liverpool and the wider city region is close to failing to meet the European Union (EU) air quality standard for Nitrogen Dioxide (NO_2) which is measured as an annual

	mean of 40 µg/m³. High levels of NO_2 have a health impact on the local population; in particular those suffering from existing heart related conditions, asthma and chronic obstructive pulmonary disease. Whilst air pollution from NO_2 cannot be said to be the single direct causal effect upon hospital emissions, it does contribute. The main source of SO_2 is fossil fuel combustion. SOx emissions in the UK have decreased substantially since 1992, due to reductions in the use of coal, gas and oil, and also to reductions in the sulphur content of fuel oils and diesel fuel used for road vehicles (DERV). The decrease in emissions over time is the continuation of an on-going trend partly due to the decline of the UK's heavy industry.
Definition	Measure air concentrations of NOx and SOx in µg/m³ at identified sampling points close to planned nature-based interventions and highway improvement schemes both pre- and post-intervention. Compare these data for differences, and also compare these data to historical city wide data to identify trends.
Strengths and weaknesses	It should be noted that diffusion tubes have two limitations. Firstly, they are an indicative monitoring technique. Whilst ideal for screening surveys, or for identifying locations where NO_2 concentrations are highest, they do not provide the same level of accuracy as automatic monitoring techniques. Secondly, as the exposure period is typically several weeks, the results cannot be compared with air quality standards and objectives based on shorter averaging periods such as hourly means. Diffusion tube samplers operate on the principle of molecular diffusion, with molecules of a gas diffusing from a region of high concentration (open end of the sampler) to a region of low concentration (absorbent end of the sampler).
Measurement procedure and tool	Diffusion tubes designed to measure dissolved gaseous emissions of NOx and SOx are a type of passive sampler; that is, they absorb the pollutant to be monitored directly from the surrounding air and need no power supply. Passive samplers are easy to use and relatively inexpensive, so they can be deployed in large numbers over a wide area, giving good spatial coverage. This has made them a popular choice for municipal authorities, who often use diffusive samplers to complement more expensive automatic monitoring techniques, or at locations where it would not be feasible to install an automatic monitor. Cities can compare outdoor air concentrations of NOx and SOx measured by diffusion tube samplers to that

	obtained using established practices to ensure that the data remain comparable to historical citywide baselines. NOx and SOx can be measured by mounting diffusion tubes on street infrastructure owned by the city council, such as lamp posts, a monitoring height of roughly 3 m. The height of the diffusion tube placement is a little higher than adult head height but is necessary in a public place to reduce unauthorised removal of tubes and disruption to monitoring. The diffusion tubes typically remain in situ for a month and are then removed and replaced. Usually two people are required to remove and replace tubes and a litter picker can be used to retrieve and replace tubes. Retrieved diffusion tubes are generally sent to a laboratory for analysis. Concentrations of NOx and SOx (µg/m^3) will be provided following laboratory analysis.
Scale of measurement	Street-neighbourhood
Data source	
Required data	The location and nature of the various NBS interventions will dictate the final positioning and type of diffusion tube and they will not necessarily be spread equally between NBS demonstration areas or other air quality monitoring stations. An option exists to consider some limited replication at key sites and to utilise any current data from existing diffusion tube sampling at appropriate locations.
Data input type	Numerical data associated at different places at different times.
Data collection frequency	Both the NBS intervention site and the control study site should be sampled on the same occasion. Each fixed sampling location at a study site should be sampled every month for one year pre-intervention, and for a period of at least two years following NBS implementation.
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	None identified
Additional information	

References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099. Mullaney, J., Lucke, T., Trueman, S.J., 2015. A review of benefits and challenges in growing street trees in paved urban environments. Landscape Urban Plan. 134, 157–166. doi:10.1016/j.landurbplan.2014.10.013. Baró, F., Haase, D., Gómez-Baggethun, E., Frantzeskaki, N., 2015. Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities. Ecol. Indic. 55, 146–158. doi:10.1016/j.ecolind.2015.03.013. SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf

12.7 Concentration of particulate matter (PM_{10} and $PM_{2.5}$), NO_2, and O_3 in ambient air

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Ana Ascenso[2], Ana Isabel Miranda[2], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Concentration of particulate matter (PM_{10} and $PM_{2.5}$), NO_2, and O_3 in ambient air	Air Quality
Description and justification	Air pollution is considered the single largest environmental health risk in the world, causing an estimated 2-6 million or more yearly deaths globally (Health Effects Institute [HEI], 2018; World Health Organisation [WHO], 2016). An important focus of research has been on the role of urban vegetation in the formation and removal of air pollutants in cities (e.g., Miranda et al., 2017) and the associated impacts of air pollution on morbidity, mortality and life-expectancy (e.g., Costa et al., 2014). The most relevant pollutants in air are particulate matter of different sizes (PM2.5, PM10), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), benzene (C_6H_6) and toxic metals (As, Cd, Ni, Pb and Hg) (EEA, 2018b). Whilst different pollutants can have large local effects, the most prevalent pollutants with most serious health effects are particulate matter, ozone and nitrogen dioxide, which are selected for metrics here.
Definition	Concentration of $PM_{2.5}$, PM_{10}, NO_2 and ground-level O_3 (µg/m^3) in ambient air
Strengths and weaknesses	+ Accurate results with automated measurements - Some of the measurement systems can be expensive and they need constant management and upkeep
Measurement procedure and tool	Air pollution concentrations can be estimated based on measured and/or modelled concentrations in ambient air (O_3, NOx, VOC, PM_{10} and $PM_{2.5}$) near the NBS intervention area. Data can be retrieved from air quality monitoring stations or from measured values during experimental campaigns. Data can also be estimated by applying air quality models, such as the WRF-Chem model (National Oceanic and Atmospheric Administration [NOAA], n.d.), which estimates 3D concentration fields with an hourly resolution at the grid, neighbourhood or city scale.

	Particulate matter (PM_{10} and $PM_{2.5}$) concentration: Particulate matter is measured using an air sampler that draws ambient air at a constant flow rate through a specially shaped inlet onto a filter that is weighed periodically to measure the accumulated particle load. The inlet defines the particle size cut-off (2.5 or 10 µm). A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of particulate matter using standardized air sampler equipment is undertaken. Daily averages are averaged over a year to reach a yearly average, which acts as the indicator (ISO, 2018). *Nitrogen dioxide (NO2) concentration:* To quantify nitrogen dioxide, a stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of nitrogen dioxide using standardized equipment is undertaken. An average of hourly averages is used to calculate a daily average and daily averages to calculate a yearly average, which acts as the indicator (ISO, 2018). *Ground-level ozone (O_3) concentration:* A stationary measuring station is placed in a representative traffic, urban, industrial or rural location and continuous measurement of ozone using standardized equipment is undertaken. The convention for ozone measurement is to calculate a daily maximum 8-hour mean, which acts as the indicator (ISO, 2018).
Scale of measurement	District to region scale
Data source	
Required data	Pollutant measurement data
Data input type	Quantitative
Data collection frequency	Continuous measurements with hourly, daily, monthly, and yearly averages
Level of expertise required	Low – for continuous measurements Moderate – for evaluating data artefacts
Synergies with other indicators	Other indicators in the *Air quality* indicator group
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified

Additional information	
References	Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., … Teixeira, J.P. (2014). Integrating Health on Air Quality Assessment - Review Report on Health Risks of Two Major European Outdoor Air Pollutants: PM and NO2. Journal of Toxicology and Environmental Health - Part B Critical Reviews, 17(6), 307-340. European Environment Agency. (2018b). Air quality in Europe – 2018 report. EEA Report No. 12/2018. Luxembourg: Publications Office of the European Union. Retrieved from https://www.eea.europa.eu/publications/air-quality-in-europe-2018 Health Effects Institute (HEI). (2018). State of Global Air 2018. Special Report. Boston, MA: Health Effects Institute. International Organization for Standardization (ISO). (2018). Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018). Available from https://www.iso.org/standard/68498.html Miranda, A.I., Martins, H., Valente, J., Amorim, J.H., Borrego, C., Tavares, R., … Alonso, R. (2017). Case Studies: modeling the atmospheric benefits of urban greening, In D. Pearlmutter, C. Calfapietra, R. Samson, L. O'Brien,S. Ostoic, G. Sanesi, R. Alonso (Eds.), The Urban Forest. Cultivating Green Infrastructures for People and the Environment (pp. 89-99). New York: Springer International Publishing. National Oceanic and Atmospheric Administration (NOAA). (n.d.). Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). Retrieved from https://ruc.noaa.gov/wrf/wrf-chem/ World Health Organization (WHO). (2016). Ambient air pollution: A global assessment of exposure and burden of disease. Geneva: World Health Organization. Retrieved from https://www.who.int/phe/publications/air-pollution-global-assessment/en/

12.8 Concentration of particulate matter at respiration height along roads

Project Names: URBAN GreenUP (Grant Agreement no. 730426) and UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Raúl Sánchez[1], Jose Fermoso[1], Silvia Gómez, María González[1], Jose María Sanz[1], Esther San José[1], Laura Wendling[2], Ville Rinta-Hiiro[2], Maria Dubovik[2], Arto Laikari[2], Malin zu-Castell Rüdenhausen[2]

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Concentration of particulate matter ($PM_{2.5}$ and PM_{10}) at respiration height along roadways and streets	Air Quality
Description and justification	Road transport and construction operations are identified as major sources of air pollutants in cities. Airborne particulate matter is associated with harmful effects on human cardiovascular and respiratory health. Particles ≤ 10 µm in diameter (PM10), and particularly the finer particles ≤ 2.5 µm in diameter (PM2.5), are associated with road transport vehicles and are of concern due to their small size. One micron (µm) is one-millionth of a meter, or 0.001 millimetres. Green infrastructure along urban streets may act as barriers to direct dispersal of particulate atmospheric pollutants - such as those from vehicles – away from pedestrian areas. Particulates may be deposited on the leaf surface of vegetation or taken up into the leaf surface wax layer, reducing atmospheric particulate concentrations. Monitoring of air quality parameters is complex; involving many potentially interacting variables. Variation in weather conditions; prevailing wind direction and speed; species, size, density, location and structure of vegetation; and the configuration of built urban infrastructure are among that factors that can affect the trajectory and rate of dispersal of particulate pollutants. To assess the impact of NBS on atmospheric concentration of particulate matter, compare outdoor air concentrations of PM10 and PM2.5 at average respiration height (1.5 m above ground level) at locations with and without street-side green interventions to evaluate whether the NBS are associated with reduced local concentrations of airborne PM2.5 and PM10.
Definition	The concentration of PM2.5 and PM10, respectively, per cubic metre of air (units µg m^{-3}) at a measuring height of 1.5 m above the ground surface to represent the air quality experienced by bicyclists and pedestrians.

Strengths and weaknesses	- This method requires the use of specialised equipment (PM monitoring device). - Monitoring campaigns involve manual measurements, requiring personnel.
Measurement procedure and tool	Measure air concentrations of PM2.5 and PM10 at defined sampling points at a height of 1.5 m above ground level and a range of linear distances from NBS street tree/green wall locations, both pre- and post-intervention. Compare these data to measurements taken at analogous locations on equivalent stretches of road without street-side NBS at similar times of day on the same dates. A portable photometric sampler designed to measure ambient PM2.5 and PM10 concentrations can be used to gather data on a non-continuous basis, i.e., during planned field monitoring campaigns. Data can be collected and stored on the device, then can be downloaded later to a PC. Compare the particulate matter (PM2.5 and PM10) values qualitatively and quantitatively for the periods before and after the interventions in the NBS and reference sections. Quantitatively assess using the following expression: $\boldsymbol{PM\ impact} = \left(\frac{NBS\ Measures\ average\ after\ intervent. - NBS\ Expected\ average\ a}{NBS\ Expected\ average\ after\ intervent.}\right. \times 100$ Where *measures average after intervent.* is the average value of measurements after interventions and *Expected value after intervent.* (but supposing that interventions had not been done) is: $\boldsymbol{NBS\ Expected\ average\ after\ intervent.} = \left(\frac{Ref.\ average\ after\ intervent.}{Ref.\ average\ before\ intervent.}\right) \times NBS\ Measures\ before\ intervent.$ PM impact can be calculated both for PM2,5 and PM10. Positive or null PM impact values indicates negative or no impact of the NBS on PM concentration for that implementation. Negative values indicates a positive impact of that NBS on PM concentration.
Scale of measurement	Building - street –neighbourhood scale
Data source	
Required data	Atmospheric PM2.5 and PM10 concentration data (in µg m^{-3}) obtained at a height of 1.5 m above ground level using (a) portable monitoring device(s).

Data input type	
Data collection frequency	Both intervention and analogous control study sites should be sampled on the same occasion during each round of sampling (i.e., an NBS intervention site and matched control should be sampled on the same date and as close to the same time of day as possible). Ideally, each pre-determined sampling location at a study site should be repeat sampled every 4 weeks for one year pre-intervention, and for at least two years following intervention.
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	Potential to collaborate with local universities or secondary schools (e.g., science and/or health classes) to collect data, depending on availability of sampling equipment.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099. Mullaney, J., Lucke, T., Trueman, S.J., 2015. A review of benefits and challenges in growing street trees in paved urban

	environments. Landscape Urban Plan. 134, 157–166. doi:10.1016/j.landurbplan.2014.10.013. Baró, F., Haase, D., Gómez-Baggethun, E., Frantzeskaki, N., 2015. Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities. Ecol. Indic. 55, 146–158. doi:10.1016/j.ecolind.2015.03.013.

12.9 Mean level of exposure to ambient air pollution

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Mean level of exposure to ambient air pollution	Air Quality
Description and justification	Air pollution consists of many pollutants, among other particulate matter. These particles are able to penetrate deeply into the respiratory tract and therefore constitute a risk for health by increasing mortality from respiratory infections and diseases, lung cancer, and selected cardiovascular diseases. The mean annual concentration of fine suspended particles of less than 2.5 microns in diameters ($PM_{2.5}$) is a common measure of air pollution. The mean is a population-weighted average for urban population in a country, and is expressed in micrograms per cubic meter [µg/m3]. Other important pollutants are ozone and NO_X. This indicator can be calculated using the different pollutants depending on the data availability and problems caused by each pollutant (according maximum levels reached in extreme events). This indicator has been defined using the SDG indicators numbers 3.9.1 and 11.6.2 as references but adapting it for use at urban scale.
Definition	This KPI is useful to assess the level of population exposed to low air quality levels in the city and the importance of this challenge for the city. Further analysis could be developed using public health or hospital admission data to correlate the importance or green infrastructure on air quality levels. This KPIs is calculated from ground measurements by the official Air Quality monitoring networks in cities applying a methodology defined by URBAN GreenUP Project adapted from different sources. Additionally, information on the

	type of the zone (road traffic, city background, industrial, etc.) has been assigned to the different areas/streets of the city to weight population.
Strengths and weaknesses	- Specific Method for polluted air solutions. - PM monitoring device required.
Measurement procedure and tool	**Data processing** Calculation of annual and monthly mean levels of NO_2, O_3, PM_{10} and $PM_{2.5}$ at each station location. There are three main types of stations for city domains (excepting industrial sites that are no considered for this KPI). ▪ Road traffic ▪ Urban background ▪ Peri-urban background According to this classification, it can be obtained average values for road traffic areas, urban areas and peri-urban areas. Then, using a GIS software, a model of the city can be built that classifies all locations/streets/areas of the city in those categories. Spatial Analysis software QGIS is the GIS software proposed to be used, due to it is an open source and multiplatform software and it is distributed under Creative Commons Attribution-Share Alike 3.0 licence (CC BY-SA). We recommend to use the last long-term release repository, most stable (QGIS 2.18 is currently the last one). Data processing involved in this KPI can be done with the standard version and the standard toolbox. **Results** The main result of this KPI is a city map where can be shown air quality average levels for the city. This outcome can be used to define population exposition levels and to highlight buildings used by vulnerable groups such as schools or residences for the elderly.
Scale of measurement	Street/Building
Data source	
Required data	Air Quality monitoring stations network in major urban agglomerations. **Measurements** Concentrations of NO_2, O_3 and airborne particulate matter are measured by recording PM mass per cubic meter of air ($PM_{2.5}$ and PM_{10}).

	Unit of measurement PM - Micrograms (mcg) per cubic meter, µg/m^3. (Microgram (µg) One-millionth of a gram; a milligram (mg) = 1000 micrograms). NO_2 – Micrograms (mcg) per cubic meter, µg/m^3. (Microgram (µg) One-millionth of a gram; a milligram (mg) = 1000 micrograms). O_3 - Micrograms (mcg) per cubic meter, µg/m^3. (Microgram (µg) One-millionth of a gram; a milligram (mg) = 1000 micrograms).
Data input type	Continuous monitoring of NO_2, O_3 and particulate matter.
Data collection frequency	Continuous monitoring in the selected points hourly.
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence.

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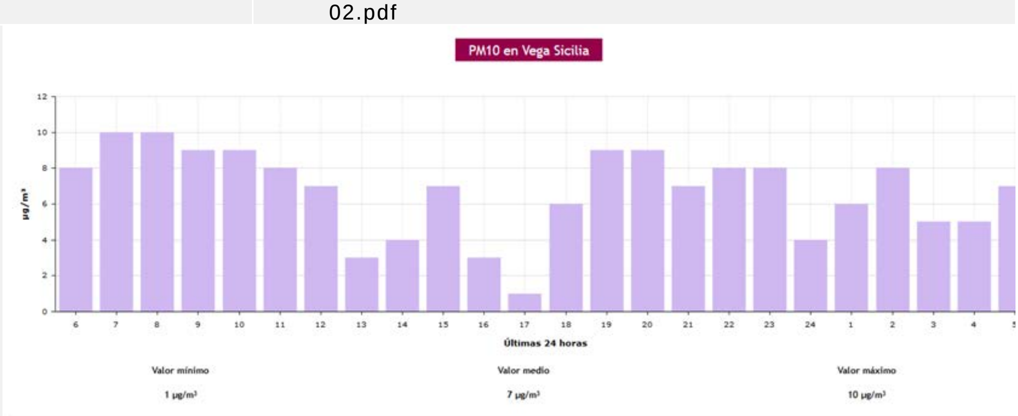
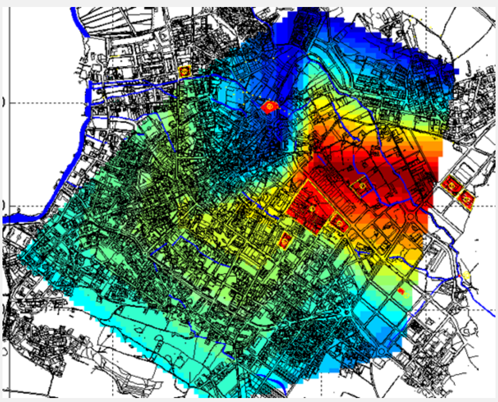
SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf
SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf



Generic PM10 data collection in Valladolid.



GIS analysis of air quality in a model city.

12.10 Morbidity, Mortality and Years of Life Lost due to poor air quality

Project Name: UNaLab (Grant Agreement no. 730052)

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Morbidity, Mortality and Years of Life Lost due to poor air quality	**Air Quality Health and Wellbeing**
Description and justification	Air pollution has been related to numerous adverse health effects, typically expressed in several morbidity and mortality endpoints (see Costa et al., 2014). In particular, an increasing amount of epidemiological and clinical studies observes that exposure to air pollution is associated with increased risk of heart disease, myocardial infarction and stroke as well as lung cancer (e.g., Costa et al., 2014). While the impact of these health effects may appear low at the individual level, the overall public-health burden is sizable as the entire population is exposed (Pascal et al., 2011).
Definition	Reduction in years of life (y) due to premature mortality in comparison with standard life expectancy (Morbidity): Long-term (annual) incidence of chronic bronchitis due to poor air quality calculated using atmospheric NO_2 and PM_{10} data (Mortality): Long-term (annual) incidence of mortality due to poor air quality calculated using atmospheric $PM_{2.5}$, PM_{10}, O_3 and NO_2 data
Strengths and weaknesses	+ The indicator is easy to define - The method needs corresponding air pollutant concentration, demographic and epidemiological input data
Measurement procedure and tool	The general approach in health impact assessment is to use exposure-response functions, linking the concentration of pollutants to which the population is exposed to the number of health events occurring in that population (Costa et al., 2014; Silveira et al., 2016). Therefore, the following aspects are usually considered: i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age

groups, and iv) exposure time. The health response is usually calculated by:

$\Delta R = IR \times CRF \times \Delta C \times Pop$

Where,

- ΔR is the response as a result of the number of the unfavourable implications (cases, days or episodes) over all health indicators;
- IR is the baseline morbidity/mortality annual rate (%); this information is available in the national statistical institute of each country;
- CRF is the correlation coefficient between the pollutant concentration variation and the probability of experiencing a specific health indicator (%; i.e., Relative Risk (RR) associated with a concentration change of 1 $\mu g\ m^{-3}$);
- ΔC indicates the change in the pollutant concentration ($\mu g\ m^{-3}$) after adoption of the adaptation/mitigation measure;
- Pop is the population units per age group exposed to pollution.

Morbidity (chronic bronchitis) due to poor air quality is calculated using NO_2 and PM_{10} to determine CRF and ΔC in the preceding equation.

Mortality, assessed as total mortality, is calculated using PM_{10}, $PM_{2.5}$, O_3 and NO_2 to determine CRF and ΔC in the preceding equation.

Both morbidity and mortality are based on long-term (annual) effects (Table). Where air quality data are derived from WRF-Chem results can be calculated on a daily/weekly/monthly/annual basis at the grid, neighbourhood or city scale.

Table. Air pollutant health indicators (WHO, 2013)

Pollutant	**Health outcome**	**Age group**
PM_{10}	Chronic bronchitis (incidence)	>18 y
	Chronic bronchitis (prevalence)	6-18 y

	Total mortality	<1 y
		>30 y
$PM_{2.5}$	Total mortality	>30 y
NO_2	Total mortality	>30 y
	Prevalence of bronchitic symptoms in asthmatic children	5–14 y
O_3 (April-September)	Total mortality (respiratory diseases)	>30 y

Years of life lost (YoLL) is an often-used health indicator, and refers to the total number of years of reduced life due to premature mortality. Using the mortality indicator, the YoLL can be calculated as the number of deaths multiplied by a standard life expectancy at the age at which death occurs (see Gardner & Sanborn, 1990).

Scale of measurement	Street to metropolitan scale
Data source	
Required data	i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age groups, and iv) exposure time
Data input type	Quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Moderate
Synergies with other indicators	Other indicators in the *Air quality* indicator group
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	

References	Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., … Teixeira, J.P. (2014). Integrating Health on Air Quality Assessment-Review Report on Health Risks of Two Major European Outdoor Air Pollutants: PM and NO2. Journal of Toxicology and Environmental Health - Part B Critical Reviews, 17(6), 307-340. Gardner, J.W., & Sanborn, J.S. (1990). Years of potential life lost (YPLL) – what does it measure? Epidemiology (Cambridge, Mass.), 1(4), 322–329. Pascal, M., Corso, M., Ung, A., Declercq, C., Medina, S. & Aphekom. (2011). APHEKON-Improving knowledge and communication for decision making on air pollution and health in Europe, Guidelines for assessing the health impacts of air pollution in European cities, Work Package 5, Deliverable D5. Saint-Maurice, France: French Institute for Public Health Surveillance. Silveira C., Roebeling P., Lopes M., Ferreira J., Costa S., Teixeira J.P., ... Miranda A.I. (2016). Assessment of health benefits related to air quality improvement strategies in urban areas: An Impact Pathway Approach. Journal of Environmental Management, 183, 694-702.

12.11 Avoided costs for air pollution control measures

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Recommended citation: The Mersey Forest, Natural Economy Northwest, CABE, Natural England, Yorkshire Forward, The Northern Way, Design for London, Defra, Tees Valley Unlimited, Pleasington Consulting Ltd, and Genecon LLP (2010). GI-Val: the green infrastructure valuation toolkit. Version 1.6 (updated in 2018). https://bit.ly/givaluationtoolkit

Avoided costs for air pollution control measures	**Air Quality** **New Economic Opportunities and Green Jobs**
Description and justification	GI-Val is The Mersey Forest's green infrastructure valuation toolkit. The current prototype is free and open source, and can be downloaded under a Creative Commons License from: https://www.merseyforest.org.uk/services/gi-val/. It

	takes the form of a spreadsheet calculator and a user manual. GI-Val Tool 4.6, can estimate the impact of nature-based solutions on various air pollutants, in tonnes per year, and from those quantities it can estimate the avoided costs of other measures to remove from the air sulphur dioxide (SO_2), carbon monoxide (CO) and PM_{10}. The tool uses a benefit transfer method based upon the Chicago Urban Forest Climate Study by the USDA Forest Service (Nowak et al, 1994). It is possible that monitoring in some cities will provide more accurate figures for the removal of air pollutants – if so, the tool can simply be used to assign a monetary value to air pollution attenuation. An independent assessment of GI Val by the Ecosystems Knowledge Network is available from this link, along with links to other tools: https://ecosystemsknowledge.net/green-infrastructure-valuation-toolkit-gi-val
Definition	This KPI values green infrastructure in economic units taking into account other than conventional functionalities.
Strengths and weaknesses	- Tool developed using English data. - The toolkit remains a prototype and this means there are some green infrastructure benefits for which it cannot calculate a direct financial value. While there is a rich body of evidence that illustrates and demonstrates the different types of benefits deriving from quality green infrastructure, robust valuation techniques do not yet exist for all benefits. Therefore some valuations come with detailed caveats as they are based on limited evidence at this stage. - The toolkit's calculation is designed to be useful for initial, indicative project appraisal, providing a range of figures indicating the potential impact of a green infrastructure intervention or the value of an existing green infrastructure asset. The toolkit does not assess the quality of the design or detailed management requirements of green infrastructure. It does not replace a full cost benefit analysis, but it provides a basic valuation at a much lower cost. - Valuations such those made with a toolkit or cost benefit analysis also need to be seen as part of a much bigger picture. The valuation should not replace community engagement and local dialogue about what is valued about a place. Calculating economic value of green assets will always be a controversial technique and financial

	value should only be seen as one factor in decision-making. - The reported GVA values include transfers from one organisation to another, which means that although GVA increases for the beneficiaries, it may not increase for the study area as a whole.
Measurement procedure and tool	The toolkit provides a set of calculator tools, to help assess an existing green asset or proposed green investment. They are organised under eleven key benefits of green infrastructure: The toolkit looks at how the range of green infrastructure benefits derived from an asset or investment can be shown: • in monetary terms – applying economic valuation techniques where possible • quantitatively – for example with reference to jobs, hectares of land, visitors • qualitatively – referencing case studies or important research where there appears to be a link between green infrastructure and economic, social or environmental benefit but where the scientific basis for quantification and/or monetisation is not yet sufficiently robust. The toolkit uses standard valuation techniques to assess the potential benefits provided by green infrastructure within a defined project area. These benefits are assessed in terms of the functions that the green infrastructure may perform, support or encourage, depending upon the type of project. The USDA Forest Service's Chicago Urban Forest Climate Study provided monetary values per metric tonne for pollution emission prevention, based upon control strategies available at the time of study publication. The Chicago Urban Forest Climate Study calculated pollution absorption capacity and typical monetary values at individual tree level. The values determined in 1994 ranged from US$0.04 per year for small trees to more than US$2 per year for large trees. Accounting for 76.3% inflation 1994-2020 and currency conversion from USD to EUR (1 USD ≈ 0.9 EUR), the values determined in the Chicago Urban Forest Climate Study range from the 2020 equivalent of US$0.07 (0.08 €) per year for small trees to more than US$3.53 (4.26 €) per year for large trees in 2020. Tool 4.6 is based on these data.
Scale of measurement	Street to city
Data source	

Required data	General information about green infrastructure
Data input type	Numeric data
Data collection frequency	Individual assessments
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	Developing the toolkit's next iteration will require wide and sustained collaboration. To facilitate this process, interested parties are invited to pass the toolkit to others who might be able to incorporate it into their work and to provide feedback on their experience in using the toolkit, good and bad! Sources of improved evidence Suggestions for improving the tools Ideas for new tools The consortium who led the development of this toolkit has handed over the responsibilities for co-ordinating future work to the Green Infrastructure Value Network (GIVaN). Further information on the network can be found at: www.bit.ly/givaluationtoolkit
Additional information	
References	http://www.merseyforest.org.uk/services/gi-val/ Nowak, McPherson and Rowntree, 1994. Chicago's urban forest ecosystem: results of the Chicago urban forest climate project. United States Department of Agriculture US Forest Service. Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index Bottalico, F., Chirici, G., Giannetti, F., De Marco, A., Nocentini, S., Paoletti, E., Salbitano, F., Sanesi, G., Serenelli, C., Travaglini, D., 2016. Air pollution removal by green infrastructures and urban forests in the city of Florence. Agric. Agric. Sci. Procedia 8, 243–251. doi:10.1016/j.aaspro.2016.02.099. SDG indicator 3.9.1 https://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf

PLACE REGENERATION

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13 RECOMMENDED INDICATORS OF PLACE REGENERATION

13.1 Derelict land reclaimed for NBS

Project Name: UNaLab (Grant Agreement no. 730052)

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Reclamation of derelict land	**Place Regeneration**
Description and justification	Brownfield land refers to urban developed areas that are currently idle. Typically, they are sites of previous commercial or industrial activities, which might have detected or suspected pollution and soil contamination problems, hindering their future development. Redeveloping brownfields can save pristine green spaces from development as well as reclaim unused spaces into meaningful application (University of the West of England [UWE] Science Communication Unit, 2013).
Definition	Reclamation of idle/ derelict and/or contaminated land (brownfields), expressed as total area (ha), area per capita or % of contaminated area reclaimed

Strengths and weaknesses	+ Simple and easy to calculate + Provides a measure that can be easily followed - Definition and classification of areas as brownfield is not rigorously defined, and thus comparison between areas and countries can be misleading without closer case studies
Measurement procedure and tool	Idle, developed areas within the community are identified and their combined surface area is calculated using maps. This is done yearly and the percentage change in the area is reported, as well as the actual area remaining.
Scale of measurement	Street to metropolitan scale
Data source	
Required data	Proportion of idle/ derelict and/or contaminated land (brownfields) redeveloped each year for productive use via implementation of NBS, and the absolute area of identified brownfield remaining
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Not identified
Connection with SDGs	SDG 9 Industry, infrastructure and innovation, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through citizens' reports on brownfield areas in their communities
Additional information	
References	University of the West of England (UWE) Science Communication Unit. (2013). Science for Environment Policy (issue 39): Brownfield Regeneration. Bristol, United Kingdom: University of the West of England Science Communication Unit.

13.2 Quantity of blue-green space as ratio to built form

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Ratio of open spaces to built form	**Place Regeneration**
Description and justification	Urban space and environment can have an effect in resident health, resilience to weather events and even crime rate, and access to green urban space is seen as positive. Several terms and definitions have been used including green space, open space, public space, urban greenery and public park. Benefits of open spaces relate to both their materials and functions: the increased biodiversity and ecosystem services that increased vegetation and soil permeability and water retention can offer, as well as the potential increased social benefits of open meeting spaces, areas for recreation, sports and relaxation (WHO, 2016).
Definition	Ratio of open spaces to built form within a defined urban area (ratio)
Strengths and weaknesses	+ Simple and easy to use - Large uncertainties of inclusion of all relevant urban features
Measurement procedure and tool	The simplest method is to measure the proportional area physically occupied by buildings. This method however does not take into account any other form of non-building space that not considered beneficial open space, such as roads and parking lots. Another simple method would be to calculate the green space of urban area, based on surface type counting hard impermeable surfaces as grey areas and soft permeable surfaces as green areas. This method misses all covered parks and terraces, which can form a large portion of open areas in urban environments, even if they are not green areas (Jim, 2004). For the purpose of this indicator, a suitable parameter is the selection of all urban green areas, added with selected open 'grey' open areas, such as public squares or pedestrian precincts. The total area covered by buildings is calculated from maps or appropriate sources. The green area is calculated and selected grey open areas are added. The ratio of the open area to the building area is calculated.

Scale of measurement	Street to metropolitan scale
Data source	
Required data	Amount of green spaces, buildings and other infrastructure assets in the urban area
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Relation to *Reclamation of contaminated land (brownfields)* indicator and to the whole *Green Space Management* indicator group
Connection with SDGs	SDG 9 Industry, infrastructure and innovation, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Jim, C. (2004). Green-space preservation and allocation for sustainable greening of compact cities. Cities, 21(4), 311-320. University of the West of England (UWE) Science Communication Unit. (2013). Science for Environment Policy (issue 39): Brownfield Regeneration. Bristol, United Kingdom: University of the West of England Science Communication Unit. World Health Organization. (2016). Urban green spaces and health: A review of evidence. Copenhagen: WHO Regional Office for Europe. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0005/321971/Urban-green-spaces-and-health-review-evidence.pdf?ua=1

13.3 Perceived quality of urban green, blue and blue-green spaces

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Perceived quality of urban green, blue and blue-green spaces	**Place Regeneration**
Description and justification	Perceived quality of space is one of the factors to influence the successfulness of public space, especially in terms of engaging users in activities (Fongar et al., 2019). The value of this indicator is seen in the assessment and promotion of social benefits of NBS in general, and as a monitoring tool for specific aspects of individual NBS (e.g., maintenance of the place, attractiveness of place in terms of various senses such as smell, sound, easiness of finding a place, etc.). Attractiveness of the area for a specific use is a discrete indicator of NBS attractiveness/perceived quality of space understood in terms of stimulation for users to get involved with a particular activity in the space. For example, natural elements and their arrangement in (green) spaces can facilitate calmness and serenity, recovery from stress, and improve mental fatigue. Also, certain arrangement of elements can stimulate the user to actively use the space. Maintenance of place is understood as appropriate handling of vegetation (pruning, cutting branches, mowing grass, vegetation conditions) as well as urban equipment and cleanliness (waste management). Such indicator addresses the pleasantness of place use. A sense of place security is an important aspect of perceived quality of space, considered one of the most important parameters in decision making for visiting and spending leisure time in a location (Rezaie at al.,2019). Additionally, the indicator focuses on spatial parameters addressing safety, such as good orientation in the place, the appropriate lightness of the place and settings of spatial components, which can motivate people to explore. Thus, this indicator addresses sense of security via spatial characteristics and reflects on coherence and legibility as well as complexity and mystery as defined by Kaplan and Kaplan (1989). Access to green space (i.e., structural accessibility) is associated with better health outcomes, such as lower body

	mass index scores, overweight and obesity levels; improved mental health and wellbeing and increased longevity in older people (Institute of..., 2014). Accessibility is often considered in terms of proximity from green space to user's home, however, the perceived accessibility is also very important and is influenced by safety, easy access (no physical barriers), connectivity, continuity of paths, etc. (Žlender, 2017). The pleasantness of place in terms of sound, smell and microclimatic conditions: Although the vision is the most reliable sense, the perception of the environment is multi-sensory (Shahhosseini et al., 2014). Sensory stimulation is particularly important for elderly suffering from dementia since it can improve orientation and trigger memory (Haas et al. 1998). Also, pleasant microclimatic conditions, such as air temperature, humidity etc. affect human comfort, experiencing the space, and behavior patterns. Place attachment and identity refers to a positive emotional bond between user and place. Giving character and identity to a place is essential to creating a meaningful place for people (Lyinch, 1960; Memluk, 2012). In order to promote NBS, it is especially important to consider this indicator since stronger place identity is significantly associated with greater agreement regarding the balance between humans and nature (Budruk at al., 2009).
Definition	Self-reported perceptions of space quality of NBS.
Strengths and weaknesses	+ General promotion of social benefits of the NBS, which can contribute to the implementation of NBS in spatial planning practice + Gathering information about compatibility of different types of NBS regarding their ability to enable certain aspects of quality of space. +Monitoring tool for NBS (e.g., maintenance of the place, easiness of finding a place) that can help to maintain, improve specific aspects of space design +Gathering information about shared notions of perceived quality of space and needs at community level -NBS can address various city challenges and because of NBS process characteristics the assessment of the perceived quality must therefore be understood in relation to specific context, solution, and purpose of the evaluation. The questionnaire needs to be adjusted to NBS specifics.
Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) Maintenance of the place:

	o T: *Parks and Recreation Questionnaire Results Summary* (The City of Ellensburg, 2015). Adapted to purposed of NBS research A sense of security in a place: o T: *Safety concerns issues for park users* (Gökçen Firdevs, Y. 2006). Adapted to purposed of NBS research Coherence and legibility: o T: *The experience of nature: A psychological perspective* (Kaplan, R., Kaplan, S. 1989) Adapted to purposed of NBS research Place attachment & identity o T: *The measurement of place attachment: Personal, community, and environmental connections* (Christopher M. Raymonda, C. M., Brownb,G., Weber, D. 2010) Complexity and mystery o T: *The experience of nature: A psychological perspective* (Kaplan, R., Kaplan, S. 1989) Adapted to purposed of NBS research
Scale of measurement	• Attractiveness of the area for a specific use. The questionnaire must be adjusted according to the individual NBS and intended use (e.g., gardening, social interaction, relaxation…) 1. Do you find the place attractive in terms of stimulation for gardening / social interaction / relaxation / physical activity 1 Yes, it's attractive 2 No, it's unattractive • Maintenance Adapted from Parks and Recreation Questionnaire Results Summary (The City of Ellensburg, 2015) 1. How would you rate the general upkeep and maintenance of the space? (Cleanliness, maintenance of urban equipment and vegetation)? 1 good 2 ok 3 excellent 4 poor • A sense of security in a place Adapted from Safety concerns issues for park users (Gökçen Firdevs, Y. 2006) 1. How do you feel in the (green) space in relation to its physical appearance and scenery? 1 Unsafe (can you determine why?) 2 Neither unsafe nor safe 3 Safe Easiness of finding a place (structural accessibility)

	1. Is this place easy to find? (Considering the journey, connectivity, continuity of paths, safety, physical accessibility (barriers), level of orientation) 1 The space is easy to find 2 The space is difficult to find • The pleasantness of place in terms of sound, smell and microclimatic conditions 1. Do you find this space attractive in terms of smell, sound and microclimatic conditions (e.g., temperature regarding the shading)? 1 Yes, it's attractive 2 No, it's unattractive (please specify why) • Place attachment & identity Adapted from The measurement of place attachment: Personal, community, and environmental connections (Christopher M. Raymonda, C., M., Brownb,G., Weber, D. 2010) 1. Are you very attached to the place? 1 Yes 2 No 2. Do you identify strongly with this place? 1 Yes 2 No 3. Would you feel less attached to the place if the native plants and animals that live here disappeared? 1 Yes 2 No 4. Doing my activities in this place is more important to me than doing them in any other place. 1 Yes 2 No Please specify your age:
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives and challenges
Data input type	Quantitative (quantitative and qualitative, if case study methodology and/or participatory data collection are opted for)
Data collection frequency	- Data collection frequency for general promotion of social benefits of the NBS: Before NBS implementation and aligned with timing of targeted (especially long- term) objectives - Data collection frequency as a monitoring tool: assessment of the specific aspects of individual NBS that can help maintain, improve NBS (e.g., maintenance of the place, A sense of security in a place, The attractiveness of place in terms of smell, sound and other senses)
Level of expertise required	☒ Quantitative data collection requires no expertise. ☒ Methodology and data analysis require high expertise in psycho-social research
Connection with SDGs	Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all Goal 6. Ensure availability and sustainable management of water and sanitation for all Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts* Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection, GIS with top-down goals of understanding neighborhood dynamics, location-based GIS) may be applied to collect community-relevant information about factors that play a role in members' perception of quality; data can further inform NBS implementation and expansion.
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13.4 Place attachment (Sense of Place): Place identity

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Place attachment (Sense of Place): Place Identity		Place Regeneration
Description and justification	Environmental psychology's place theory is still challenged by a lot of criticism aimed at confusion related to terminologies and concepts used in describing place attachment, and at its lack of developmental theory	

	(Counted, 2016). Place attachment is sometimes used interchangeably with "sense of place" - a personal identification with a location or landscape on an emotional level as an individual or as a member of a community (Wolf, Krueger, & Flora, 2014). A number of studies have confirmed the expectation grounded in social identity and self-categorization theories that the greater the identification with the place, the greater the desire to express positive attitudes in relation to environmental transformations that could, in turn, give a more positive character to that place (Bernardo & Palma-Oliveira, 2012, 2016). Psychometric measures for assessing place attachment behaviors have been developed on the foundation conferred by a general agreement among theorists on the definition of place attachment as an "affective bond or link between people and specific places" (Hidalgo & Hernandez, 2001, as quoted in Counted, 2016). Measurements of emotional/symbolic attachments to places provide a means for people to articulate natural resource values (Williams & Vaske, 2003) that contribute to NBS initiatives, actual implementation, and expected success. Jorgensen and Stedman (2001) advanced *an attitude-based conception of sense of place* (SOP) conceived as a complex psychosocial structure that organizes self-referent cognitions (*place identity*), emotions (*place attachment*) and behavioral commitments (*place dependence*). This multidimensional construct makes for theoretical support in instances where self-evaluations contrast significantly for certain attitude objects. For example, a person may feel favorable toward their lakeshore property, but consider it peripheral to their identity and a poor place to perform certain behaviors (Jorgensen & Stedman, 2001). Research aimed at exploring the relationship between green space (density, maintenance, proximity) and place attachment has yielded mixed results. On one hand, there are studies (e.g., Kim & Kaplan, 2004, Mohapatra & Mohamed, 2013, Xu, Matarrita-Cascante, Lee, & Luloff, 2019) which contend that natural features of the physical environment and open spaces (e.g., neighborhood parks) play a particularly important role in place attachment and the sense of community. Conversely, there is research data (Kimpton, Wickes, & Corcoran, 2014) that does not support the suggestion that physical features like green space (e.g., living next to green spaces, living in a green community) influence how attached residents feel towards their community. Instead, Kimpton et al. (2014) report that community socio-structural characteristics such as social ties, ethno-racial diversity, affluence or economic disadvantage are strong predictors of place attachment.

	Brown, Raymond and Corcoran (2015) advance data and suggestions for future research founded on public participation GIS (PPGIS) and related crowd-sourcing mapping methods. The authors also highlight the need for an operationalization, measurement and calibration of the concept of place attachment that would render it suited to predict certain events or outcomes like place-protective or place-enhancement behaviors if the concept is to have any utility for land usage or decision support in the future.
Definition	Jorgensen and Stedman (2001): o SOP is an individual's favorable or unfavorable attitude toward spatially demarcated object. SOP can be inferred from responses of a cognitive, affective or conative nature. o *Place identity* can be regarded as an individual's cognitions, beliefs, perceptions or thoughts that the self is invested in a particular spatial setting. o *Place attachment* can be defined in terms of an individual's affective or emotional connection to a spatial setting. o *Place dependence* can be considered as the perceived behavioral advantage of a spatial setting relative to other settings.
Strengths and weaknesses	+ reliable indicator of psychosocial resources that boost individual self-esteem, a sense of belonging to one's community, and communication about environmental values and policies (Williams & Vaske, 2003) + can inspire and encourage individuals to actively protect green places/NBS, and engage in pro-environmental behavior (Wolf et al., 2014) + oriented towards inclusiveness, high potential to further trust within community, and to inculcate a community sense of pride -abuse of terminologies, and confusion related to concepts related to people-place relations, which leads to methodological gaps and challenges (Counted, 2016)

Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: *Place Identity Scale* (Williams & Vaske, 2003) comprising 6 items that measure place dependence and place identity as dimensions of place attachment o T: *Sense of Place (SOP) inventory* (Jorgensen & Stedman, 2001) - 12 items developed to measure the three dimensions of an attitude-based place attachment experience, namely: place identity, place attachment, and place dependence ☒ *Qualitative P*: o T: case study methodology – structured interviews, case study analysis o T: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation
Scale of measurement	▪ Place Identity Scale (Williams & Vaske, 2003) *Items are presented in a 5-point "strongly disagree" (1) to "strongly agree" (5) format with a neutral point of 3.* 1. I feel "X" is a part of me. 2. "X" is very special to me. 3. I identify strongly with "X". 4. I am very attached to "X". 5. Visiting "X" says a lot about who I am. 6. "X" means a lot to me. ▪ Sense of Place (SOP) inventory (Jorgensen & Stedman, 2001) *Place Identity Items:* 1. Everything about my [...] is a reflection of me. 2. My [...] says very little about who I am. 3 I feel that I can really be myself at my [...] 4 My [...] reflects the type of person I am. *Place Attachment Items:* 1 I feel relaxed when I'm at my [...] 2 I feel happiest when I'm at my [...] 3 My [...] is my favorite place to be. 4 I really miss my [...] when I'm away from it for too long. *Place Dependence Items:* 1. My [...] is the best place for doing the things that I enjoy most. 2. For doing the things that I enjoy most, no other place can compare to my [...]

	3. My [...] is not a good place to do the things I most like to do. 4. As far as I am concerned, there are better places to be than at my [...]
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (long-term) and challenges ✓ Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods)
Data input type	Quantitative (quantitative and qualitative, if case study methodology and/or participatory data collection are opted for)
Data collection frequency	After NBS implementation or aligned with timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis require high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection through case study methodology requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for

Synergies with other indicators	SC1 Bonding social capital SC4.1 Trust in community SC4.2 Solidarity between neighbors SC4.3 Tolerance and respect SC5.1 Perceived safety SC5.2 Actual/real safety SC11.1 Positive environmental attitudes motivated by contact with NBS SC11.2 Environmental Identity SC12 Social desirability HW3 General Wellbeing and Happiness HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community-relevant information on symbolic and emotional bonds with NBS/green spaces.
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13.5 Recreational value of public green space

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Recreational value of blue-green spaces (Applied and EO/RS combined)	**Place Regeneration**
Description and justification	The most basic measure for this indicator is increase/decrease in the number of visitors to a blue-green space before and after a change in how it is designed or managed. This data can be captured through a variety of methods including interviewing locals on likelihood of visiting the space (Coldwell and Evans 2018) and monitoring visitor numbers through physical counts or visitor profiling in relation to specific pursuits (Cope et al. 2000; Cessford and Muhar 2003). The most typical practice for assessing the causal link for recreational value of blue-green spaces is through generating direct feedback from users and/or local communities in the form of questionnaires. A combination of the number of visitor metrics and attractiveness of 'offer' metrics (functional, physical characteristics considered to be associated with the attractiveness of a space) can generate the most useful data in relation to value of NBS interventions and promotion of learning for NBS delivery in other blue-green spaces. The contribution of earth observation/remote sensing tools for the assessment of the cultural value of blue and green spaces are restricted to supporting measures mapping Land Use/Land Cover (LULC), for instance a basic modelling approach currently emerging uses aerial photography to quantify NBS quality. Evaluation of recreational value of blue-green space can be used to: • Ensure that changes related to NBS implementation has a positive impact on visitors; • Ensure that green-blue spaces are providing a broad offer in terms of attractiveness for communities; • Support the design of green-blue spaces to ensure they are providing a NBS offer in terms of social, economic and environmental benefits.
Definition	This indicator represents a quantification of the number of visitors/recreational activities within a greenspace or blue-green space in order to evaluate, or measure an increase in, recreational benefits as a result of NBS. Examples of

	features and activities that can attract visitors to NBS include features such as large trees, benches, education days, and communication zones for picnicking.
Strengths and weaknesses	**Applied methods:** Robustness of evidence is very much based on the design of the questionnaire and the sample size of respondents. Visitor number count robustness can be a challenge due to the difficulty in capturing visitor numbers at some sites. **EO/RS methods:** The finescale resolution of some greenspace features of cultural value makes identification from anything less than high resolution images unreliable. Combining participatory assessment of cultural value and mapping of greenspace features can increase the reliability of evidence generated.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects, refer to Connecting Nature Indicator Metrics Reviews Env24_Applied and Env24_RS.
Scale of measurement	**Applied methods:** Analysis is performed on a single site scale and can comprise sites ranging from very large parks and open spaces to micro-scale pocket parks. Typically, replication across sites is used for comparative purposes as city-wide assessment is possible, although generally spatial modelling methods would be applied for this to minimise effort required. **EO/RS methods:** Remotely sensed land use/land cover data is available for use at various geographical scales
Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env24_Applied and Env24_RS.
Data input type	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env24_Applied and Env24_RS.
Data collection frequency	Data collection frequency will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env24_Applied and Env24_RS.

Level of expertise required	**Applied methods:** Some expertise is needed for the design of the evaluation (e.g., survey method, question selection). Once decided though, a low level of expertise is required for carrying out the survey or carrying out counts. Similarly, data analysis can require low expertise if basic inventories or correlations are required. **EO/RS methods:** The Sentinel Application Platform for Earth Observation processing and analysis requires advanced expert sensing data, including derived knowledge.
Synergies with other indicators	**Applied methods:** Strong synergies with health and wellbeing indicators and social cohesion indicators in relation to public use of the sites for physical activity and social events. Also, synergies with environmental indicators (e.g., biodiversity measures, water regulation and air temperature) in relation to synergies and trade-offs in benefits driven by changes in use of blue-green spaces. **EO/RS methods:** Demographic, structural and remotely-sensed data can be combined to develop a set of indicators to assess green space, with consideration to three main dimensions: quantity (indicators include green space per inhabitant, green space per bare soils), quality (e.g., mean size of green space, shape index of green space) and spatial distribution (e.g., share of population served by green space, aggregation index of green space).
Connection with SDGs	SDG3, SDG4, SDG5, SDG9, SDG10, SDG11, SDG13-SDG17: Links to quality of greenspace; Links to environmental education; Gender neutral recreation activities; Improved green infrastructure; Social equality in relation to recreation opportunities; Sustainable urban development; Thermal comfort zones for recreation; Potential for the creation of more water bodies; Potential habitat creation; Environmental Justice in relation to greenspace recreation; Opportunities for collaborative working.
Opportunities for participatory data collection	Good opportunities for participation through which communication of the benefits of an NbS approach can be delivered. This can be achieved both through the questionnaire process and involving citizen science in data collection. Methods of amenity characterisation can also encourage stakeholders to consider what they would like in their local blue-green space and give a broader view of what is possible. Combining participatory assessment of cultural value and mapping of greenspace features can increase the reliability of evidence generated.
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13.6 Incorporation of environmental design in buildings

Project Name: UNaLab (Grant Agreement no. 730052)

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Incorporation of environmental design in buildings	Place Regeneration
Description and justification	Environmental design is a broad concept concerning the structural, design and systemic features of buildings defining their impact on their environment. It is related to the concept of green buildings, which refers to environmentally sustainable design, construction, operation, maintenance and end of life of buildings.
Definition	Degree to which buildings are designed to be environmentally friendly with respect to energy efficiency, water consumption, waste production, indoor environmental quality, and implementation of NBS (unitless value)
Strengths and weaknesses	+ Rapid and simple method - Crude assessment of environmental design of buildings
Measurement procedure and tool	The area is divided into buildings, groups of buildings or blocks that represent similar building stock, as seen suitable. Each component is assessed on its environmental design considering incorporated environmental design considering parameters listed in Table 1. The building(s) being assessed are scored from 0 to 1 with respect to each parameter. The average point score (0 to 5) of a building provides the indicator value, i.e., the degree to which buildings are designed to be environmentally friendly with respect to these parameters. Table 1: Parameters for environmental design in buildings (or groups of buildings). **Parameter** | **Methods to consider (examples)** | **Scoring**

1	Energy efficiency	Improved insulation Reflecting windows Improved ventilation Heat exchangers in ventilation Smart lighting, smart electronics Renewable electricity (solar/wind) Heat pumps	0 points: No design incorporated 0.5 points: Some measures taken 1 point: Good measures taken
2	Water consumption	Low water toilets Separate greywater collection Rainwater collection and use	As no. 1
3	Waste production	Waste separation On-site composting Building material demolition design	As no. 1
4	Environmental quality	Indoor air quality measure/control Indoor/outdoor noise level control Indoor/outdoor lighting level control	As no. 1
5	Nature-based solutions	Incorporation of NBS A green roof Rain garden	As no. 1
Environmental design			**Sum of points**

Scale of measurement	District to metropolitan scale
Data source	
Required data	Energy efficiency, water consumption, waste production, indoor environmental quality, and implementation of NBS of buildings
Data input type	Semi-quantitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Some relation to *Rainwater or greywater use for irrigation purposes* indicator; relation to *CO_2 emissions related to building energy consumption* and *Mean or peak daytime temperature – Predicted Mean Vote-Predicted Percentage Dissatisfied* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 7 Clean and affordable energy, SDG 9 Industry, infrastructure and

	innovation, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., & Tookey, J. (2017). A critical comparison of green building rating systems. Building and Environment, 123, 243–260. Sharifi, A., & Murayama, A. (2013). A critical review of seven selected neighborhood sustainability assessment tools. Environmental Impact Assessment Review, 38, 73–87. Sharifi, A., & Murayama, A. (2014). Neighborhood sustainability assessment in action: Cross-evaluation of three assessment systems and their cases from the US, the UK, and Japan. Building and Environment, 72, 243–258.

13.7 Preservation of cultural heritage

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Preservation of cultural heritage	Place Regeneration
Description and justification	Unlike ecological, economic and social sustainability, culture is not institutionalised as an aspect of sustainable development at present. Hawkes (2001) introduced cultural sustainability as a “fourth pillar” of sustainable development and emphasised the role of cultural heritage in urban planning. Extensive discourse (e.g., UNESCO, 2001; UNESCO, 2005) on the relationship between culture and sustainable development together with numerous scientific studies exploring social and cultural dimensions of sustainability indicate that cultural sustainability is linked to issues such as social equity and social justice, participation and engaged governance, social cohesion, and social capital (Soini & Birkeland, 2014).

Definition	The extent to which preservation of local cultural heritage is considered during urban planning (unitless value)
Strengths and weaknesses	+ Simple and straightforward assessment - Subjective evaluation of heritage preservation
Measurement procedure and tool	The extent to which urban design and heritage conservation are integrated within urban development so that it enhances or connects to the existing character of the place, e.g., preservation, restoration and/or adaptive re-use of historic buildings and cultural landscapes, can be assessed using a five-point Likert scale: **Not at all — 1 — 2 — 3 — 4 — 5 — Very much** 1. Not at all: no attention has been paid to existing cultural heritage in urban planning. 2. Fair: heritage places have received some attention in urban planning, but not as an important element. 3. Moderate: some attention has been given to the conservation of heritage places. 4. Much: heritage places are reflected in urban planning 5. Very much: preservation of cultural heritage and connections to existing heritage places are a key element of urban planning.
Scale of measurement	District to regional scale
Data source	
Required data	Information on preservation of cultural heritage, including built heritage as well as the cultural landscapes within an urban area
Data input type	Qualitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Not identified
Connection with SDGs	SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city

projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Hawkes, J. (2001). The Fourth Pillar of Sustainability: Culture's essential role in public planning. Melbourne, VIC: Common Ground Publishing Pty Ltd in association with the Cultural Development Network (Vic.).

Soini, K., & Birkeland, I. (2014). Exploring the scientific discourse on cultural sustainability. Geoforum, 51, 213-223.

Tweed, C., & Sutherland, M. (2007). Built cultural heritage and sustainable urban development. Landscape and Urban Planning, 83(1), 62-69.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2001). UNESCO Universal Declaration on Cultural Diversity. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000124687.page=67

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2005). Convention on the Protection and Promotion of the Diversity of Cultural Expressions. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000142919

14 Additional Indicators of Place Regeneration

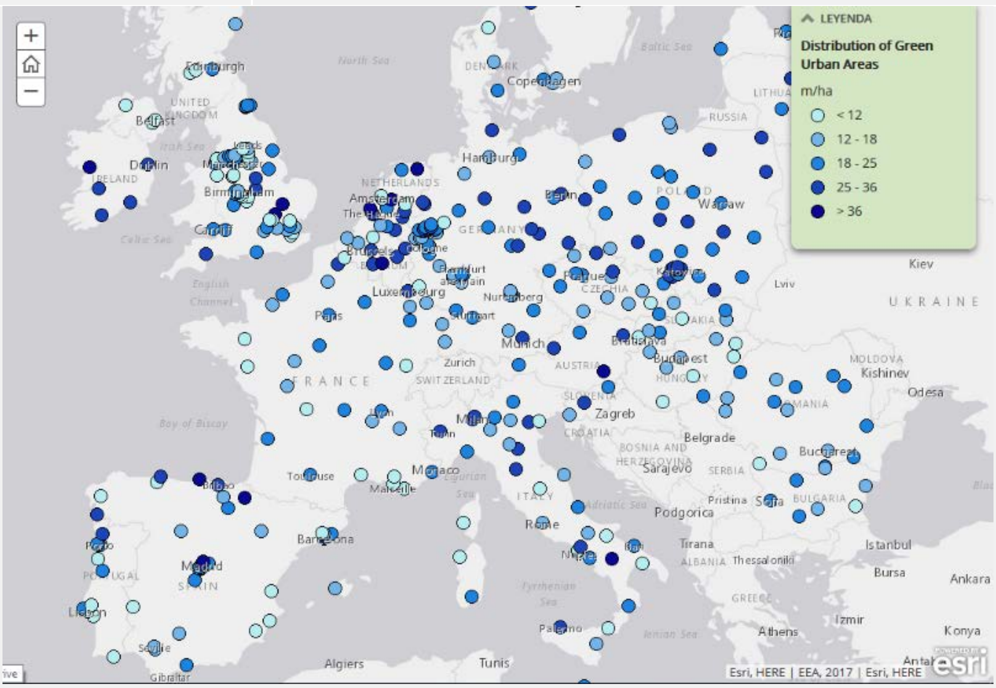
14.1 Share of Green Urban Areas

Project Name: Indicators for urban green infrastructure (EEA)

Author/s and affiliations: EEA, ETC/ULS

Share of Green Urban Areas	Green Space Management Place Regeneration
Description and justification	Green urban areas (GUAs) such as parks, public and private gardens, and even trees lining streets can facilitate climate change adaptation and mitigation, improve health and quality of life, and may favour biodiversity conservation. Vegetated areas in cities can generate a cooling effect thanks to evapotranspiration and shading, which may improve the thermal comfort of urban dwellers and increase their resilience to heatwave events. Moreover, green urban areas are unsealed, allowing the infiltration of storm water and decreasing rainwater runoff. The presence of GUAs favours pollution control as vegetation provides cleaner air by removing pollutants such as nitrogen dioxide and microscopic particulate matter. GUAs have an important value beyond their environmental benefits and aesthetic assets. Exposure to greenspaces can restore the physical and mental health of city dwellers by enhancing psychological health and reducing blood pressure and stress levels.
Definition	The proportion of all vegetated areas within the city boundaries in relation to the total area.
Strengths and weaknesses	Strengths: the indicator is easy to measure and it is easy to communicate. Weaknesses: resolution of the data (minimum mapping unit 0.25 ha). Green linear elements are not currently included.
Measurement procedure and tool	This parameter is based on several classes (11230, 11240, 14100, 14200, 20000, 30000) of the Urban Atlas data, which contain substantial green spaces (the two least dense residential classes with a sealing degree < 30 %, urban parks, sports and leisure facilities, forest, semi-natural and agriculture). It is computed for the core city as defined by Eurostat/Urban Audit.
Scale of measurement	Minimum mapping unit 0.25 ha
Data source	

Required data	Urban Audit data
Data input type	
Data collection frequency	Every 6 years. Currently available for 2006 and 2012. Date for 2018 is under production.
Level of expertise required	Land use and GIS expertise
Synergies with other indicators	Distribution of green urban areas (EEA) Access to green areas in Europe (DG Regio)
Connection with SDGs	SDG-11 (Sustainable cities and communities), specifically target 11.7 (universal access to safe, inclusive and accessible, green and public spaces)
Opportunities for participatory data collection	
Additional information	
References	https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/sub-sections/urban-green-infrastructure/typology-for-urban-green-infrastructure https://eea.maps.arcgis.com/apps/MapSeries/index.html?appid=42bf8cc04ebd49908534efde04c4eec8%20&embed=true



14.2 Land composition

Project Name: MAvES (Mapping, Assessment and Valuation of Ecosystems and their Services) (JRC-D3- Institutional project)

Author/s and affiliations: Grazia Zulian[1], Joachim Maes[1], Guido Ceccherini[2]

[1] *European Commission Directorate-General Joint Research Centre Directorate D (D3 -Land Resources)*

[2] *European Commission Directorate-General Joint Research Centre Directorate D (D1 -Bio-Economy)*

Land composition		**Green Space Management** **Place Regeneration**
Description and justification	Land composition is used to assess the co-occurrence of land types within each Functional Urban Area. It represents the arrangements of ecosystem types within and around cities.	
Definition	Land composition or co-occurrence of land use types, is a measure of spatial distribution of elements or components of a landscape. To quantify land composition we use the Landscape Mosaic (LM), model available in Guido's tool box (Vogt and Riitters 2017). A land mosaic is a tri-polar classification scheme that represents the land type dominance, the interface zone and the mix zone within a defined area. The classification uses the threshold values of 10%, 60%, and 100% along each axis to partition the tri-polar space into 19 classes. These threshold values are indicative for the presence (10%), dominance (60%), or uniqueness (100%) of each land cover type. The model measures land type heterogeneity and allows to consider trade-offs occurring between intra-land type changes (i.e., modification of the area of a given land type) and inter-land types changes (i.e., direction of change). It provides a measure of the relative contributions of the three key land types in percentage within a given neighborhood/observation area.	
Strengths and weaknesses	-spatially explicit -> provides a detailed analysis of change in urban green infrastructure -relatively complex	

Measurement procedure and tool	Dominant land types were extracted from Corine Land Cover. Agricultural areas include all agricultural land types identified in Corine, natural areas include all natural and semi-natural land types, developed areas include all artificial land types including urban green. Parameters applied for the analysis of 700 EU Functional Urban Areas

Dominant land types		
Dominant type	Corine Land Cover	notes
A = Agricultural	[12 -> 22]	all agricultural land types included in CLC
N= Natural	[23-36]	for cities we exclude lakes
D = Developed	[1 -> 11]	Urban green is classified as artificial

Spatial parameters		
resolution (m)	moving window	observation area (km^2)
100	15 pixels	2.25

Scale of measurement	Functional Urban Areas
Data source	
Required data	- Corine Land Cover (CLC) 2000-2018, Version 20 - the model can be implemented using any land use land cover data
Data input type	-raster (vector data will be rasterised)
Precision	100 m
Data collection frequency	Year or time-series range (for available data at EU scale): 2000–2018 https://land.copernicus.eu/pan-european/corine-land-cover
Level of expertise required	-GIS programmer (advanced)
Synergies with other indicators	- With structure of Urban green and Urban Forest
Connection with SDGs	//
Opportunities for participatory data collection	no
Additional information	

References

Landscape Mosaic (LM), model available in Guido's tool box (http://forest.jrc.ec.europa.eu/download/software/guidos/)

Vogt P, Riitters K (2017) GuidosToolbox: universal digital image object analysis. Eur J Remote Sens 50(1): 352–361. doi: 10.1080/22797254.2017.1330650

+ next MAES report will include the methodology applied to all EU cities

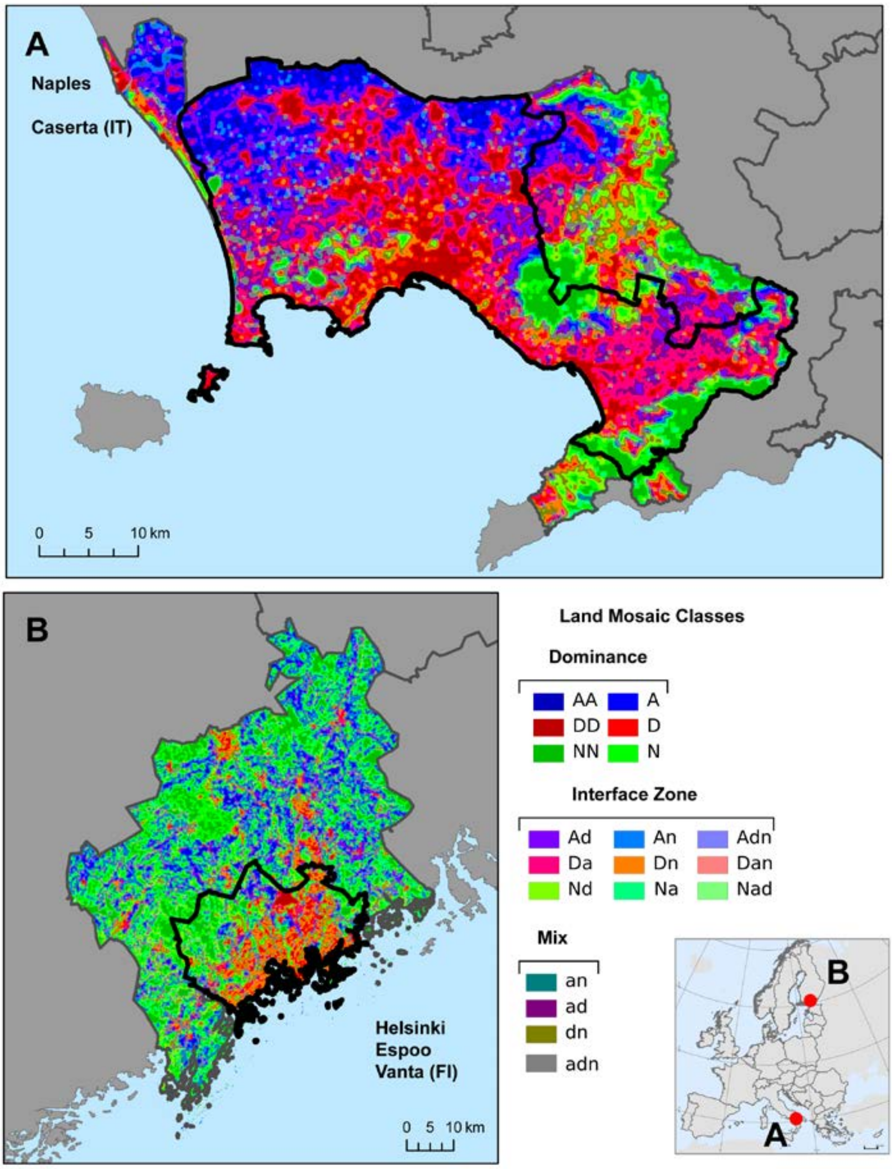


Figure 1: Example of Land Mosaic maps in Helsinki (FI) and Naples (IT). A = Agriculture; D = Developed; N = natural; Mix = mixed presence of all land classes.

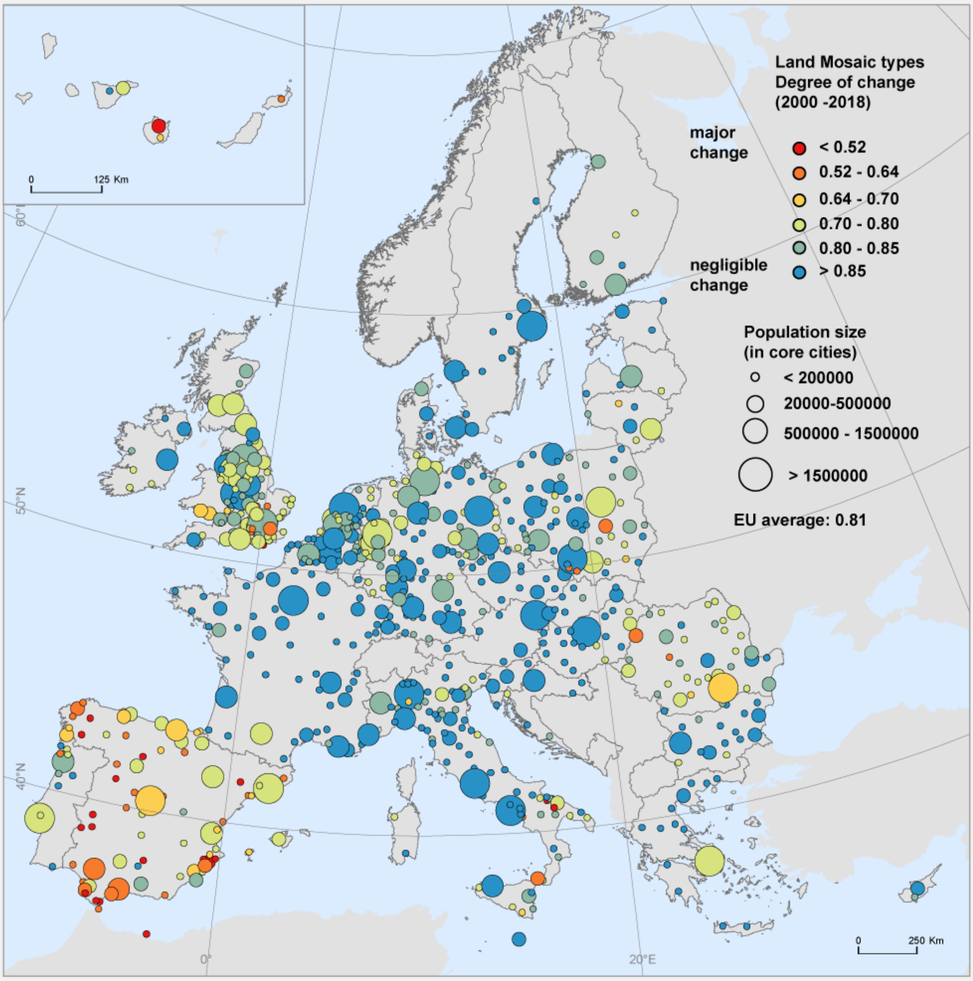


Figure 2: Magnitude of change between 2000 and 2018.

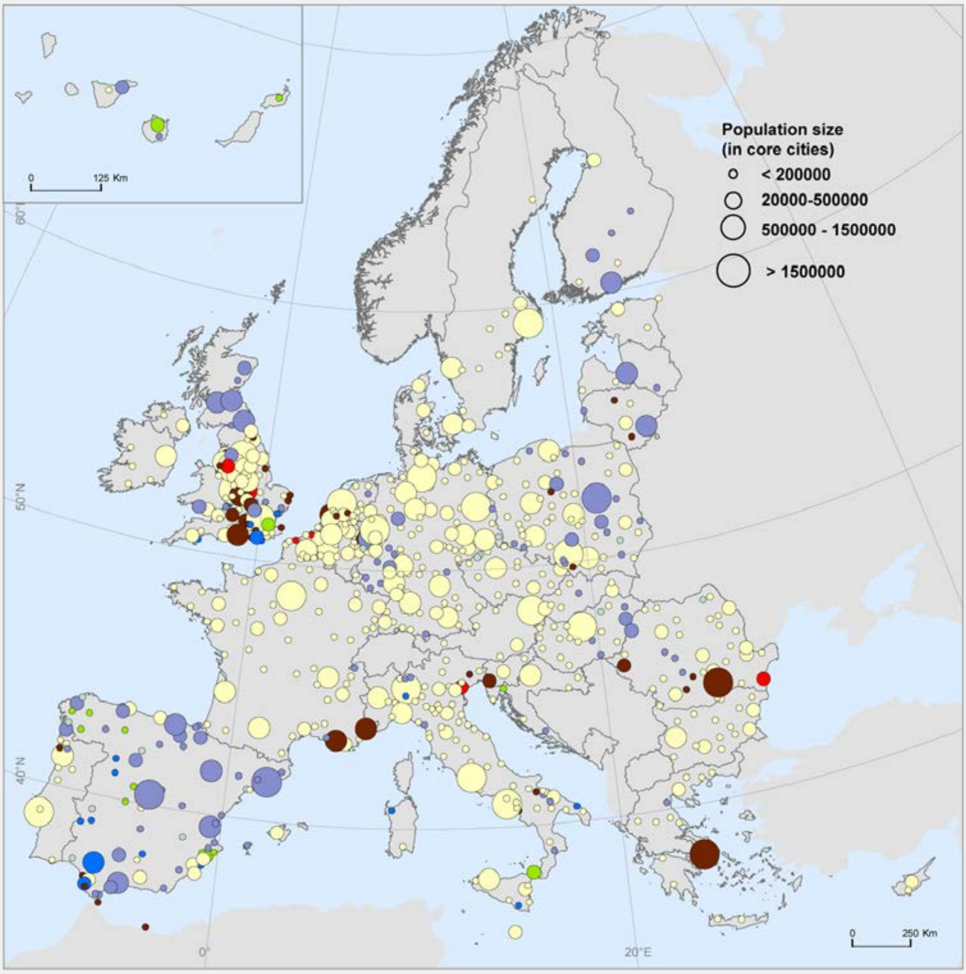
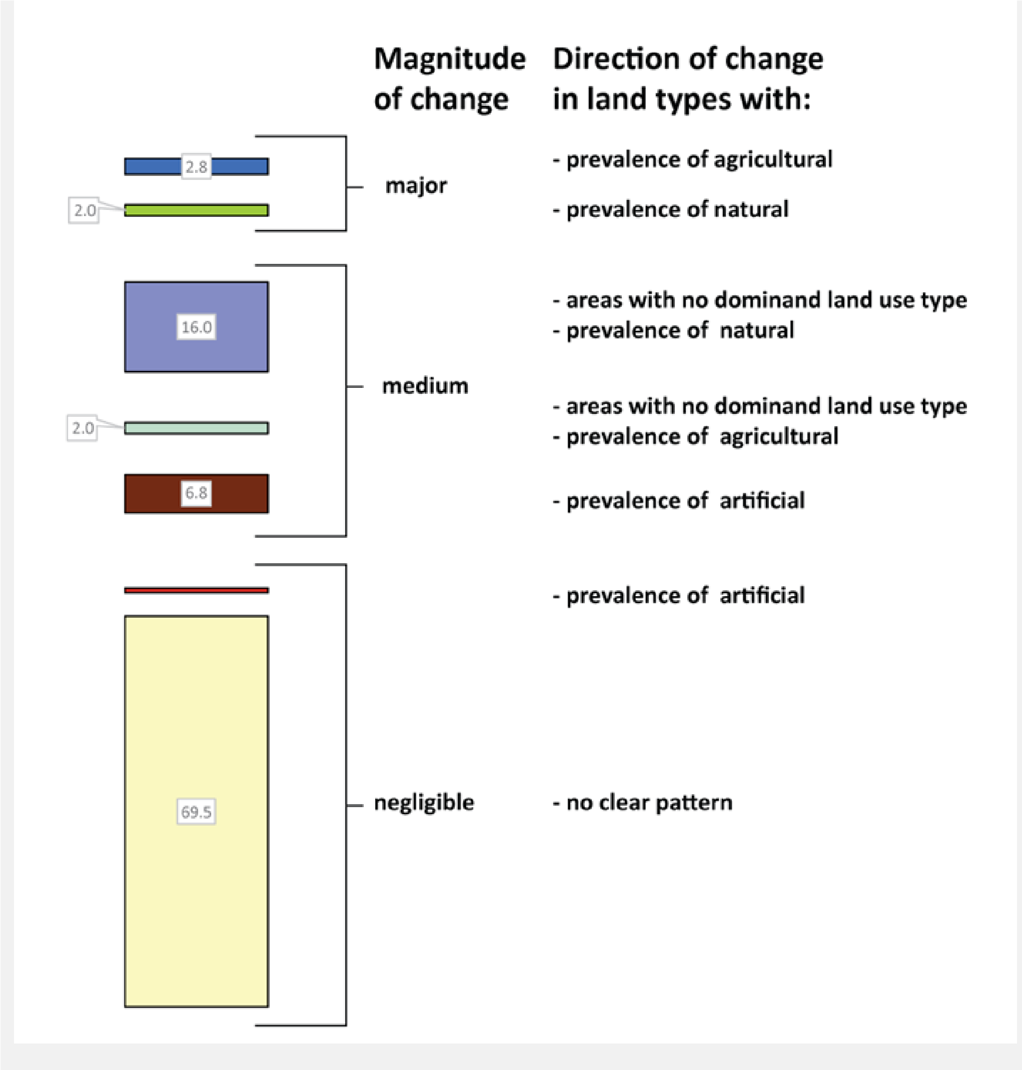


Figure 3: European cities classified according to magnitude of change and main direction of change (between 2000 and 2018)



Magnitude of change
Direction of change in land types with:
2.8
2.0
major
- prevalence of agricultural
- prevalence of natural
16.0
- areas with no dominand land use type
- prevalence of natural
medium
2.0
- areas with no dominand land use type
- prevalence of agricultural
6.8
- prevalence of artificial
- prevalence of artificial
69.5
negligible
- no clear pattern

14.3 Land take index

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

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Land Take Index	**Place Regeneration**
Description and justification	Indicators of Soil Physical Resilience sub-criterion will assess if the project scenarios enhance the ability of a soil to resist or recover their healthy state in response to destabilising influences.
Definition	The Land Take Index is calculated as the ratio between the surface in the study area occupied by Sealed Soils (such as housing, industrial, commercial settlements, public services, infrastructures, mines, dumps) and the whole total surface of the study area.
Strengths and weaknesses	
Measurement procedure and tool	GIS/Model/Survey
Scale of measurement	-
Data source	
Required data	Geographical data, land use data.
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	

References	

14.4 Area devoted to roads

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Area devoted to roads	**Place Regeneration**
Description and justification	Roads are open areas, but depending on the road type, typically do not yield the same positive effects associated with the open urban areas/urban public spaces. Roadways are generally non-permeable, and depending on the road type, are inaccessible and potentially dangerous, produce air, light and noise pollution, and form barriers to movement and ecological compartmentalization.
Definition	Total proportion of a defined urban area devoted to roadways for motorised vehicle use only (ratio or fraction)
Strengths and weaknesses	+ Simple and easy to use - Undefined threshold values for the total area/roads area ratio
Measurement procedure and tool	The total area covered by grey roads for cars is calculated from maps or estimated from appropriate sources, and the ratio to the total area is calculated
Scale of measurement	Street to metropolitan scale
Data source	
Required data	Road type, speed, congestion, traffic type and structure
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Relation to *CO_2 emissions related to vehicle traffic, Annual air pollutant capture/removal by vegetation, Particulate matter (PM_{10} and $PM_{2.5}$), Nitrogen dioxide (NO_2) and*

	ground-level ozone (O_3) concentration indicators and *Water management* indicator group
Connection with SDGs	SDG 9 Industry, infrastructure and innovation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	

14.5 Traditional knowledge and uses reclamation

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

[1] *Aalto University, Department of Built Environment, Espoo, Finland (gerardo.caroppi@aalto.fi)*

[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Traditional Knowledge and Uses Reclamation	**Place Regeneration**
Description and justification	The broken link between generations, between young and old people, interrupts the natural transmission of traditional knowledge, which is based on previous experiences and drives the loss of intangible heritage composed of traditional skills, social organization forms, awareness, understanding and ability to use natural resources. The survival of the intangible heritage is a necessary precondition to ensure the maintenance and care of tangible heritage (UNESCO, 2003; Council of Europe, 2000). It is the values, attitudes and beliefs of the indigenous people which form the intangible heritage and these principles ensure the safeguarding and promotion of the tangible assets and result in recovery, upgrading and maintenance actions (Filipe & de Mascarenhas, 2011). Without the transmission of local knowledge and traditional skills, the tangible heritage could perish since a result of lack of know-how about suitable interventions and maintenance will inevitably lead to its decline. Consequently, without protection of intangible heritage, the tangible heritage may be destroyed (Stephenson, 2008).

Definition	The Indicators assess the ability of NBS to reclaim traditional knowledge and techniques.
Strengths and weaknesses	A deep phase of analysis concerning traditional knowledge has to be carried out; therefore, data mining could be highly time-consuming.
Measurement procedure and tool	A preliminary context analysis with regard to traditional knowledge and uses (e.g., traditional building techniques) should be carried out. Therefore, the project documents should be analysed to detect if that traditional knowledge will be used in the implementation of the Design Scenario.
Scale of measurement	Dichotomic (Yes/No)
Data source	Project team
Required data	Project layout map and technical report
Data input type	Documents and reports
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	Council of Europe (2000). European Landscape Convention, Florence, Italy. Filipe M., de Mascarenhas M.J. (2011). Abandoned Villages and related Geographic and Landscape context: guidelines to natural and cultural heritage conservation and multifunctional valorisation. European Countryside, 3(1), 21-45. DOI: 10.2478/v10091-011-0002-3 Stephenson J. (2008). The Cultural Values Model: An integrated approach to values in landscapes. Landscape and Urban Planning, 84(2), 127-139. DOI: 10.1016/j.landurbplan.2007.07.003 UNESCO (2003). Convention for the Safeguarding of the Intangible Cultural Heritage, Paris, France.

14.6 Traditional events organised in NBS areas

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Traditional Events Organized in NBS Areas	Place Regeneration
Description and justification	The survival of the intangible heritage is a necessary precondition to ensure the maintenance and care of tangible heritage (UNESCO, 2003; Council of Europe, 2000). It is the values, attitudes and beliefs of the indigenous people which form the intangible heritage and it is these principles that ensure the safeguarding and promotion of the tangible assets and result in recovery, upgrading and maintenance actions (Filipe & de Mascarenhas, 2011). Without the transmission of local knowledge and traditional skills, the tangible heritage could perish since a result of lack of know-how about suitable interventions and maintenance will inevitably lead to its decline. Consequently, without protection of intangible heritage, the tangible heritage may be destroyed (Stephenson, 2008).
Definition	The Indicators assess the ability of NBS to offer new spaces for traditional events. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Long Term Scenario computing the number of traditional events organized in the new area created. In the Long-term scenario the indicator should be assessed considering data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Strengths and weaknesses	A deep phase of analysis concerning traditional events organized in the study area has to be carried out; therefore, data mining could be time-consuming.
Measurement procedure and tool	A preliminary context analysis with regard to traditional events organized in the study area should be carried out. Therefore, the indicator will be calculated counting the number of traditional events that have been organized in the new area created by the project.
Scale of measurement	No.

Data source	Local organizations for the promotion of the study area; Municipalities
Required data	Events organized in the study area
Data input type	Documents and reports, websites
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	Council of Europe (2000). European Landscape Convention, Florence, Italy. Filipe M., de Mascarenhas M.J. (2011). Abandoned Villages and related Geographic and Landscape context: guidelines to natural and cultural heritage conservation and multifunctional valorisation. European Countryside, 3(1), 21-45. DOI: 10.2478/v10091-011-0002-3 Stephenson J. (2008). The Cultural Values Model: An integrated approach to values in landscapes. Landscape and Urban Planning, 84(2), 127-139. DOI: 10.1016/j.landurbplan.2007.07.003 UNESCO (2003). Convention for the Safeguarding of the Intangible Cultural Heritage, Paris, France.

14.7 Social active associations

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

[1] *Aalto University, Department of Built Environment, Espoo, Finland (gerardo.caroppi@aalto.fi)*

[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Social Active Associations	**Place Regeneration**
Description and justification	Local associations play an important role in the preservation of identity. In many cases, associations are the custodians of local knowledge and traditions. Therefore, the more social active associations there are in the area, the higher will be the probability to ensure local identity reclamation.
Definition	The Indicators assess the number of Social Active Associations that organize their activities in the study area. This Indicator can be calculated in the Baseline, as well as the Design Scenario and the Long Term Scenario. In the Long-term Scenario, the indicator should be assessed considering data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Strengths and weaknesses	The data concerning local association are usually easy to be achieved since they are enrolled in national, regional or municipal registers.
Measurement procedure and tool	A preliminary analysis should be carried out consulting Social Association Registers with regards to the study area. Therefore, the indicator will be calculated counting the number of Social Active Association that organize their activities in the study area.
Scale of measurement	No.
Data source	National, regional or municipal registers
Required data	Social association registers
Data input type	Official registers
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	

Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

14.8 Retail and commercial activity in proximity to green space

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Direct economic activity: Use of ground floor building space for retail, commercial or public purposes in the area surrounding implemented NBS	**New Economic Opportunities and Green Jobs** **Place Regeneration**
Description and justification	The atmosphere of a neighbourhood and its overall liveability are influenced by the use of ground floor spaces for commercial and public purposes. The availability of amenities not only enhances the consumer experience, but also contributes to successful retail and commerce by supporting small businesses and retailers (Arlington Economic Development, 2014). Residential and office buildings generally have the most potential for increased use of ground floor space.
Definition	Proportion of ground floor surface of buildings within a specified distance from implemented NBS that is used for commercial or public purposes, expressed as percentage of total ground floor surface
Strengths and weaknesses	+ The indicator is easy to define - A lot of input data needs to be collected and processed
Measurement	This metric is calculated as:

procedure and tool	$$\left(\frac{Ground\ floor\ space\ for\ commerical\ or\ public\ use\ (m^2)}{Total\ ground\ floor\ space\ (m^2)}\right) \times 100$$ This indicator may be limited to a defined urban area within a specific distance from NBS (e.g., an area with a given distance or walking time from implemented NBS).
Scale of measurement	Neighbourhood or district scale
Data source	
Required data	Data about ground floor space usage can be obtained from administrative documents and/or from interviews with the department for urban planning within the local municipality
Data input type	Quantitative
Data collection frequency	before and after NBS implementation
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the indicator group *Economic activity & Green Jobs* indicators
Connection with SDGs	SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Arlington Economic Development. (2014). Ground Floor Retail and Commerce: Policies, Guidelines and Action Plan. Draft – September 2014. Arlington, VA: Arlington Economic Development Department, Real Estate Development Group. Retrieved from https://www.arlingtoneconomicdevelopment.com/index.cfm?LinkServID=6E1B9F23-AA29-D1AC-1DFE1072C67F5C64&showMeta=0 Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., and Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys project D1.4. http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

14.9 Number of new businesses created and gross value added to local economy

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Jose Fermoso[1], Silvia Gómez[1], María González[1], Esther San José[1], Raúl Sánchez[1]

[1] *CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain*

Direct economic activity: New businesses attracted and additional business rates		New Economic Opportunities and Green Jobs Place Regeneration
Description and justification	This KPI, related to economic aspects measurements, evaluates how NBS interventions can increase the attraction of businesses, or how to increase the value of the existing ones. This value, evaluated through the measurements of number of new business created and the percentage of the gross value added, will reflect the economic opportunities and potential of NBS solutions.	
Definition	The impact assessment of the implementation of NBS in terms of new business creation and improvement on business rates.	
Strengths and weaknesses	- Medium or long term assessment. - It needs municipality data from different departments. - This KPI will require citizens' collaboration, so recovering the data could be difficult.	
Measurement procedure and tool	- **Number of business created (direct value buss related NBS by zone)** Direct value on business created by zone NBS affected, before and after implementation, during the established period. Number of business created= n * Z [(nº business) (€/m^2)] Where n is referring to the number of business and Z to its increased value (NBS related by zone), during the established period of implementation (directly related to the each particular NBS) - **Gross value added (GVA)** Defined as the difference between the value of goods and services produced and the cost of raw materials and other non-labour inputs, which are used up in production. The research should conclude what is the total contribution of NBS in % of the total GVA to the region/area economy in Euro/ by year.	

Scale of measurement	City / neighbourhood
Required data	City official data, city platforms, questionnaires, small-medium enterprise account (Related to de NBS investment zone)
Data input type	▪ (nº business) (€/m^2) ▪ (nº business or nº users) (kg/year) (€/year)
Data collection frequency	Annually
Level of expertise required	Technical / Basic
Synergies with other indicators	-
Connection with SDGs	SDG1 / SDG4 / SDG5 / SDG8 / **SDG10** / **SDG11** **/ SDG12**
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl An impact evaluation framework to support planning and evaluation of nature-based solutions rojects; An EKLIPSE Expert Working Group report, 2017 "The Model of the Environmental Sustainability Matrix" (“El Modelo de la matriz de Sostenibilidad Ambiental”); La ordenación Urbana y el Desarrollo Sostenible, Angel Ibañez Ceba, Fermín Cerezo Rubio, August 2009 Expert evaluation network delivering policy analysis on the performance of Cohesion policy 2007-2013, 2013, “Job

	creation as an indicator of outcomes in ERDF programmes", Synthesis report, August 2013, A report to the European Commission Directorate-General for Regional and Urban Policy Forestry Commission, Scotland, The economic an d social contribution of forestry for people in Scotland, David Edwards, Jake Morris, Liz O´Brien, Vadims Sarajevs and Gregory Valatin, September 2008 Guidance Document on Monitoring and Evaluation – ERDF and Cohesion Fund, Concepts and Recommendations, Programming Period 2014-2020, European Commission, April 2013. Annex1

14.10 Social return on investment

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Social Return on Investment (SROI)	New Economic Opportunities and Green Jobs Place Regeneration
Description and justification	This indicator seeks to capture the value of improvements in social well-being (in monetary terms) arising from nature-based solutions. It should be used only in cases where additional information relating to the notional monetary value of one or more social well-being indicators is needed for the purpose of funding applications, investor requirements (*see Indicator 12.2.5 Private Finance / Private Investment in NBS / Bioeconomy*) or comparing the value of different projects for which there are a range of different impacts.
Definition	*Social Return on Investment (SROI)* is generally reported as a ratio between the monetary value of outputs/outcomes and the monetary value of inputs. As such, it provides both a quantifiable cost-benefit analysis of a given project / programme, as well as a tool for comparing different investments either as a forecast or a post investment evaluation. Proponents of the SROI measurement approach claim that it takes a more 'holistic' view of the various impacts

	that a given project/programme has on beneficiaries, but this is a matter of debate – and also depends on the specific choices made by and resources available to the SROI assessment team. Calculating SROI can only be done if there are clearly identifiable social well-being output/outcome indicators of value arising from the target project/programme, and credible SROI reporting generally requires the services of a qualified SROI expert. While the product of an SROI assessment is a quantifiable and comparable measure of expected or achieved return on resources deployed, the *process* of conducting an SROI assessment is also seen as a valuable activity as it explicitly involves stakeholders and beneficiaries in the assessment process. This is generally thought to increase the credibility of the measurement and also to raise the awareness of all stakeholders of the aims and value of the project. The specifics of this process are described in the measurement and procedure section below.
Strengths and weaknesses	+ The indicator is a meaningful and comparable at multiple levels of aggregation and across different projects; + It is a powerful tool for assessing 'value for money' (VfM) of projects with a range of social benefits; + It is widely supported by a range of social investment NGOs, think-tanks, impact investors and associations, the EU and the WHO. - It is time-consuming and often quite expensive to conduct an SROI assessment; - it requires significant expertise to calculate, to explain and to evaluate its significance; - SROI – along with other approaches to social value measurement - has been widely criticised for incorporating estimated attributions of value, 'heroic' assumptions of causality and over-simplifying the unique and heterogeneous impacts of social innovation (see references section)
Measurement procedure and tool	Details on the procedure for measuring SROI are widely available through any number of public websites and associations. The website for the EU initiative "Responsible Research and Innovation (RRI)" is a good place to start when looking for further information. The RRI 'Toolkit' has a link to a seminal SROI guidebook from the UK, "A guide to Social Return on Investment", from which the summary procedure included here is drawn. SROI is a 6-stage process that begins with the definition of scope for the assessment and identifying the stakeholders who will be involved and the main outcomes (impacts) to be measured. If the work of defining the NBS project's 'theory of change' has already been done (as part of the development of another indicator measurement), then this should provide a

good starting point for Stage 1: scope and stakeholder definition – which includes those expected to benefit from the project (beneficiaries) as well as those providing any maintenance or other services related to the NBS and those funding the project. Work on other social well-being indicators will also provide useful input to Stage 2: Mapping Outcomes. Each stage is outlined below – however this factsheet does not substitute for detailed step-by-step guidance available from the recommended sources if an SROI assessment is to be undertaken.

Stage 1: Establishing scope and identifying stakeholders. There are three steps in this stage: 1) establishing the scope of the analysis; 2) identifying stakeholders and 3) deciding how to involve stakeholders. In this stage the purpose of the SROI should be explicit – not only whether it is a forecast or a post-investment evaluation, but also defining (and agreeing) the goal of producing the measurement and the resources that are available to undertake the assessment. The 'audience' for the resulting measurement(s) should also be defined in this step. This may simply be the group of stakeholders – or may go beyond that group if there are objectives that require this – such as policy influence and/or knowledge sharing.

It is important to decide which of the various activities or components of the NBS will be included as it may be possible only to examine a subset of all possible value producing components due to time / resource constraints. When considering the stakeholders, be sure to include those who might be negatively affected as well as those who are expected to be positively affected. Lastly, the decision about how to involve stakeholders is critical to ensure that the SROI includes those impacts that really matter to stakeholders and you can be completely transparent about how the valuation was developed and calculated.

Stage 2: Mapping Outcomes. As in the previous stage, this stage may be informed by work done in other indicator development exercises – particularly those that addressed social well-being impacts arising from the NBS. However, to do a proper SROI, the definition of outcomes must be co-produced with the identified stakeholders, so if this was not done in other impact indicator activities it will need to be done here. 'Mapping outcomes' involves figuring out what each stakeholder contributes (inputs) and/or receives (outputs / outcomes) from the various activities included within the scope of the SROI assessment. Identifying these is best done with the stakeholders as they are most likely to know about the actual inputs / outputs affecting and important to them. If the

SROI is a forecasting exercise, then it may be possible to find estimates from previous / similar activities, relevant research and/or databanks produced for this purpose. Note that there may be 'chains' of outputs, outcomes arising over time from the NBS – which will need to be identified here. For example, an accessible park may provide greater opportunities for exercise for older people, which are taken up by some proportion of the population, and as a result these individuals are fitter and happier – which results in less healthcare expense and feelings of social isolation. Each of these outcomes will need to be defined and valued as appropriate.

It is in this stage that a monetary value is assigned to inputs as this is the less complex of the valuation steps. Valuing a volunteer's time or the expected effort required by beneficiaries to generate outcomes can, of course, be complicated, but by and large, this aspect of valuation is generally much less challenging than the next stage of valuing outcomes.

SROI manuals recommend creating an 'Impact map' for the project being assessed, which is essentially a list of stakeholders, impacts (inputs/outputs) and activities that generate each impact for each stakeholder. Other approaches to measuring impact more generally begin with a 'Theory of Change' model, which supports SROI as well as other approaches to measuring social impact. A theory of change (ToC) model explains in a graphical way the causal links between inputs, activities, context and outcomes. Mayne (2015) provides a useful overview of Theory of Change models, which may be helpful in developing a wide range of impact indicators for NBS.

Stage 3: Evidencing and Valuing Outcomes. While the previous stages may be quite challenging for the assessment team to decide among the various alternatives for defining activities, stakeholders and outcomes, it is this stage that is the most complex stage of the SROI methodology and the one that creates the most controversy (although Stage 4 has its own unique challenges). Essentially this stage is about deciding how outcomes will be demonstrated and what represents their 'fair' value.

Again, if there are already processes for gathering evidence of social well-being outcomes, then it would be advisable to 're-use' the data from these processes for assessing SROI. However, at a minimum, these indicators must be confirmed with the stakeholders identified in stages one and two and some effort needs to be made to balance objective and subjective indicators. More on this may be found in the Guide to Social Return on Investment (Nicholls et al 2012). Once the indicators of impact are agreed with stakeholders, the next step is to assign monetary values.

While it is likely that the monetary values assigned to each non-monetary input/output will be specific to the project, stakeholders and context, there are some efforts at creating standard monetary values for widely produced social outcomes in a given country. An example of a monetary value databank for social outcomes in the UK is the HACT Social Value Bank – for activities related to housing - and a paper explaining the relationship between this databank and SROI may be found here. The methodology behind these valuations is found in Trotter et al (2014) and Fujiwara (2013). Most NBS projects, however will need to develop their own monetary values through using benchmarks, published or proprietary cost data or tools specifically developed for this purpose. An overview of tools for this purpose may be found on the 'Sopact' site.

It should be noted here that the SROI ratio is generally formulated as the net present value of outcomes divided by the net present value of inputs. So it will be necessary to gather or estimate the ongoing delivery of outcomes over an agreed time period in order to fully align with the SROI approach (see Stage 5).

If the purpose of the SROI assessment is to deliver a post-investment / implementation evaluation, the next step will be to collect the data required to 'evidence' the outcomes of interest. It will be up to the evaluation team to decide how many periods of data are required and this should be related to the expected time frame of the impact.

Stage 4: Establishing Impact. This stage draws on the decisions and data collected in previous stages and then applies a calculation model that draws heavily on economics and social policy evaluation approaches to 'adjust' the raw impact figure for issues of deadweight, displacement, drop-off and attribution. As noted above, the steps for accomplishing this are detailed in Nicholls et al (2012) or any number of SROI guidebooks.

At the highest level, the SROI calculation multiplies each instance of an achieved outcome by the monetary value determined in Stage 3 and then adjusts this 'gross' valuation by estimates or evidence of:

1) *Deadweight* – a concept from economics that represents the outcomes that would have happened over time even if the activity being assessed had not taken place. This is generally measured via reference to control groups (or other benchmark measures) of people who were not beneficiaries of the activity / NBS;

2) *Displacement* – a concept from social policy (and economics) that represents the extent to which outcomes generated by the activity being assessed eliminated, shifted or replaced other outcomes. A typical example of displacement is when a benefit (e.g, job, access to services) is made available to one individual/group that would have otherwise gone to a different individual/group;

3) *Drop-off* – this concept comes from education / training policy analysis and is a measure of the decrease in impact over time of a given activity. An example of drop-off is decreasing impact of a sustainability awareness programme on an individual's likelihood of changing their consumption patterns. This adjustment would only be used in cases where the expected impact of an NBS extends over multiple years;

4) *Attribution* – this is an assessment of how much of the outcome achieved was caused by the contribution of the NBS as opposed to other organisations / individual choices. Nicholls et al (2012) provides a good example: "alongside a new cycling initiative there is a decrease in carbon emissions in a borough. However, at the same time, a congestion charge and an environmental awareness programme began. While the cycling initiative knows that it has contributed because of the number of motorists that have switched to cycling, it will need to determine what share of the reduced emissions it can claim and how much is down to the other initiatives (p.59)"

These adjustments to gross outcomes are usually expressed as percentages and, again, Nicholls et al (2012) contains a good example of how the adjustments may be applied to the outcome values to calculate net impact.

Stage 5: Calculating SROI.

Having completed all of the previous steps, the SROI assessor should now be in a position to calculate SROI. An overview is provided here, but it is recommended that those undertaking an actual SROI calculation refer to Nicholls et al (2012).

The basic model is a based on a net present value (NPV) calculation which is arrived at by estimating (or measuring – if it is a post implementation assessment) the amounts and number of years in which costs will be incurred and social value achieved and then applying a 'discount rate' for the time-value of money. For more on NPV and choosing a discount rate see

	HBR article here or to go to Nicholls et al (2012) for SROI specific examples. The monetary equivalent value of social impact was estimated in Stage 3 and this value must be adjusted in each year by applying the adjustment percentages determined in Stage 4. The present value calculation for outcomes should only be done after the adjusted financial value of the social outcomes are calculated for each year. By applying the discount rate to the adjusted annual financial values for outcomes, the total present value of the NBS project is produced. This figure is divided by the total costs of the NBS to produce the SROI for the project as a ratio of benefits to costs. If the SROI is greater than 1, then the NBS creates value. If it is less than 1, then it does not. SROI guidelines suggest that assessors undertake two additional analyses in order to provide further information about the SROI measurement produced. These are: 1) a *sensitivity analysis* – which provides information on the extent to which the result would change if the assumptions in any of the previous steps were altered, and 2) a '*payback period'* calculation – which gives an idea of how long it would take for the NBS to pay back the initial investment. Both of these are standard financial calculations that may be applied to the figures generated (see Nicholls et al 2012). **Stage 6: Reporting, using and embedding measurement.** This last stage is an important one to build into to any SROI project plan as it will ensure that the hard work of the previous steps. The first step in this stage is to review the results with stakeholders and get their feedback on the credibility and significance of the measurement. There is also a degree of accountability to stakeholders given their significant interest in and contribution to the measurement. Beyond stakeholders the use of the SROI depends upon the aim of the original undertaking, with a forecast generally reported to potential investors / funders and an evaluation reported to this group plus others with an interest in how the project is meeting its aims. It is important to note that one of the main indicators of a successful SROI is the extent to which it is used to inform decisions and/or changes to the various elements of the NBS over time. Finally, it may be appropriate to get outside assurance of the validity of the SROI measure and this can be provided by an accredited SROI assurance provider. Information on assurance (or becoming an accredited SROI provider) may be found here – or by contacting SVI. "Social Value International" (SVI) is an association of member organisations that are interested and/or experts in approaches

	to valuing social outcomes and interested parties are encouraged to connect with their local SVI association for support in applying SROI in their location.
Scale of measurement	Will be defined based on the scale of measurement for the underlying social well-being indicators
Data source	
Required data	- Amount (in monetary terms) of investment in the NBS being assessed for SROI - indicators of social well-being value created by the NBS - stakeholder-based attribution of monetary value to a unit of the social well-being indicator - evidence-based attribution of the proportion of social well-being created to the NBS – generally linked to a clear theory of change, and examined for 'drop-off' over time - evidence-based
Data input type	Qualitative and Quantitative
Data collection frequency	If being used as a planning / forecasting tool then data collection will occur at the planning stages of the project
Level of expertise required	Very High
Synergies with other indicators	SROI is highly dependent upon the collection of relevant *Social well-being indicators* to provide the underlying drivers of valuation. Synergies with *Benefit/Cost* and *Private Finance* indicators as data collected for SROI may be useful for these measures and vice versa.
Connection with SDGs	SDG 3 Good Health & Well-being; SDG 4 Quality Education; SDG 5 Gender Equality; SDG 8 Decent Work & Economic Growth; SDG 10 Reduced Inequalities; SDG 9 Industry, Innovation & Infrastructure; SDG 16 Peace, Justice & Strong Institutions
Opportunities for participatory data collection	A core element of SROI assessment is the involvement of beneficiaries and stakeholders in the defining of value and of attribution of effects (see procedure section above). This engagement with stakeholders is generally seen to be a positive feature of the methodology as it increases stakeholder awareness of the project benefits and also accords beneficiaries with direct and meaningful input to the creation of the impact indicator.
Additional information	
References	Ebrahim, A.; Rangan, V.K. (2014) "What impact? A framework for measuring the scale and scope of social performance". Calif. Manag. Rev. 2014, 56, 118–141. Fujiwara (2013) "The Social Impact of Housing Providers". HACT Report accessed at: https://www.hact.org.uk/sites/default/files/uploads/Archives/2013

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14.11 Population mobility

Project Name: proGIreg (Grant Agreement no. 776528)

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Population mobility	**Place Regeneration** **New Economic Opportunities and Green Jobs**
Description and justification	One of the aims of T4.4 is to look at how gentrification can be happening in the cities where the NBS will be implemented through proxy indicators. The quantification of gentrification is a very lively subject of scientific research at the moment and is out of the scope of the proGIreg project. However, it will be possible to extract several lines of intuition on what's happening with the population in the NBS implementation areas in terms of mobility between rented/owned property, frequency of moving and the reason for moving.

Definition	For the purpose of this project we will consider population mobility to be: The % of people whose last move was in the past 1 year, 2 years and 5 years.
Strengths and weaknesses	
Measurement procedure and tool	In the GQ we ask respondents to tell us when was the last time that they moved (Q51) and the reason for moving (Q52). To 51 they will answer with the year.
Scale of measurement	Same as GQ. NBS implementation district (300 respondents) and control district (300 respondents)
Data source	
Required data	Answers to GQ
Data input type	Respondent answer year of last move
Data collection frequency	Twice in life of project: before implementation (pre-GQ) and after implementation (post GQ)
Level of expertise required	That of the interviewers conducting the GQ. Computation of final indicator is simple and will be done by T4.4 leaders.
Synergies with other indicators	Connected to other economic and labour indicators
Connection with SDGs	Goal 8: Decent work and economic growth
Opportunities for participatory data collection	None
Additional information	
References	

14.12 Population growth

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Population Growth (Natality + Immigration)	Place Regeneration
Description and justification	If NBS are conceived and designed to provide multiple socio-economic benefits, combining natural risk mitigation with the creation of new attractive spaces and services, natural heritage enhancement with accessibility to resources, they could give new job opportunities to young people and reverse negative population trends that usually affect rural and mountainous territories. Positive demographic change can be used as an Indicator of the performance of the Design Scenario in terms of quality of life.
Definition	The Indicator can be defined as the increase, in terms of percentage, of the population living in the area where the new infrastructure (both NBS, Hybrid solutions and Grey infrastructures) is implemented. In the Baseline Scenario Population increasing should be calculated taking into account population trend in the previous 30 years, in order to understand if a decreasing rate in the last 10 years point out a structural or a temporary problem. Population trend is likely to increase (and elderly rate is likely to decrease) if new jobs opportunities will be created. To esteem increase or decrease of such demographic indexes in relationship with the realization of a project or another, it is possible to use a probabilistic scale. In the Long-term scenario population increasing should be calculated considering statistical data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Strengths and weaknesses	It could be difficult to get the data concerning population living in the area in the Long Term Scenario
Measurement procedure and tool	Population increasing ΔP, due to both natural population balance (difference between births and deaths) and social one (varying between immigrants and emigrants), can be expressed by the following formula:

	$$\Delta P = \frac{P_{LTS} - P_{BS}}{P_{BS}} \cdot 100$$ where P_{BS} is the total population living in the area at the Baseline Scenario; P_{LTS} is the total population living in the area at the Long Term Scenario (e.g., 5-10 years after NBS or solutions and Grey infrastructures have been implemented).
Scale of measurement	%
Data source	National Statistical Institute and/or Municipal General Register Office
Required data	Population data
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	
References	

14.13 Proportion of elderly residents

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Proportion of elderly residents	**Place Regeneration**
Description and justification	The main proportion of inhabitants in rural and mountainous landscapes is people over 65 years of age. Inhabitants of these areas are economically disadvantaged regarding the supply of essential services for daily life such as health services care and basic goods stores. This combination of reduced communities with limited facilities and economic options can cause the abandonment of these areas by young people. If the depopulation trend continues, the impact on ageing population will be felt more and more dramatically; as the maintenance of basic services declines further and there are fewer younger people to help in the care of these dependents (Gellrich & Zimmermann, 2007; Molina Ibanez & Farris, 2011; Mottet et al., 2006). Decreasing in Elderly Rate can be used as an Indicator of the performance of the Design Scenario in terms of quality of life.
Definition	The Indicator can be defined as the change, in terms of percentage, of the elderly rate in the area where the new infrastructure (both NBS, Hybrid solutions and Grey infrastructures) is implemented. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Long Term Scenario computing the percentage difference between the Elderly Rate in the Design Scenario and the Elderly Rate in the Baseline Scenario. In the Long-term scenario Elderly Rate should be calculated considering statistical data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Strengths and weaknesses	It could be difficult to get the data concerning population living in the area in the Long Term Scenario
Measurement procedure and tool	*Elderly rate* at a given time can be expressed by the following formula: $$ER = \frac{P_{>65}}{P} \cdot 100$$ where

	$P_{>65}$ is the population over 65 years old; P is the total population. *Elderly* $$\Delta ER = \frac{ER_{LTS} - ER_{BS}}{ER_{BS}} \cdot 100$$ where ER_{BS} is the Elderly Rate in the area at the Baseline Scenario; ER_{LTS} is the Elderly Rate in the area at the Long Term Scenario (e.g., 5-10 years after NBS or solutions and Grey infrastructures have been implemented).
Scale of measurement	%
Data source	National Statistical Institute and/or Municipal General Register Office
Required data	Population data
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	
References	Gellrich M., Zimmermann N.E. (2007). Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. Landscape and Urban Planning, 79(1), 65-76. DOI: 10.1016/j.landurbplan.2006.03.004 Molina Ibáñez M., Farris M. (2011). Políticas públicas para el desarrollo rural: un análisis multiescalar. Geographicalia, 59-60, 225-265. DOI: 10.26754/ojs_geoph/geoph.201159-60836 Mottet A., Ladet S., Coque N., Gibon A. (2006). Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. Agriculture, Ecosystems and

	Environment, 114(2-4), 296-310. DOI: 10.1016/j.agee.2005.11.017

14.14 Areal sprawl

Project Name: Nature4Cities (Grant agreement: No. 730468)

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Areal Sprawl	**Place Regeneration**
Description and justification	Areal sprawl is the territorial aspect of several urban transitions. According to literature (Speck, 2013; Saelens et al. 2003.) the planning of city centres can avoid areal sprawl. If downtown is liveable, less people will tend to move to the outskirts of the city and undertake the burden of daily commute for the desired quality of their place of residence. Nature-based solutions are highly relevant from compact urban form point of view. Compactness can be also achieved with the balanced availability of green spaces and ecosystem services. In addition, unrestricted urban sprawl endangers natural environment around the city and the protective zones that mitigates the intensity of urban heat island.
Definition	Areal sprawl indicator describes the level of compactness of a city, as the ratio between total building floor area to the area of the convex hull of the built space. The convex hull of a set of points is the minimal convex envelope that contains those points. Computing this shape gives a fair ground to compare different cities or neighbourhoods, and a closer approximation to the actual built density.
Strengths and weaknesses	
Measurement procedure and tool	• computation of convex hull • collection or calculation of total floor area • ratio $\mathrm{Conv}(S)=\left\{\sum_{i=1}^{\lvert S\rvert}\alpha_i x_i \;\middle\vert\; (\forall i:\alpha_i\ge 0)\wedge\sum_{i=1}^{\lvert S\rvert}\alpha_i=1\right\}.$ General formula for a convex hull: $AS = A_{\text{convex hull}}/A_{\text{built space}}$ Output measurement unit: m^2 / m^2 (or m^3/m^2)

	Tools: convex hull surface calculation software or library, like: Shapely, SciPy
Scale of measurement	Neighbourhood and city scale
Data source	
Required data	- Total floor area of buildings. If this is impossible to acquire directly it can be approximately calculated knowing the ground area of buildings and their heights. - To assess the impact of a future project, a tool that simulates urban evolution is needed.
Data input type	- Municipality databases - Open sources like Open Street Map - But in any case, data has to be georeferenced
Data collection frequency	Before / after the project's implementation, to characterize it is effects on the local environment
Level of expertise required	It can be used after minimal explanation. The concept of total floor area against the convex hull area of a city can be translated roughly as built "volume" against the city size.
Synergies with other indicators	
Connection with SDGs	SDG 3 Good Life and Well-being, SDG 11 Sustainable Cities and Communities, SDG 13 Climate action
Opportunities for participatory data collection	-
Additional information	
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	- Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies - Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

14.15 Access to public amenities

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Access to public amenities (Applied and EO/RS combined)	**Place Regeneration**
Description and justification	Density of public amenities has been used as an indicator of compactness or urban sprawl (and less car use). Accessible local services and facilities can reduce travel, particularly by private cars and help ensure sustainable communities. It can also be viewed as an indicator of health/wellbeing and quality of life. Public amenities are services/facilities which are provided by the government or town/city councils for the general public to use, with or without charge, for instance libraries, social welfare points etc. (CITYkeys). Access to public amenities partially measures the mix and distribution of different facilities and uses in a city and the proximity of public services to the residential location of city dwellers. Remote sensing imagery has been widely adopted for analysis of spatial inequalities in distribution and accessibility to public amenities in cities (Joseph et al., 2012). Major techniques for this include dasymetric mapping, regression models and geostatistical models (Jensen et al., 2004; Joseph et al., 2012), spatial visualization and overlay analysis with georeferencing and digitization (Borana and Yadav, 2017; Travland et. al., 2017). There are some studies on accessibility of public amenities where amenities services are shown with the help of the database management systems by using GIS and RS (Nilsson, 2014; Taylor et al., 2017). Research indicates that urban population today prefer more open, well designed, structured, and built amenities as opposed to wildland recreation areas (Johnson et al., 2004; Travland

	et. al., 2017). Thus, an urban park should offer a variety of facilities and amenities including playgrounds, ball fields, and walking trails to cater the needs of a multicultural society (Duncan et al., 2012; Travland et. al., 2017). Data on access to public amenities collected in these ways can be used to: • Quantify the benefits of NbS in terms of improving access to public amenities; • Assess the distribution of key public amenities in relation to planning new greenspace; • Prioritise public amenity delivery through NBS design.
Definition	Share of population with access to at least one type of public amenity (social welfare points, social meeting centres, restrooms, information displays, public telephones, rain shelters, drinking fountains, etc.) within 500m (% of people) using earth observation and remote sensing methods. By incorporating these features into NBS schemes it may be possible to increase accessibility and reduce transport distances and vehicle use.
Strengths and weaknesses	**Applied methods:** The indicator is relevant to access to services, and can be linked to quality of the built environment. The CITYkeys scoring system allows for some subjectivity and does not explicitly account for quality of services or user acceptance. Density can be a perceived experience rather than an outcome of empirical calculations (Burton, 2000). **Earth observation / Remote sensing methods:** Theoretical frameworks used to explain the location of public services and amenities include central place theory, aspects of industrial location theory and spatial diffusion theory which are all described as normative theories being able to optimize with respect to defined criteria operating in prescribed environmental conditions (Rushton, 1979). However, recent advancement in geospatial technologies has led to several applications in geographically orientated challenges, hence, the adoption of an effective decision tool like Geographic Information System (GIS), high resolution products of satellite remote sensing as well as the Global Positioning System (GPS) in solving the rather challenging task of optimal location for public amenities and facilities with respect to necessary criteria. Today, cities worldwide are affected adversely by the problem of appropriate location of public facilities and amenities. They are either

	too far from their market zone or they are too congested in a particular location or hardly accessible by local citizens and in some cases, political consideration to the siting of these facilities dominate without given considerations to the necessary criteria for demands and public interest. A number of studies have aimed to investigate the optimal determination of the locations of some public facilities in cities using geospatial techniques. A fusion of remote sensing, geographic information system (GIS) and GPS techniques have been explored by recent studies in this field (Ahmed, 2007; Borana and Yadav, 2017; Duncan et al., 2012; Johnson et al., 2004; Michael, 2008; Travland et. al., 2017). Together they provide strong evidence on distribution and access. They underline the need for development of a Geodata base of existing public amenities and facilities, and the use of Euclidean-distance geometry to spatially analyse the appropriate locations with regards to the set of standard criteria. According to existing studies, integrating remote sensing data and point-of-interest (POI) data (including location-rich semantic information) has been successfully applied in the identification of social functions of urban lands, but none were focused on a detailed and complete social functional map of UGS. Moreover, spatial patterns or distribution densities derived from the POI data have been extracted into feature vectors and then combined with physical properties derived from remote sensing data to improve the accuracy of land use identification.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Indicator Metrics Reviews Env48_Applied and Env48_RS
Scale of measurement	**Applied methods:** Typically city-scale, but can be used over smaller scales (e.g., smaller administrative units). **Earth observation / Remote sensing methods:** Can be applied at various geographical scales.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env48_Applied and Env48_RS

Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env48_Applied and Env48_RS
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env48_Applied and Env48_RS
Level of expertise required	**Applied methods**: Generally some GIS expertise is needed for mapping aspects. **Earth observation/Remote sensing methods**: An increasing number of sensors, RS data products, processing algorithms, software and tools are available for the assessment of public amenities and urban green space availability. Selecting an applicable data source and the method to process data is a complicated process which needs expert knowledge. Cost, time, expertise, and technical properties of remote sensing data are factors in this process. Thus, the assessment should be made by experts engaged in the NBS project who have expertise not only in RS, but also in urban planning, forestry, landscape ecology, regional planning. Each of them will then assess all built and land cover type combinations.
Synergies with other indicators	Remote sensing imagery provides powerful tools for masterplanning and policy analysis regarding green urban area expansion. However, measures of public amenities cannot be solely based on indicators obtained from 2D geographical information. In fact, 2D urban indicators should be complemented by 3D modelling of geographic data. The spatial locational analysis of public amenities plays an important role in the decision making of local planning and development of new utilities services. As such, mapping for this indicator can have synergies with other health and well-being indicators and greenspace mapping indicators.
Connection with SDGs	SDGs 3, 4, 5, 7, 9, 10, 11, 13, 16, 17: Access health & wellbeing services; Greater access to education opportunities; Equal gender access to services; Equal access to clean energy; Equal access to infrastructure; Social equality in relation to access to services; Sustainable urban development; Climate change adaptation; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods:** citizen participation could be through a PPGIS tool such as GLOBE app.

	Earth observation / Remote sensing methods: Uneven distribution of public amenities indicates that the existing planning might not produce acceptable results in terms of balanced development of different municipal wards. Since a number of the amenities are provided by the government, their availability and distribution must be planned carefully. A participatory approach can be an effective mechanism for assessing and ensuring the even distribution of urban amenities in a city. The results of the analysis of access to public amenities can help policy-makers and municipal authorities in proper planning in the distribution of public amenities. Validation of results on the ground as well as the participation of urban planner and policy makers is also essential.
Additional information	
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14.16 NBS distance from urban centres and public transport

Project Name: PHUSICOS (Grant Agreement no. 776681)

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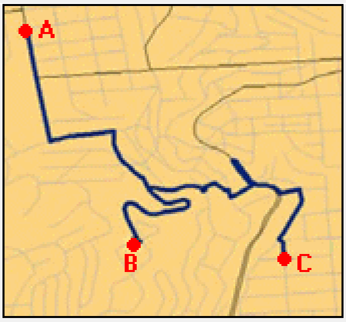
Average Distance Of Natural Resources From Urban Centres/Train Station/Public Transportation	**Place Regeneration**
Description and justification	The implementation of the Design Scenario can reduce the average distance of natural resources from urban centres/trains stations/public transportation. The more the Design Scenarios will contribute to reduce this distance, the more effective will be the benefits in terms of quality of life for the community.
Definition	The indicator can be defined as the average distance between the main entry to a natural area (park, wood, etc.) and urban centres/train station/public transportation.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of accessibility of natural areas and therefore of quality of life for the community.
Measurement procedure and tool	The indicator is equal to the average road network distance between the main entry to the natural areas (park, wood, etc.) and urban centres/train station/public transportation. Common GIS software tools allow finding the shortest route to a given location along a network of transportation routes. If the Design Scenario introduces new roads, the indicator will be calculated considering the road network of the Baseline Scenario upgraded with these new roads.
Scale of measurement	Km
Data source	Project team, Openstreetmap; Municipality Geographic Information System
Required data	Project layout map, road network data (vector data)
Data input type	Maps; Vector Data
Data collection frequency	

Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	
Additional information	
References	



A = Main entry to wood
B = Urban centre
C = Urban centre
Blue line = Shortest road network distance

14.17 Natural and cultural sites made available

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Accessibility of Natural and Cultural Sites	Place Regeneration
Description and justification	A new infrastructure, implemented in a rural landscape in order to achieve a risk reduction, could also ensure the accessibility to natural and cultural sites previously isolated.

Definition	This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) computing the size of natural and/or cultural sites, in terms of square kilometres, that were previously not accessible and now are free from any hazard and dedicated to recreational activities.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of landscape perception.
Measurement procedure and tool	The indicator is equal to the size of the parts of the cultural and natural site in the study area that were previously isolated and that are made accessible to people by the project since they are free from any hazard. Given the vector data of the project and of risk map, common GIS software tools allow calculating these areas.
Scale of measurement	km^2
Data source	Project team
Required data	Project layout map (vector data); Hazard map
Data input type	Maps; Vectorial data
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

14.18 Historical and cultural meaning

Project Name: Naturvation (Grant Agreement no. 730243)

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Historical and Cultural Meaning	Place Regeneration
Description and justification	The indicator describes the benefits of historical and cultural aspects to citizens of urban green space such as NBS. The benefits cover aspects of artistic expressions such as graffiti, arts and murals, written, drawn or painted as forms of communication (either from past times or present). Through stories of the users of NBS might dignify the historical understanding of transformation and development (1). Also, diverse elements generate thoughts about symbols and metaphors existing between one's life and nature as well as places of identity, memory and belonging (2). Cultural heritage can be seen as the intermingling of past and present practices and represents thus bridges between different periods, cultures, localities and the natural environment. Cultural heritage and diversity enrich human life with meaning and emotions, enhance the quality of the lives of citizens and is a precious and irreplaceable resource (3). Cultural assets might have a little monetary value but an immense culture significance to the local community (4).
Definition	The indicator describes the benefits of historical and cultural aspects to citizens of urban green space such as NBS.
Strengths and weaknesses	
Measurement procedure and tool	The indicator is measured through the quantity of cultural assets and symbols/elements (e.g., graffiti, arts, murals, stickers etc.) or qualitatively when measuring the impressions or feelings of users of nature in cities. The values used for the scoring of the indicator Historical and Cultural meaning were based on empirical data (1, 2, 3), modelling studies (2) and literature reviews (2, 4).
Scale of measurement	
Data source	
Required data	Qualitative and quantitative
Data input type	Qualitative assessment covers photograph analysis (1), behavioural observations (1, 3), questionnaires, consultation meetings and workshops (3) as well as a variety of interview methods (e.g., semi-structured

	interviews) (1, 3, 4). Quantitative approaches include site surveys (3, 4) and geographical data (i.e., digital elevation model, DEM, GIS data, (historic & current) land use) (4).
Data collection frequency	
Level of expertise required	
Synergies with other indicators	
Connection with SDGs	*SDGs:* 11
Opportunities for participatory data collection	
Additional information	
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14.19 Cultural value of blue-green spaces

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: S. Connop[1], D. Dushkova[2], D. Haase[2] and C. Nash[1]

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Cultural value of blue-green spaces (Applied & EO/RS combined)	Place Regeneration
Description and justification	The most basic measure for this indicator is counting an increase/decrease in the number of events promoting cultural benefits held in a blue-green space. This can be carried out before and after a change in how the blue-green space is designed or managed to assess the net benefit of a new NBS initiative. Cultural benefits are some of the non-material benefits of ecosystems, including providing opportunities for recreation, physical activity, socializing, and restoring capacities (Chen et al. 2019). In addition to the basic information on number of events, additional detail can be captured in relation to how well attended events were. This can be captured by counting the numbers of attendees through ticket sales, ticket collection on the day of the event, sign-in processes or monitoring visitor numbers through physical counts or visitor profiling in relation to specific pursuits (Cope et al. 2000; Cessford and Muhar 2003). There is no real direct contribution of earth observation/remote sensing tools for the assessment of the cultural value of blue and green spaces of NBS in cities. However, these tools could be used in an indirect way for mapping Land Use/Land Cover (LULC) as a background layer for mapping and presenting indicator results. Evaluation of cultural value of blue-green space can be used to: • Monitor the value of cultural events in relation to visitor numbers; • Assess that changes related to NbS implementation have a positive impact on visitors in relation to attending cultural events; • Ensure that changes related to NbS implementation promote socio-environmental justice.

Definition	A measure of the number of cultural events/number of people involved to evaluate the cultural benefits of blue-green spaces using applied methods.
Strengths and weaknesses	**Applied methods**: Robustness of evidence is very much based on the design of the questionnaire and the sample size of respondents. Event counts are straightforward and robust, but without the additional data on attendees and demographics, the value of the data is limited. Visitor number counts and demographic data robustness can be a challenge due to the difficulty in capturing representative visitor numbers at some sites. **Earth observation / Remote sensing methods**: See Applied above.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects can be found in: Connecting Nature Indicator Metrics Reviews Env29_Applied and Env29_RS
Scale of measurement	**Applied methods**: Analysis is performed on a single site scale and can comprise sites ranging from very large parks and open spaces to micro-scale pocket parks. Typically, replication across sites is used for comparative purposes. City-wide replication would involve substantial effort as remote sensing data is not an option for quantifying attendees or events. **Earth observation / Remote sensing methods**: Mapping could be carried out on a city or city district scale.
Data source	
Required data	Required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env25_Applied and Env25_RS
Data input type	Data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env25_Applied and Env25_RS
Data collection frequency	Data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Indicator Metrics Reviews Env25_Applied and Env25_RS

Level of expertise required	**Applied methods**: Some expertise is needed for the design of the evaluation (e.g., survey method, question selection). Once decided though, a low level of expertise is required for carrying out the survey or carrying out counts. Similarly, data analysis can require low expertise if basic inventories or correlations are required. **Earth observation / Remote sensing methods**: See Applied above.
Synergies with other indicators	Strong synergies with health and wellbeing indicators and social cohesion indicators in relation to public use of the sites for physical activity and social events. Also, synergies with environmental indicators (e.g., biodiversity measures, water regulation and air temperature) in relation to synergies and trade-offs in benefits driven by changes in use of blue-green spaces.
Connection with SDGs	All SDGs except 6 & 7: Potential for job creation, neighbourhood revitalisation; Links to historic food production; Links to social cohesion and recreation; Links to heritage education; Opportunities for gender fair cultural association; Income generation associated with heritage; Infrastructure renovation; Social equality in relation to cultural/heritage opportunities; Sustainable urban development; Links to responsible production and consumption if linked to historic sustainable practices; Climate change adaptation; Potential co-benefits related to more sustainable water management; Possibility for a return to more sustainable management; Environmental Justice in relation to greenspace heritage; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods**: Good opportunities for participation through which communication of the benefits of an NBS approach can be delivered. This can be achieved both through the questionnaire process and involving citizen science in data collection. Capturing data on types of cultural events and demographics of attendees can also encourage community members to input information to blue-greenspace managers about the type of events that would be most attractive. **Earth observation / Remote sensing methods**: See Applied above.
Additional information	
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14.20 Opportunities for tourism

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Development of Tourism	Place Regeneration
Description and justification	Some NBS projects could promote a new touristic development of rural and mountainous area in many different ways: by creating a new qualified natural attraction (a riverside, a green infrastructure, a new sport trial in natural context), increasing accessibility to and/or connecting existing cultural heritage sites or landscape viewpoints. This could increase touristic activeness in the study area.
Definition	The indicator could be defined as the number of visitors over a year. The number of visitors can be defined as the amount of people visiting the study area. In the Baseline Scenario, the indicator will be calculated consulting data on tourism, counting the number of visitors in the study area. In the Design Scenario, the indicator will be assessed adopting a five-point Likert item with categories “Very Poor”, "Poor", "Average", "Good", and "Very Good to evaluate the likelihood of occurring the increasing of touristic activeness. In the Long Term Scenario, the indicator will be calculated, as in the Baseline Scenario, considering the data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Strengths and weaknesses	Collecting the data necessary to assess the indicator could be time and money consuming.
Measurement procedure and tool	The number of visitors can be monitored through a direct survey or assessed using models. Both these approaches entail an ex-post indicator evaluation. Ad hoc direct survey can be carried out in different periods over the year, for instance one week for each season, and the number of visitors detected can be multiplied for the number of weeks in a year. When there is no time and/or economic resources for an ad hoc direct survey the number of visitors can be estimated through models that

	needs official data concerning tourists (National institute of statistics, Regional tourism agency, etc.) and/or other proxy data (amount of solid urban waste produced; electricity consumption in private houses; number of houses available for vacation).
Scale of measurement	No./year
Data source	Public agencies (National institute of statistics, Regional tourism agency, Municipalities, etc.)
Required data	Number of visitors in the study area
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	Medium
Synergies with other indicators	Number Of Visitors In New Recreational Areas
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	
References	

14.21 Building structure – Urban form

Project Name: MAvES (Mapping, Assessment and Valuation of Ecosystems and their Services) (JRC-D3- Institutional project)

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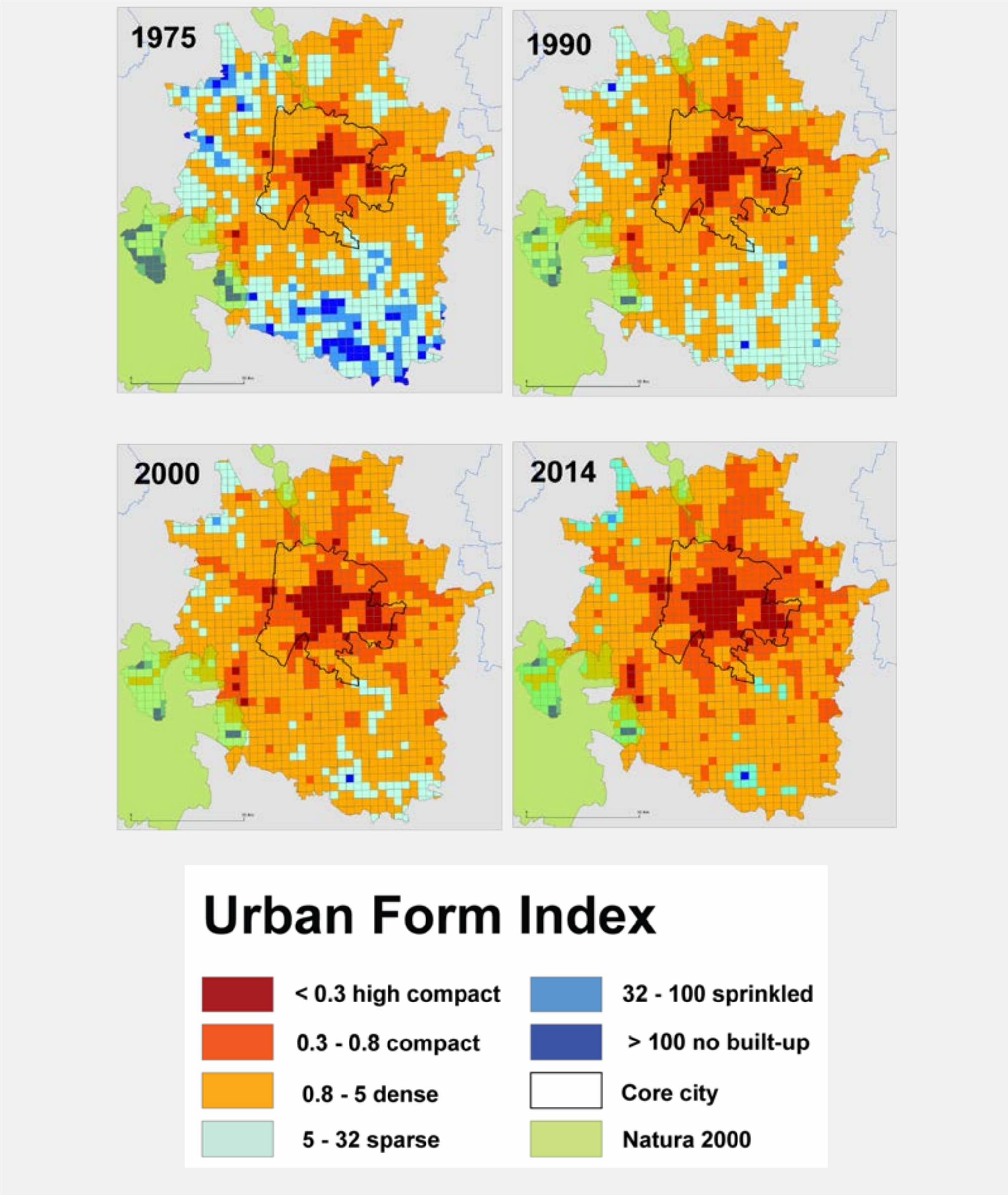
[1] *European Commission Directorate-General Joint Research Centre Directorate D (D3 -Land Resources)*
[2] *European Commission Directorate-General Joint Research Centre Directorate D (D1 -Bio-Economy)*

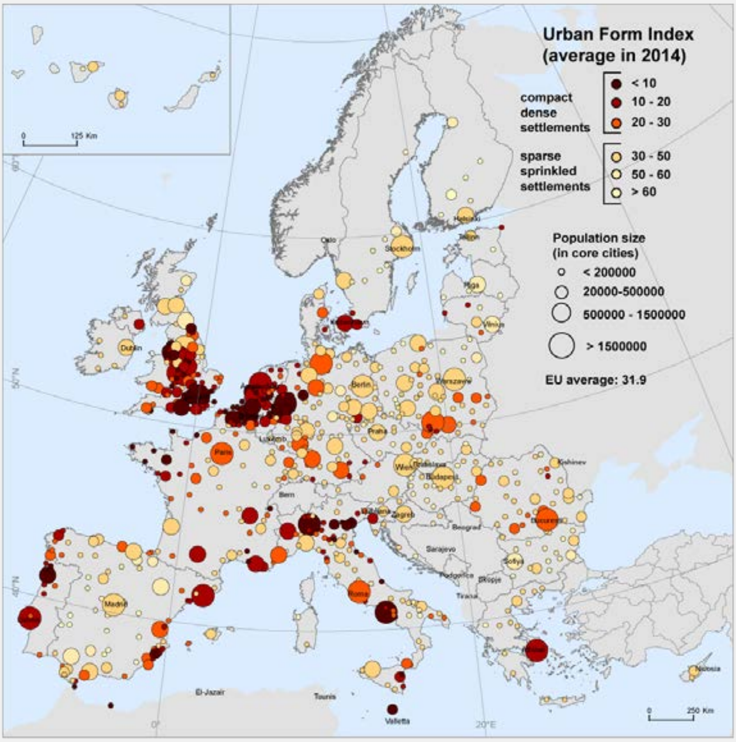
Building Structure	**Place Regeneration**
Description and justification	Urban Form provides a spatially explicit metric to describe the settlements pattern. The indicator has been derived, and adapted at European scale, from the sprinkling (SPX) index -mean Euclidean

	nearest neighbor distance-, which analyses the fragmentation of urban settlements through a purely geometric point of view (Romano et al. 2017; Saganeiti et al. 2018).
Definition	Assuming the circular form as compact as possible, the index is based on the calculation of distances between different built-up areas on a 2 km buffer around each 1 km grid cell, within Functional Urban Areas. The distance buffer of 2 km around each sub-reporting unit (1 km cell) was chosen following previous works on urban sprawl developed at European scale (Aurambout et al. 2018). The higher the index the higher the degree of fragmentation of the territory. For the analysis the indicator has been classified in six classes which represents categories of urban form which, according to the literature, have an impact on city performance in terms of mobility, urban resilience, ecosystem services and biodiversity (Cortinovis et al. 2019).
Strengths and weaknesses	-spatially explicit -> provides the urban form structure -relatively complex
Measurement procedure and tool	Urban Form: $$Urban_{Form} = \frac{(Max_{-\,bld-dist})}{R}$$ where: Max(bld-dist) = the maximum distance between all built up areas extracted within a 2 km horizon (1 km buffer around each 1 km cell); the distance is measured within the target FUA and the adjacent FUAs in order to take the boundary effect into consideration. R= ray of an hypothetical built-up zone with and area equal to the sum of all the built up areas in the considered horizon
Scale of measurement	Functional Urban Areas
Data source	
Required data	-Built-up data (GHS built-up grid, derived from Landsat, multitemporal R2018A, 30-m (EPSG:3857). - the model can be implemented using any built –up or imperviousness data sets
Data input type	-raster (vector data will be rasterised)
Precision	30 m
Data collection frequency	Year or time-series range (for available data at EU scale): 1975-1990-2000-2014 (http://data.jrc.ec.europa.eu/collection/GHSL)

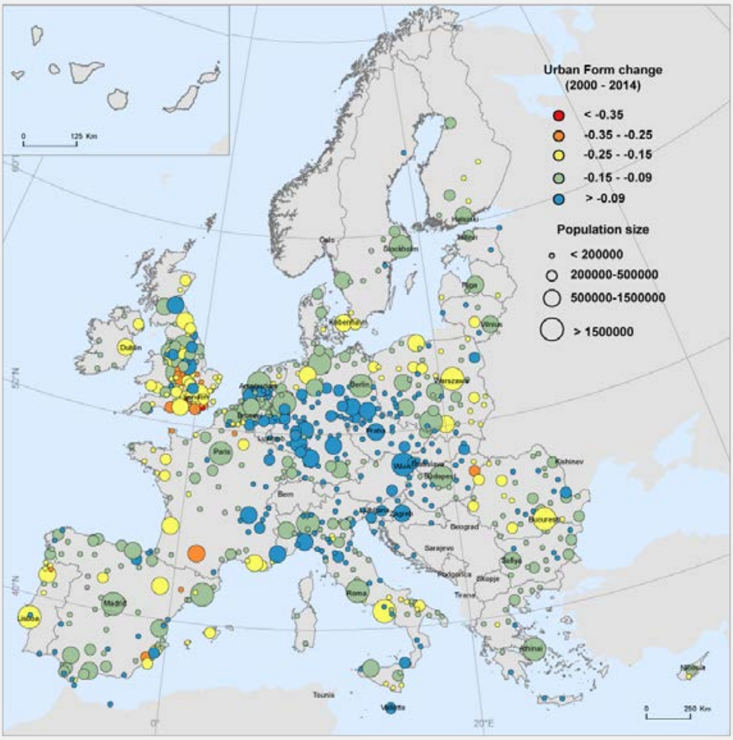
Level of expertise required	-GIS programmer (advanced)
Synergies with other indicators	- With soil sealing - With structure of Urban green and Urban Forest - With type of mobility or commuting behaviour - ...others....
Connection with SDGs	//
Opportunities for participatory data collection	No
Additional information	
References	Pesaresi M, Syrris V, Julea A (2016) A new method for earth observation data analytics based on symbolic machine learning. Remote Sens. doi: 10.3390/rs8050399 Romano B, Zullo F, Fiorini L, Ciabò S, Marucci A (2017) Sprinkling: An approach to describe urbanization dynamics in Italy. Sustain. doi: 10.3390/su9010097 Saganeiti L, Favale A, Pilogallo A, Scorza F, Murgante B (2018) Assessing urban fragmentation **+ next MAES report will include the methodology applied to all EU cities**



1975
1990
2000
2014
Urban Form Index
< 0.3 high compact
0.3 - 0.8 compact
0.8 - 5 dense
5 - 32 sparse
32 - 100 sprinkled
> 100 no built-up
Core city
Natura 2000



Example of status map



Example of trend map

14.22 Material used coherence

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Material Used Coherence	Place Regeneration
Description and justification	Indicators of Application of Suitable Materials and Technologies sub-criterion will assess the coherence of used material and techniques with local materials and conditions.

Definition	It assesses whether the construction materials used are coherent or not with local natural materials and if they produce negative impacts on landscape perception.
Strengths and weaknesses	
Measurement procedure and tool	Survey/Living Labs
Scale of measurement	Dichotomic (Yes/No)
Data source	
Required data	Information about used materials.
Data input type	Qualitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	11
Opportunities for participatory data collection	Living Labs
Additional information	
References	

14.23 Techniques used coherence

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Techniques Used Coherence	**Place Regeneration**
Description and justification	Indicators of Application of Suitable Materials and Technologies sub-criterion will assess the coherence of used material and techniques with local materials and conditions.
Definition	It assesses whether the typology of used techniques is invasive or not for landscape (e.g., huge excavation, cave, deforestation to build new road for caterpillars). In a long-term scenario, those above mentioned Indicators could be re-assessed, monitoring, through a direct survey, if the materials/techniques used have produced impact on landscape.
Strengths and weaknesses	
Measurement procedure and tool	Survey/Living Labs
Scale of measurement	Dichotomic (Yes/No)
Data source	
Required data	Information about used materials.
Data input type	Qualitative
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	11

Opportunities for participatory data collection	Living Labs
Additional information	
References	

14.24 Design for sense of place

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Design for sense of place	**Place Regeneration**
Description and justification	The phrase "design for a sense of place" relates to a complex concept involving the embodiment of tangible and intangible qualities in the design that make a place distinctive (create an identity). The unique place identity or sense of place in turn fosters authentic human attachment and a feeling of belonging. The sense of place concept arises from the examination of people's connectedness and identity with the built environment, in parallel with evaluation of people's perceptions and experiences of the built environment through design (Hu & Chen, 2018).
Definition	The extent to which 'sense of place' is considered during urban planning or during the planning and implementation of a specific project (unitless value)
Strengths and weaknesses	+ Simple and straightforward assessment - Subjective evaluation of people's connectedness and identity with the built environment, and people's perceptions and experiences of the built environment through design
Measurement procedure and tool	Design principles to foster a sense of place include preserving existing elements, ensuring safety and focusing on the creation of places that (Bosch et al., 2017): - Are welcoming and respond to, or express the values of groups within the community for whom the place is designed;

	- Are comprised of several physical and social settings for events and activities that make places pleasant and culturally relevant; - Are scaled and proportioned to facilitate easy navigation, interaction and overview by the users; and, - Have identifiable features, landmarks or historical places to enhance visual appeal and orientation. The extent to which a given NBS project has considered design for a sense of place can be qualitatively rated on a five-point Likert scale: **Not at all — 1 — 2 — 3 — 4 — 5 — Very much** 1. Poor: no attention has been paid to the idea of creating a sense of place in the design of the NBS project; residents are not able identify any distinctive elements. 2. Fair: the idea of creating a sense of place has received some attention in the NBS project, but not as an important element. 3. Average: some attention has been given in the NBS project design to the idea of creating a sense of place. 4. Good: Much attention has been given to the idea of creating a sense of place in the NBS project design. 5. Very good: The focus on creating a sense of place in the design is clearly and recognizably present in the NBS project, even for outsiders.
Scale of measurement	Building to municipality scale
Data source	
Required data	Design, implementation and features of an NBS project
Data input type	Qualitative
Data collection frequency	Annually, and before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Some relation to *Cultural heritage*-related indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city

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14.25 Viewshed

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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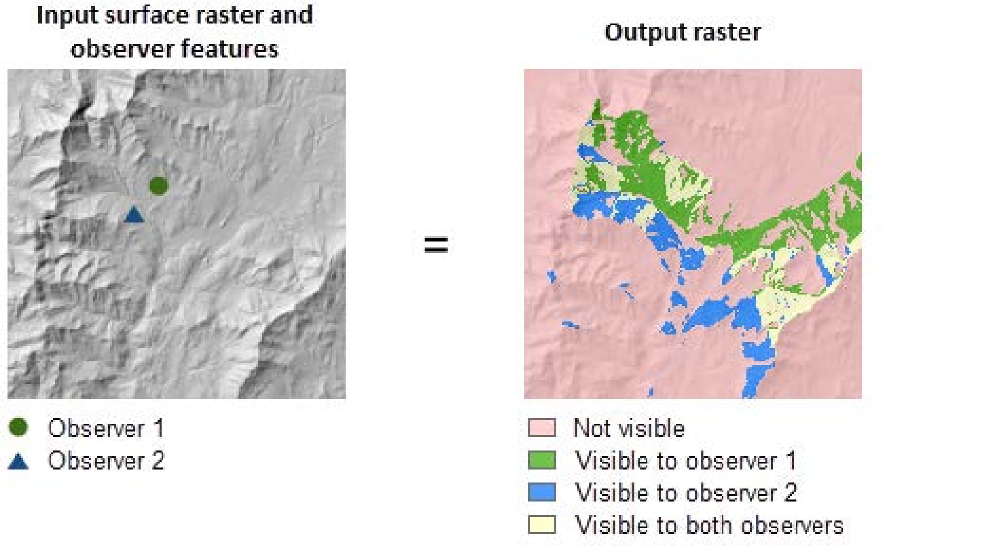
Viewshed	Green Space Management Place Regeneration
Description and justification	Some NBS could contribute to enhance landscape enjoyment increasing the amount of perceivable scenic sites. If the project foreseen the built of new natural trails, the scenic enjoyment of new viewsheds could be a co-benefit for population and tourists.
Definition	A viewshed is the geographical area that is visible from a location. It includes all surrounding points that are in line-of-sight with that location and excludes points that are beyond the horizon or obstructed by terrain and other features (e.g., buildings, trees). This Indicator could be calculated both in the Baseline Scenario taking into account the viewshed from all the scenic sites already existing, and in the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) considering, in addition, the new scenic sites created by the project.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of landscape perception. It could be difficult to find accurate data concerning digital terrain models.
Measurement procedure and tool	Given the vector data of the scenic site locations (point features) and a digital terrain model of the study area, common GIS software tools allow to achieve.

	The viewshed of a scenario is equal to the envelop of the viewshed obtained considering each scenic sites in the study area. In the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) the viewsheds from the new scenic sites created by the project have to be taken into account too.
Scale of measurement	km^2
Data source	Project team; Regional or Municipal Geographic Information System
Required data	Project layout map (vector data); Digital terrain model
Data input type	Maps; Vectorial and Raster data
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	



Source: www.arcgis.com

14.26 Scenic sites and landmarks created

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Scenic Sites And Landmarks Created	Place Regeneration
Description and justification	Some NBS could contribute to enhance landscape enjoyment increasing the amount of perceivable scenic sites and creating new landmarks that could represent new elements of local identity. If the project foreseen the built of new scenic sites, the enjoyment of landscape from other point of view could be a co-benefit for population and tourists.
Definition	A scenic site is a viewpoint where it is possible to enjoy the view of area valued for its aesthetic qualities. The area may be made up primarily of natural vegetated cover and water, or include structures and manmade landscaping.

	A landmark is a feature of a landscape that is easily seen and recognized from a distance, especially one that enables someone to establish their location. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) computing the new scenic sites and landmarks created by the project.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of landscape perception.
Measurement procedure and tool	Given the project layout map, the indicator will be calculated counting the number of scenic sites and landmarks created by the project.
Scale of measurement	No.
Data source	Project team;
Required data	Project layout map
Data input type	Maps
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

14.27 Scenic paths created

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Scenic Paths Created	Place Regeneration
Description and justification	Some NBS could contribute to enhance landscape enjoyment increasing the amount of perceivable scenic sites. If the project foreseen the built of new natural trails, the scenic enjoyment of landscape could be a co-benefit for population and tourists.
Definition	A scenic path is a route where it is possible to enjoy the view of area valued for its aesthetic qualities. The area may be made up primarily of natural vegetated cover and water, or include structures and manmade landscaping. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) computing the length of new scenic paths created by the project.
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of landscape perception.
Measurement procedure and tool	The indicator is equal to the length of new scenic paths network created by the project. Given the vector data of the scenic paths network, common GIS software tools allow calculating its length.
Scale of measurement	km
Data source	Project team;
Required data	Project layout map (vector data)
Data input type	Maps
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	

Connection with SDGs	3
Opportunities for participatory data collection	
Additional information	
References	

KNOWLEDGE AND SOCIAL CAPACITY BUILDING FOR SUSTAINABLE URBAN TRANSFORMATION

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15 Recommended Indicators of Knowledge and Social Capacity Building for Sustainable Urban Transformation

15.1 Citizen involvement in environmental education activities

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Environmental Education Opportunities		Knowledge and Social Capacity Building
Description and justification	Environmental education (EE) is a learning process that increases people's knowledge and awareness about the environment and associated challenges, develops the necessary skills and expertise to address the challenges, and fosters attitudes, motivations, and commitments to make informed decisions and take responsible action (UNESCO, Tbilisi Declaration, 1978). EE is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution (Stapp, Havlick, Bennett, Bryan, Fulton, & MacGregor, 1969), i.e., *an environmentally literate citizenry*. The term EE refers to education about the environment, including population growth, pollution, resource use and	

misuse, urban and rural planning, and modern technology with its demands upon natural resources. The goals and objectives of EE were agreed upon at UNESCO's Tbilisi Intergovernmental Conference (UNESCO, 1978), came to define the aforementioned notion of environmental literacy (i.e., components), and include *awareness, knowledge, affect, skills, and participation*. EE departs from learning opportunities that help people better understand and connect with the environment close to home, i.e., the environment in their own neighborhoods and communities (Carter and Simmons, 2010). Cole (2007) draws attention to local and cultural appropriateness in designing these learning opportunities, in that the ideas taught need to originate from and resonate with locally and culturally appropriate knowledge, values, and ways of living. Although not all EE programs have the potential to generate social capital among participants (e.g., classroom instruction), there are forms of EE that can foster social connectivity, trust, and associational and volunteer involvement (e.g., programs that incorporate collective opportunities for volunteer and associational involvement around stewardship, like community gardening and tree planting, or those that incorporate opportunities for intergenerational learning and collective decision-making, like place-based learning, school-community partnership for sustainability, environmental action, action competence, community-based natural resource management EE, social-ecological systems resilience) (Krasny, Kalbacker, Stedman, & Russ, 2015). For this reason, environmental education opportunities presented to a community are envisioned as a significant indicator of its resources for associational involvement in NBS, and of contexts for building trust.

Hailing the importance of green spaces beyond health benefits, Wolsink (2012a, 2012b) reports data of an explorative study conducted in all secondary schools in Amsterdam that indicates that proximity to green spaces is associated with the number of environmental education excursions. Specifically, the study suggests that increasing urban green spaces has a positive impact on environmental education activities, including the number of visits to green places. The author strongly affirms the environmental justice imperative of recognizing environmental education "as a viable stake in the urban development of green spaces" (Wolsink, 2012 a, p. 179).

Using a quasi-experimental research design, Kudryavtsev, Krasny and Stedman (2012) found empirical support for the hypothesis that interventions such as environmental

	education can nurture sense of place (Kudryavtsev, Stedman, & Krasny, 2012) in high school students. As sense of place has been found to cultivate place-specific pro-environmental behaviors (see Indicator SC 6), data gathered by Kudryavtsev et al. (2012) on youth participants in urban environmental education summer programs in the Bronx support the expectation that urban environmental education programs that cultivate the significance of urban green space "may inspire community-based initiatives to create more urban farms, roof gardens, community gardens and greenways, or to further restore aquatic ecosystems and urban forests" (p. 11). Derr (2017) emphasizes the sustainable benefits of participatory environment education by finding empirical support for *built environment education (BEE)*, an empowering model of education aimed at facilitating a stronger role of young people in decision making and shaping their environments. Elaborating on two cases in the City of Boulder, Colorado where children and youth were involved in the redesign of a natural public space, the author argues that BEE which includes participatory processes that facilitate group action and action competence furnishes "a holistic educational framework in which young people can explore nature, integrate multiple capabilities, and think about care of the social, cultural, and natural environment" (Derr, 2017, p. 14).
Definition	EE opportunities generally designate educational programs sponsored by elementary and secondary schools, colleges and universities, youth camps, municipal recreation departments, local or international not-for-profit organizations, and private entrepreneurs.
Strengths and weaknesses	+ indicator of resources (capacity-building, psychosocial, etc.) that forge participation, pro-activeness and tenacity in the pursuit of environmentally responsible goals + oriented towards inclusiveness, high potential to further sense of belonging and trust within community, and to inculcate a community sense of pride, and efficacy -limited information on outcomes (environmental literacy, EL) - data on EE opportunities reflects enough potential for capacity-building, but the actual quality of EE curricula (e.g., local/cultural appropriateness), as well as the outcome (i.e., environmental literacy) can only be explored through studies aimed at evaluating EE programs (see Cole, 2007; Farmer et al., 2007; Kopnina, 2013; McBeth & Volk, 2010; Merenlender et al., 2016; Tidball & Krasny, 2010; Varela-Losada, et al., 2016)

Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: add-on items to any survey/questionnaire to collect accounts of EE programs attended in the past year, if any, as well as topic/theme covered; open-ended question(s) can be included to collect information about perceived usefulness, and/or how the knowledge/skills garnered have been put to use, if the case. o T: adapted items from "Instructor/Student/Parent Environmental Survey" (see Cruz Lasso de la Vega, 2004, p. 25  and Appendix) ☒ *Qualitative P*: ▪ *Qualitative methodologies can be used to explore the outcomes of EE opportunities experienced by community members in longitudinal research* o T: case study methodology – structured interviews, case study analysis, phenomenological analysis o T: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation
Scale of measurement	▪ *EE Opportunities - 4 items* to investigate accounts of EE programs attended in the past year, and their perceived usefulness (formulated for present study) 1. Have you participated in an EE program in the past year? Yes No (skip to ...) 2. What was the main theme of the EE program you attended? (*please indicate*) …………………………………………….. 3. How would you rate the applicability of the knowledge and skills acquired in the EE program? 1 very low …..5 very high 4. Have you had a chance to apply the knowledge and/or skills acquired since your participation in the EE program? If so, please describe. Yes (*please describe*) ……………………………………………….. No
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (long-term) and challenges

	✓ Desirable: evaluations of EE programs, especially of those designed to promote NBS
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods are opted for)
Data collection frequency	Aligned with NBS implementation and timing of targeted objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection (case study, for example) requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC6 Place attachment (Sense of Place): Place Identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC11.1 Positive environmental attitudes motivated by contact with NBS SC11.2 Environmental Identity SC12 Social desirability
Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods (e.g., phenomenological analysis) may be applied to collect community-relevant information on EE programs (and their outcomes) specifically related to a certain NBS/green space initiative in a community/city, and accounting for country/community/place-distinctive culture.
Additional information	
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15.2 Social learning regarding ecosystems and their functions/services

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Social learning concerning ecosystems and their functions and services	Knowledge and Social Capacity Building
Description and justification	Social learning has long been established as essential to policy change, and thus is essential to mainstreaming NBS. To monitor social learning, it is essential to examine how policies and processes have actually changed. Such changes can encompass adoption of new interventions, techniques, policy, and processes in response to past experience and new information (Hall, 1993). Semi-

	structured interviews, participant observation, and content analysis will all be used as part of baseline monitoring and throughout the project to understand how decision makers, policy makers and practitioners are incorporating new knowledge about NBS into their processes, discussions, and documents.
Definition	Using a mixed methods case study, we will be measuring social learning.
Strengths and weaknesses	- This KPI will require citizens' collaboration, so recovering the data could be difficult.
Measurement procedure and tool	In progress. This KPI will focus on a particular form of social learning known as policy learning. In both baseline and post-intervention monitoring, monitoring for this KPI will include structured content analysis on key policy documents relevant to the study area will be undertaken, using a range of techniques including word-frequency counting, key-word-in-context listings, concordances, classification of words into content categories, content category counts, and retrievals based on content categories and co-occurrences (Druckman 2005; Weber 1990). In addition, using purposive, non-probability sampling, baseline and post-intervention monitoring will includes interviews key individuals involved in making relevant policies and making decisions with respect to green infrastructure and NBS in the City of Liverpool, with data being collected until saturation (Minichiello et al. 2008). Sometimes these adjustments will require small, incremental changes, and sometimes they will require radical shifts in approach, and it may also require time for changes to be made on paper, so interviews will allow access to the most up-to-date thinking and information. To ensure consistency in data collection, an interview guide based on the key theoretical elements of policy learning (Suškevičs et al. 2017; Dovers and Hussey 2013) will be used to analyse baseline knowledge of NBS, examine current processes and implementation of policy, and identify adjustments to processes and policies. At the same time, participant observation will be used to analyse decision-making in real-time and evaluate how it evolves over the course of four years. Two levels of policy learning will be assessed: 10 how policy problems are constructed and how solving the problem should be approached (i.e., scope of policy and its goals), and 2) instrumental learning, where lessons about policy design

	and knowledge about when a particular policy instrument is appropriate or viable (May 1992). Data from all methods will be analysed using Nvivo, using a combination of deduction and induction, using a priori codes from theory (Creswell 2013), followed by a second level of analysis where emergent themes were identified from coding patterns in the data (Miles and Huberman 1994). A selection of interviews will also be blindly coded by another researcher to check intercoder reliability is at least 85%.
Scale of measurement	City / neighbourhood
Data source	
Required data	
Data input type	
Data collection frequency	
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG4 / SDG8 / **SDG10** / **SDG11**
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl

15.3 Pro-environmental identity

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Adina Dumitru[1], Catalina Young[2], Irina Macsinga[2]

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Environmental Identity	Knowledge and Social Capacity Building
Description and justification	Another concept that describes human-nature relationship and presents the promise of explaining/predicting pro-environmental behavior relevant to NBS is that of environmental identity (EID), understood as a dimension of social identity that resides in our ties to the natural world, like connections to pets, trees, mountain formations, or particular geographic locations which have commonly been studied under the construct of "place identity" (Clayton, 2003). In the overall analysis, environmental identity has been theoretically and methodologically invested with the potency to prompt and sustain ecological behavior both as a product of complex interactions between our self-concept and the natural world (i.e., self-relevant beliefs infused by contact with natural environment), and as a driving force behind personal, social, and political choices and actions (i.e., environmentally sustainable behavior) (Clayton, 2003; Balundė, Jovarauskaitė, & Poškus, 2019; Freed, 2015; Olivos & Aragonés, 2011). For instance, Dresner, Handelman, Steven Braun, and Rollwagen-Bollens (2014) surveyed and interviewed 172 adults participating in 18 urban volunteer events in area parks across Portland, Oregon between February and June 2012. Based on the annual frequency of participation in such events, the stewards were differentiated as first-time volunteers, mid-level volunteers (3-10 events/year), and frequent volunteers (>10 events/year). Environmental identity was reported as one of the main three factors that explained the variation in survey response across the board, alongside pro-environmental behavior and civic engagement. Environmental identity, pro-environmental behavior, and civic engagement were positively correlated with the frequency of volunteer participation in park area events, with frequent volunteers scoring the highest degree of attention to environmental issues, environmental identity, and self-reported pro-environmental behaviors (Dresner et al., 2014). Clayton (2003) devised a psychometric instrument for the measurement of EI (i.e., Environmental Identity Scale - EIS), and advanced research data in support of "the idea that environmental identity is a meaningful and measurable construct, with consequences for attitudes and behavior, and that by thinking about environmental identity we learn something beyond what we learn by talking about attitudes and values" (pp. 52-58). Balundė et al. (2019) carried out a meta-analysis to investigate the relationship between EI and other two constructs devised to represent the human-nature relations, namely "connectedness with nature" (Schultz, 2002) and "environmental self-identity" (van der Werff, Steg, & Keizer, 2013). Their results confirmed a strong correlation between measures of connectedness with

	nature and environmental identity (see also Olivos, Aragonés, & Amérigo, 2011) as well as environmental self-identity, indicative of the fact that, although theoretically discernible, they may be psychometrically undistinguishable, thus redundant (Balundė et al., 2019). Accordingly, we have included EIS (Clayton, 2003) as measurement of participants' relationship with nature, environment, and NBS, in view of its psychometric properties having been examined and confirmed cross-culturally (i.e., Spain) (Olivos & Aragonés, 2011). In line with research on environmental education and the evolution of environmental attitudes (see SC 10 and SC 11.1), Bremer (2014) argues that childhood experiences with nature are highly influential in shaping an environmental identity. Her qualitative analysis of interviews and surveys of six students and their parents indicate that caregivers have a significant role in environmental identity development. The authors concludes that the greatest influence upon environmental identity formation is accomplished when parents "are deeply involved in their child's life, engage in a positive relationship with the child, and guide their child's attention toward the environment while also allowing their child to make discoveries and develop independent moral reasoning" (Bremer, 2014, p. 64). Along similar lines, Prévot, Clayton, and Mathevet (2018) advocate for access and opportunities for children and young people to experience nature freely and bring forth data collected on 919 French students that support the contention that there is a strong positive correlation between childhood experiences with nature (i.e., rurality) and environmental identity. The authors show that this relation is mediated by adult behavior (i.e., visiting natural areas) which "promotes higher scores of environmental identity in a virtuous cycle: previous experiences predict both identity and current behavior, and identity and current behavior reinforce each other." (Prévot et al., 2014, p. 271-272).
Definition	. . . environmental identity is one part of the way in which people form their self-concept; a sense of connection to some parts of the nonhuman natural environment, based on history, emotional attachment, and/or similarity, that affects the way in which we perceive and act towards the world; a belief that the environment is important to us and an important part of who we are. (Clayton, 2003, pp. 45-46)
Strengths and weaknesse s	+indicator of resources (beliefs, motivation, affect, etc.) that create preconditions for environmentally responsible choices, decisions, or behaviors +better predictor of behavior than environmental attitudes (EA) (Clayton, 2003; Olivos & Aragonés, 2011), but not a solidly proven predictor of pro-environmental behavior – e.g., Freed (2015) sheds light on how environmental structures (i.e., recycling bins outside classrooms and around campus) can

	influence behaviors without changing a person's environmental identity -variability across cultures of constructs applied to the EI operationalization - as part of social identity, "understanding of oneself in a natural environment cannot be fully separated from the social meanings given to nature and to environmental issues, which will vary according to culture, world view, and religion" (Clayton, 2003, p. 53); EIS is based on North American understandings of the ways in which we value and interact with nature, and thus far cross-cultural validated only on Spanish population (Olivos & Aragonés, 2011)
Measurement procedure (P) and tool (T)	☒ *Quantitative P – self-report measures*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: *Environmental Identity Scale* (Clayton, 2003) made up of 24 items that measures the relationship between self and nature, inspired by identity theory. The structure of the scale was based in part on discussions of the factors that determine a collective social identity, and include the salience of the identity, the identification of oneself as a group member, agreement with an ideology associated with the group, and the positive emotions associated with the collective (Clayton, 2003, p. 52).
Scale of measurement	▪ EIS (Clayton, 2003) – 24 items *Please indicate the extent to which each of the following statements describes you by using the appropriate number from the scale below.* *1 - not at all true of me ...2...3...4 - neither true nor untrue...5...6...7 - completely true of me* *_____ 1. I spend a lot of time in natural settings (woods, mountains, desert, lakes, ocean).* *_____ 2. Engaging in environmental behaviors is important to me.* *_____ 3. I think of myself as a part of nature, not separate from it.* *_____ 4. If I had enough time or money, I would certainly devote some of it to working for environmental causes.* *_____ 5. When I am upset or stressed, I can feel better by spending some time outdoors "communing with nature".* *_____ 6. Living near wildlife is important to me; I would not want to live in a city all the time.* *_____ 7. I have a lot in common with environmentalists as a group.*

	_____ *8. I believe that some of today's social problems could be cured by returning to a more rural lifestyle in which people live in harmony with the land.* _____ *9. I feel that I have a lot in common with other species.* _____ *10. I like to garden.* _____ *11. Being a part of the ecosystem is an important part of who I am.* _____ *12. I feel that I have roots to a particular geographical location that had a significant impact on my development.* _____ *13. Behaving responsibly toward the earth -- living a sustainable lifestyle -- is part of my moral code.* _____ *14. Learning about the natural world should be an important part of every child's upbringing.* _____ *15. In general, being part of the natural world is an important part of my self-image.* _____ *16. I would rather live in a small room or house with a nice view than a bigger room or house with a view of other buildings.* _____ *17. I really enjoy camping and hiking outdoors.* _____ *18. Sometimes I feel like parts of nature -- certain trees, or storms, or mountains-- have a personality of their own.* _____ *19. I would feel that an important part of my life was missing if I was not able to get out and enjoy nature from time to time.* _____ *20. I take pride in the fact that I could survive outdoors on my own for a few days.* _____ *21. I have never seen a work of art that is as beautiful as a work of nature, like a sunset or a mountain range.* _____ *22. My own interests usually seem to coincide with the position advocated by environmentalists.* _____ *23. I feel that I receive spiritual sustenance from experiences with nature.* _____ *24. I keep mementos from the outdoors in my room, like shells or rocks or feathers.*
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges ✓ Desirable: Data on pro-environmental behaviour relevant to NBS
Data input type	Quantitative
Data collection frequency	Before/after NBS implementation, aligned with medium and long-term objectives.
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise

Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC6 Place attachment (Sense of Place): Place Identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC10 Environmental education opportunities SC11.1 Positive environmental attitudes motivated by contact with NBS SC14 Social desirability
Connection with SDGs	Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	-
Additional information	
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15.4 Pro-environmental behaviour

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Pro-environmental behaviour	**Knowledge and Social Capacity Building**
Description and justification	Pro-environmental behavior (PEB) represents another dimension of interest in the evaluation of NBS' impact and foreseeable sustainability. Narrowly defined as "behavior which has a significant impact on the environment" (Krajhanzl, 2010, p. 252), PEB has been central to both theoretical and empirical endeavors aimed at shedding light on the factors that foster accountability in relation with nature. Evidently, the behavior addressed in PEB can be encountered in various unintentional forms (e.g., purchase of soya products). Moreover, environmental theory employs a variety of terms to capture different nuances of the pro-environmental manifestation, like "ecological behavior" (Kaiser, 1998), "sustainable behavior" (Tapia-Fonllem, Coral-Verdugo, Fraijo-Sing, & Duron-Ramos, 2013), "environment-protective behavior", "environment-

preserving behavior", "environmentally responsible behavior" (Krajhanzl, 2010). For instance, Tapia-Fonllem et al. (2013) emphasize that "although sustainable behavior is, in practical terms, synonymous with pro-environmental behavior, the latter has been used to emphasize efforts to protect the natural environment, while the former specifies actions aimed at protecting *both* the natural and the human (social) environments" (p. 712).

Pro-environmental behavior has been investigated in relation with numerous other variables pertinent to NBS research, such as environmental stewardship (Dresner, Handelman, Steven Braun, & Rollwagen-Bollens, 2014; Whitburn, Milfont, & Linklater, 2018), place attachment (Ramkissoon, Weiler, & Smith, 2012; Takahashi & Selfa, 2015), connectedness to nature (Whitburn et al, 2018), environmental identity (Brick, Sherman, & Kim, 2017; Brick & Lai, 2018), or education (Kudryavtsev, Krasny, & Stedman, 2012; Meyer, 2015).

Whitburn et al. (2018) explored the relationship between pro-environmental behaviors and personal relationship with nature in a quasi-experimental research with 423 participants from 20 neighborhoods varying with respect to their vegetation. The authors measured past PEB as participants' active involvement in a tree-planting action and reported results that indicate a strong association between connectedness to nature and engagement in PEB. Moreover, participants' involvement in tree-planting and the level of neighborhood greenness explained 46% of the variance in PEB, where connectedness to nature, environmental attitudes, and use of nature for psychological restoration acted as mediators.

Dresner et al. (2014) surveyed and interviewed 172 adults participating in 18 urban volunteer events in area parks across Portland, Oregon between February and June 2012. Based on the annual frequency of participation in such events, the stewards were differentiated as first-time volunteers, mid-level volunteers (3-10 events/year), and frequent volunteers (>10 events/year). Pro-environmental behavior, environmental identity, and civic engagement were positively correlated with the frequency of volunteer participation in park area events, with frequent volunteers scoring the highest degree of attention to environmental issues, environmental identity, and self-reported pro-environmental behaviors (Dresner et al., 2014).

Brick et al. (2017) built on the significance of identity signalling (i.e., the visibility of our behaviour to others) and its

	role in shaping our social identity to propose that “the most important identity for expressing and signalling pro-environmental behavior is identifying with environmentalists” (p. 227) and showed that *environmentalist identity* predicts pro-environmental behavior more strongly for self-reported high-visibility behaviors than even political orientation. Brick and Lay (2018) replicated this finding and reported that explicit identity strongly and uniquely predicted pro-environmental behaviors and policy preferences.
Definition	Pro-environmental behavior is such behavior which is generally (or according to knowledge of environmental science) judged in the context of the considered society as a protective way of environmental behavior or a tribute to the healthy environment (Krajhanzl, 2010, p. 252). Larson, Stedman, Cooper, and Decker (2015, p. 113) summarized the theoretical evidence for PEB’s multidimensionality: • Some behaviors are inherently more difficult to carry out than others, and participation levels are influenced by a wide array of social and structural factors. • Participation in PEB is influenced by both hedonic, gain, and normative goals and intent. These drastically different motives not only result in different rates of behavioral expression; they may also affect the ways in which people perceive actions and their environmental impacts. • PEB varies substantially when it comes to type of impacts (e.g., direct vs. indirect), and scope of influence or specificity (e.g., local to global)
Strengths and weaknesses	+ indicator of participation, pro-activeness and tenacity in the pursuit of environmentally responsible goals -self-reported measures are susceptible to the effects of social desirability on respondents’ answers -complex, multidimensional construct, highly dependent on social and cultural variables making it difficult to effectively measure the full range of potential pro-environmental behaviors in a single study (Larson et al., 2015) -generalizable PEB measurement scales based on behaviors that transcend place/location may not capture the reality of implemented actions playing a role in local environmental quality (Larson et al., 2015); *Local land stewardship activities* (i.e., efforts to physically enhance local environments) may represent a particularly relevant component of PEB when “place” matters (Larson et al., 2015, p. 114).

<table>
<tr><td>Measurement procedure (P) and tool (T)</td><td>
☒ Quantitative P: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

T: Pro-environmental Behavior (Brick and Lay, 2018) – 6 items adapted from the Recurring Environmental Behavior Scale (Brick et al., 2017) measuring the self-reported frequency of PEB assessed on a 5-point Likert scale - 1 (never), 3 (sometimes), 5(always)
T: Recurring Environmental Behavior Scale (Brick et al., 2017) – 21 items measuring the self-reported frequency of PEB assessed on a 5-point Likert scale - 1 (never), 3 (sometimes), 5(always)
T: General Ecological Behaviour Scale (Kaiser, Wolfing, & Fuhrer, 1999) – established as a Rasch-scale that assesses behavior by considering the tendency to behave ecologically and the difficulties in carrying out the behaviors, which depend on influences beyond people’s actual behavior control; consists of 38 items representing different types of ecological behavior and some nonenvironmental, prosocial behaviors as well; a yes/no response format for these items is used. Negatively formulated items are reversed in coding.

☒ Qualitative P:

Qualitative methodologies can be used in mixed-methods research designs to explore the dimensions of PEB, as defined by community members (i.e., participant-driven approach, Larson et al., 2015)
T: case study methodology – structured interviews, case study analysis, phenomenological analysis
T: participatory data collections methods, such as collaborative participatory data collection,

</td></tr>
<tr><td>Scale of measurement</td><td>

Pro-environmental Behavior (Brick and Lay, 2018) – 6 items

1 (never), 3 (sometimes), 5(always)
1. When you visit the grocery store, how often do you use reusable bags?
2. How often do you conserve water when showering, cleaning clothes, washing dishes, watering plants, or during other activities?
3. How often do you discuss environmental topics, either in person or with online posts (Facebook, Twitter, etc.)?
</td></tr>
</table>

	4. When you buy clothing, how often is it from environmentally friendly brands? 5. How often do you engage in political action or activism related to protecting the environment? 6. How often do you educate yourself about the environment? ▪ *Recurring Environmental Behavior Scale* (Brick et al., 2017) – 21 items *1 (never), 3 (sometimes), 5(always)* 1. When you visit the grocery store, how often do you use reusable bags? 2. How often do you walk, bicycle, carpool, or take public transportation instead of driving a vehicle by yourself? 3. How often do you drive slower than 60mph on the highway? 4. How often do you go on personal (non-business) air travel? 5. How often do you compost your household food garbage? 6. How often do you eat meat? 7. How often do you eat dairy products such as milk, cheese, eggs, or yogurt? 8. How often do you eat organic food? 9. How often do you eat local food (produced within 100 miles)? 10. How often do you eat from a home vegetable garden (during the growing season)? 11. How often do you turn your personal electronics off or in low-power mode when not in use? 12. When you buy light bulbs, how often do you buy high efficiency compact fluorescent (CFL) or LED bulbs? 13. How often do you act to conserve water, when showering, cleaning clothes, dishes, watering plants, or other uses? 14. How often do you use aerosol products? 15. When you are in PUBLIC, how often do you sort trash into the recycling? 16. When you are in PRIVATE, how often do you sort trash into the recycling? 17. How often do you discuss environmental topics, either in person or with online posts (Facebook, Twitter, etc.)? 18. When you buy clothing, how often is it from environmentally friendly brands? 19. How often do you carry a reusable water bottle? 20. How often do you engage in political action or activism related to protecting the environment?

21. How often do you educate yourself about the environment?

- *General Ecological Behaviour Scale* (Kaiser, Wolfing, & Fuhrer, 1999) – 38 items

YES/NO

Prosocial behaviour items:

1. Sometimes I give change to panhandlers.
2. From time to time I contribute money to charity.
3. If an elderly or disabled person enters a crowded bus or subway, I offer him or her my seat.
4. If I were an employer I would consider hiring a person previously convicted of a crime.
5. In fast food restaurants, I usually leave the tray on the table.*
6. If a friend or relative had to stay in hospital for a week or two for minor surgery _e.g., appendix, broken leg., I would visit him or her.
7. Sometimes I ride public transportation without paying a fare.*
8. I would feel uncomfortable if Turks lived in the apartment next door.*

Ecological behaviour items:

1. I put dead batteries in the garbage.*
2. After meals, I dispose of leftovers in the toilet.*
3. I bring unused medicine back to the pharmacy.
4. I collect and recycle used paper.
5. I bring empty bottles to a recycling bin.
6. I prefer to shower rather than to take a bath.
7. In the winter, I keep the heat on so that I do not have to wear a sweater.*
8. I wait until I have a full load before doing my laundry.
9. In the winter, I leave the windows open for long periods of time to let in fresh air.*
10. I wash dirty clothes without prewashing.
11. I use fabric softener with my laundry.*
12. I use an oven-cleaning spray to clean my oven.*
13. If there are insects in my apartment I kill them with a chemical insecticide.*
14. I use a chemical air freshener in my bathroom.*
15. I use chemical toilet cleaners.*
16. I use a cleaner made especially for bathrooms rather than an all-purpose cleaner.*

	17. I use phosphate-free laundry detergent. 18. Sometimes I buy beverages in cans.* 19. In supermarkets, I usually buy fruits and vegetables from the open bins.* 20. If I am offered a plastic bag in a store I will always take it.* 21. For shopping, I prefer paper bags to plastic ones. 22. I usually buy milk in returnable bottles. 23. I often talk with friends about problems related to the environment. 24. I am a member of an environmental organization. 25. In the past, I have pointed out to someone his or her unecological behaviour. 26. I sometimes contribute financially to environmental organizations. 27. I do not know whether I may use leaded gas in my automobile.* 28. Usually I do not drive my automobile in the city. 29. I usually drive on freeways at speeds under 100 k.p.h. _62.5 m.p.h.. 30. When possible in nearby areas waround 30 km, _18.75 miles.x, I use public transportation or ride a bike. **** Negatively formulated items.***
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (long-term) and challenges ✓ Desirable: evaluations of *"local land stewardship activities" (Larson et al., 2015), i.e., conservation-oriented actions that improve the ecological features of the neighborhood/city (e.g., tree planting) – actions specific to each NBS*
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods are opted for)
Data collection frequency	Aligned with NBS implementation and timing of targeted objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection (case study, for example) requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	P1 Type of interaction with NBS

	P2 Frequency of interaction with NBS P3 Duration of interaction with NBS P4 Perceived Quality of Green Spaces HW 12 Restoration-Recreation: Enhanced physical activity and meaningful leisure SC6 Place attachment (Sense of Place): Place Identity SC10 Environmental Education Opportunities SC11.1 Positive environmental attitudes motivated by contact with NBS SC11.2 Environmental Identity
Connection with SDGs	Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 6. Ensure availability and sustainable management of water and sanitation for all Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 12. Ensure sustainable consumption and production patterns Goal 13. Take urgent action to combat climate change and its impacts Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods can be used in mixed-methods research designs to explore the dimensions of PEB, as defined by community members (i.e., participant-driven approach, Larson et al., 2015)
Additional information	
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Whitmarsh, L., & O'Neill, S. (2010). Green identity, green living? The role of pro-environmental self-identity in determining consistency

	across diverse pro-environmental behaviours. *Journal of environmental psychology*, *30*(3), 305-314. doi: 10.1016/j.jenvp.2010.01.003

16 Additional Indicators of Knowledge and Social Capacity Building for Sustainable Urban Transformation

16.1 Children involved in environmental educational activities

Project Name: CLEVER Cities (Grant Agreement no. 776604)

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Children involved in environmental educational activities		Knowledge and Social Capacity Building
Description and justification	According to social-ecological theory, personal, environmental and social factors influence children's behaviour. Behaviour change requires environments and policies that support healthful and ecological choices, strong social norms and social support for healthful and ecological choices as well as motivation and education of individuals to make those choices (Sallis et al. 2008). Sustainability education may include initiatives related to recycling, schoolyard habitat, rainwater harvesting and management, nutrition and health, waste reduction, etc. School learning gardens provide an opportunity to engage schoolchildren in practical tasks of food growing, which can stimulate children's curiosity and interest and deepen environmental participation (Williams and Brown 2012). Additionally, research shows that school gardening and active learning has positive impacts on academic achievements of schoolchildren (Wells et al. 2015).	
Definition	Children involved in environmental educational activities 1. Number of school hours spent on teaching about rainwater management and in preparing the information board 2. Number of pupils gaining an increased knowledge on plants, gardening, nature and sustainability due to a thematic inclusion in their curriculum, cumulated over project period (n) 3. Change in knowledge about natural cycles in pupils participating in aquaponic project in comparison to those who were not involved (better result in test in %).	
Strengths and weaknesses	+ Simple and easy to calculate + Provides a measure that can be easily followed	

	- Spillover effect is possible
Measurement procedure and tool	1. observing the integration of the topic in education, curriculum and interviews 2. observations, fieldwork: counting, photographing, checklist 3. counting and comparing: in regular intervals, the achievements in class tests are compared
Scale of measurement	School
Data source	
Required data	Number of school hours, number of pupils and school results, teachers impressions
Data input type	Quantitative and qualitative
Data collection frequency	1. once in pre-intervention phase, once during the implementation and then annually 2. once in the pre-intervention phase, after the intervention annually 3. once in the pre-intervention phase, after the intervention annually
Level of expertise required	Low – medium (interviews)
Synergies with other indicators	Proportion of school children involved in gardening
Connection with SDGs	SDG 3 Good health and well-being SDG 4 Quality education SDG 11 Sustainable cities and communities SDG 12 Responsible consumption and production SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through teachers reports
Additional information	
References	Sallis, J.; Owen, N. and Fischer, E. (2008) ‘Ecological models’, in: Glanz, K.; Rimer, BK., and Viswanath, K. editors. *Health Behaviour and Health Education. Theory, Research and Practice*. Fourth edition, San Francisco: Jossey-Bass, pp. 465-485. Wells, N.M., Myers, B.M., Todd, L.E. et al. (2015) The effects of school gardens on children’s science knowledge: a randomized controlled trial of low-income elementary schools. Int J Sci Educ., 37(17), pp.2858–2878

	Williams, D.R. and Brown, J. (2012) *Learning Gardens and Sustainability Education: Bringing Life to Schools and Schools to Life*, New York and London: Routledge

16.2 Engagement with NBS sites/projects

Project Name: URBAN GreenUP

Author/s and affiliations: María González[1], Esther San José[1], Raúl Sánchez[1], Jose Fermoso[1], Silvia Gómez[1], Jose María Sanz[1]

[1] *CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain*

Engagement with NBS (sites/projects)	**Knowledge and Social Capacity Building**
Description and justification	The importance and significance of public access to environmental information and participation in environmental decision-making are enshrined in the Aarhus Convention, adopted in 1998 in the Danish City of Århus (United Nations Economic Commission for Europe, 1998). In England the National Planning Policy Framework also emphasises the importance of community engagement to achieving well-design places and public involvement in planning and decision-making (Ministry of Housing, Communities and Local Government, 2018). Moreover, academic sources highlight the benefits for environmental management of understanding the relationships between the views of different stakeholders, including the public (Baur et al. 2016). The monitoring of engagement with NBS in Liverpool is therefore of vital importance.
Definition	Fundamental to the monitoring of this KPI is the ability to monitor engagement at multiple stages of development and delivery of NBS. This KPI will therefore be monitored across the various public engagement activities and periods of the project using multiple data collection methods.
Strengths and weaknesses	- This KPI will require citizens' collaboration, so recovering the data could be difficult.
Measurement procedure and tool	In progress. Participant observation and record keeping of engagement events and consultation activities will be conducted; this will include the collection of demographic information on the individuals and organisations involved for use as descriptive statistics during analysis. Participant observation allows for the collection of data in a naturalistic setting whereby the researcher observes and participates in the common and uncommon activities of the subject group (Musante and DeWalt, 2010) – in this case by attending, observing and participating in the public engagement activities.

	Content analysis of engagement materials will also be conducted. As with other KPIs where content analysis will be used, a range of techniques will be used including word-frequency counting, key-word-in-context listings, concordances, classification of words into content categories, content category counts, and retrievals based on content categories and co-occurrences (Druckman 2005; Weber 1990). To complement the above data collection methods and provide a richer source of data on how citizens and community groups engaged with NBS, qualitative semi-structured interviews will be conducted with targeted participants. Interviews can be used to attempt to understand the world from the subject's perspective, to understand their experiences and their interpretations of them (Kvale, 1996; Mann, 2016) and so can aid in the monitoring of this KPI to further our understanding of how citizens engaged, their motivations and their experiences of engagement in NBS. Purposive and non-probability sampling will be used to select interview participants. Interview participants will be selected based on organisation or participant 'type' to ensure a range of interviewees – for example, community organisation representatives, individual citizens and interest groups. As with other qualitative data collected, data for this KPI will be analysed using the qualitative data analysis tool, Nvivo. A combination of deductive and inductive coding will be employed, using a priori codes from theory (Creswell 2013), followed by a second level of analysis where emergent themes are identified from coding patterns in the data. As elsewhere, a second researcher will blindly code a selection of interviews to check intercoder reliability is at least 85%.
Scale of measurement	City / neighbourhood
Data source	
Required data	In progress.
Data input type	In progress.
Data collection frequency	In progress
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG4 / SDG8 / **SDG10** / **SDG11**

Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Baur, J.W.R., Tynon, J.F., Ries, P. & Rosenberger, R.S. (2016). Public attitudes about urban forest ecosystem services management: A case study in Oregon cities. Urban Forestry & Urban Greening, 17, 42-53. Creswell, J. W. 2013. Qualitative inquiry and research design: choosing among five approaches, Thousand Oaks, SAGE Publications. Druckman, D. 2005. Doing research. Methods of inquiry for conflict analysis. Thousand Oaks: Sage Publications. Kvale, S. (1996). Interviews: an introduction to qualitative research interviewing. London: Sage. Mann, S. (2016). The research interview: reflective practice and reflexivity in research processes, Houndmills, Basingstoke, Hampshire UK, Palgrave Macmillan. Ministry of Housing, Communities and Local Government, (2018). National Planning Policy Framework. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728643/Revised_NPPF_2018.pdf Musante, K. and DeWalt, B.R. (2010). Participant Observation: A Guide for Fieldworkers, Blue Ridge Summit, US: AltaMira Press. Weber, R. 1990. Basic Content Analysis. Thousand Oaks, USA: SAGE Publications.

16.3 Mindfulness

Project Name: proGIreg (Grant Agreement no. 776528)

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Mindfulness	**Place Regeneration** **Health and Wellbeing** **Knowledge and Social Capacity Building**
Description and justification	Mindfulness is a well-recognized indicator that correlates with several cognitive and affective outcomes (e.g., attention, awareness, happiness, distress). The empirical investigation showed that mindfulness is strongly related to connectedness to nature and pro-environmental behaviour.
Definition	Ability of being conscious or aware of something within the environment
Strengths and weaknesses	Strengths: Reliable measurement tool; easy to assess. Weaknesses: Potential biases in self-reported data
Measurement procedure and tool	This indicator is obtained using a validated scale named "Cognitive and Affective Mindfulness Scale-Revised" (CAMS-R – Feldman et al., 2007). Participants are required to complete the CAMS-R before and after the NBS implementation. The scale includes 12 items with a 4-point Likert scale, from "Rarely/Not at all" to "Almost always".
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions (baseline) and once after (follow-up)
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness and to the indicators on mental health and well-being
Connection with SDGs	• Good health and wellbeing • Reduced inequalities • Sustainable cities and communities • Peace, justice and strong institutions

Opportunities for participatory data collection	The questionnaires can be both self-reported and administrable in an interview method.
Additional information	
References	Feldman, Hayes, Kumar, Greeson, Laurenceau (2007). Mindfulness and emotion regulation: The development and initial validation of the Cognitive and Affective Mindfulness Scale-Revised (CAMS-R). Journal of psycho-pathology and Behavioral Assessment, 29, 177.

16.4 Proportion of schoolchildren involved in gardening

Project Name: CLEVER Cities (Grant Agreement no. 776604)

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Proportion of schoolchildren involved in gardening	**Knowledge and Social Capacity Building**
Description and justification	School learning gardens provide an opportunity to engage schoolchildren in practical tasks of food growing, which can stimulate children's curiosity and interest and deepen environmental participation (Williams and Brown 2012). Since school-aged children spend a significant amount of time at school, focus of many public health programmes was on developing opportunities for physical activity along with implementing environmental change in schools (e.g., Anthamatten et al. 2011). Besides improving playgrounds, many interventions included a development of school gardens, which proved to have positive effects on both vegetable intake (Somerset & Markwell 2008; Davis et al. 2016) and physical activity (Blair 2009) as well as on decrease in sedentary time (Rees-Punia 2017) contributing to better health of children involved in gardening activities (Ozer 2007). Besides its positive effects on healthy development, research shows that school gardening and active learning has positive impacts on academic achievements of schoolchildren (Ozer 2007; Wells et al. 2015).
Definition	1. Percentage of children involved in gardening activities at school: Number of pupils being in (practical) contact with the gardening project, cumulated over project period (n)

	(can be set into a ratio to the overall amount of pupils afterwards) 2. Frequency of use or work in the school garden (times/hours per [week or month]) (based on usual schedule and independently from that schedule, e.g., during summer holidays)
Strengths and weaknesses	+ Simple and easy to calculate + Provides a measure that can be easily followed
Measurement procedure and tool	1. observations, fieldwork: counting, photographing, checklist 2. observations, questionnaire: measuring the frequency of use
Scale of measurement	School
Data source	
Required data	Number of pupils, frequency of use (times/hours per [week or month])
Data input type	Quantitative
Data collection frequency	1. once in the pre-intervention phase, after the intervention annually 2. once in the pre-intervention phase
Level of expertise required	Low
Synergies with other indicators	Children involved in environmental educational activities
Connection with SDGs	SDG 3 Good health and well-being SDG 4 Quality education SDG 11 Sustainable cities and communities SDG 12 Responsible consumption and production SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through teachers reports on gardening activities
Additional information	
References	Anthamatten P, Brink L, Lampe S, Greenwood E, Kingston B, Nigg C. (2011). An assessment of schoolyard renovation strategies to encourage children's physical activity. Int J Behav Nutr Phys Act. 8(27)

	Blair D. (2009) 'The child in the garden: an evaluative review of the benefits of school gardening', J Environ Educ., 40(2), pp.15–38. Davis, J. N., Martinez, L. C., Spruijt-Metz, D., & Gatto, N. M. (2016) LA Sprouts: A 12-Week Gardening, Nutrition, and Cooking Randomized Control Trial Improves Determinants of Dietary Behaviors. Journal of nutrition education and behavior, 48(1), 2–11.e1. doi:10.1016/j.jneb.2015.08.009 Ozer, E.J.(2007) The effects of school gardens on students and schools: conceptualization and considerations for maximizing healthy development' Health Educ Behav. 34(6), pp.846–863. Rees-Punia, E., Holloway, A., Knauft, D., & Schmidt, M. D. (2017). Effects of School Gardening Lessons on Elementary School Children's Physical Activity and Sedentary Time, Journal of Physical Activity and Health, 14(12), pp.959-964 Somerset, S., & Markwell, K. (2009). Impact of a school-based food garden on attitudes and identification skills regarding vegetables and fruit: A 12-month intervention trial. Public Health Nutrition, 12(2), 214-221 Wells, N.M., Myers, B.M., Todd, L.E. et al. (2015) The effects of school gardens on children's science knowledge: a randomized controlled trial of low-income elementary schools. Int J Sci Educ., 37(17), pp.2858–2878 Williams, D.R. and Brown, J. (2012) Learning Gardens and Sustainability Education: Bringing Life to Schools and Schools to Life, New York and London: Routledge

16.5 Citizens' awareness regarding urban nature and ecosystem services

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Citizens' awareness regarding urban nature and ecosystem services	Knowledge and Social Capacity Building
Description and justification	The conservation, rehabilitation or restoration of ecosystems and ecological processes is a key strategy to maintain, enhance or recover the natural capital, or ecosystem services, provided by intact natural systems.

	Awareness of environmental issues is a critical first step in creating support for environmental projects and programs.
Definition	The extent to which a project has used opportunities to increase citizen's awareness of urban nature and ecosystem services, and educate urban citizens about sustainability and the environment
Strengths and weaknesses	+ Nature-based solution projects are uniquely placed to contribute to citizens' awareness regarding the multiple co-benefits of urban nature, and the connection between re-naturing cities and the provision of ecosystem services - May not provide the holistic evaluation
Measurement procedure and tool	The extent to which a project exploits opportunities to increase citizens' awareness of NBS and ecosystem services, or to more generally educate citizens about sustainability and the environment, can be evaluated using a five-point Likert scale (Bosch et al., 2017): **Not at all – 1 – 2 – 3 – 4 – 5 – Very much** 1. Not at all: opportunities to increase environmental awareness were not taken into account in the project communication 2. Poor: opportunities to increase environmental awareness were slightly taken into account in the project communication. 3. Somewhat: opportunities to increase environmental awareness were somewhat taken into account in the project communication, at key moments in the project there was attention for this issue. 4. Good: opportunities to increase environmental awareness were sufficiently taken into account in the project communication; the project utilized many possibilities to address this issue in their communications. 5. Excellent: opportunities to increase environmental awareness were taken into account in the project communication; the project utilized every possibility to address this issue in both online and offline communications.
Scale of measurement	Metropolitan scale (project based)
Data source	
Required data	Information on opportunities to increase citizens' awareness of NBS and ecosystem services or to more generally educate them about sustainability and the environment
Data input type	Qualitative

Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Relation to *Design for sense of place* indicator and *Green Space Management* indicator group
Connection with SDGs	SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	Participatory data collection is the core of this metric; Questionnaires
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

16.6 Green intelligence awareness

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Jose Fermoso[1], Silvia Gómez[1], María González[1], Esther San José[1], Raúl Sánchez[1]

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Green intelligence awareness	**Knowledge and Social Capacity Building**
Description and justification	Changes in behavior and human attitudes are fundamental to achieve a more sustainable world, so that, it is very interesting to analyze the potential of an activity or intervention to increase the green intelligence awareness of a population. There is enormous opportunity for nature based solutions to promote understanding of sustainability in ways that positively influence citizen behavior. There are many available resources to learn and understand the fragility of our environmental and the responsibility of humans to protect, preserve and respect the world. Therefore, this KPI aims to reflect how the intervention is used for educational purposes and enhancement of public awareness. The Green intelligence awareness is opened to all educational and social groups, no matter what is the level of education (Post-graduate, university, school, basic education).
Definition	The KPI "Green intelligence awareness" is calculated as the Quantify the number of activities, publications or campaigns focused on the enhancement of green intelligence awareness per year, related to a NBS.
Strengths and weaknesses	- This KPI will require citizens' collaboration, so recovering the data could be difficult.
Measurement procedure and tool	There are two different categories: Educational activities and Communication activities. 1) Educational activities: The educational activities considered have to be directly or indirectly related with the URBAN GreenUP project. In the "Directly" category there are actions of the themes and NBS of the project. There can be also considered educational actions "Indirectly" related with the URBAN GreenUP project: These are activities organized by other entities and stakeholders different from the URBAN GreenUP

Consortium, which are about the URBAN GreenUP general themes, such as climate change, green infrastructure, nature based solutions, sustainability, water management, resources efficiency, etc. The measurement of the KPI “Green intelligence awareness” by educational activities is expressed in the number of activities and number of recipient people (attendees):

a) Number of educational activities (nº activities/month). We differentiate among classes: courses, conferences/symposia, lectures, workshops, seminars, guided tours.
b) Number or people that attends to the educational activities (nº attendee/activity/class), for instance, number of people that attends to a Climate Change congress. This category could be characterized according to its characteristics: Educative level (University, school), average age, sector (architect, parks and gardens, industry, mobility, biomass).

There will be recorded a monthly record. There will be identified the NBS or related theme, such as climate change, Nature Based Solutions and others.

Table 1: Record table for KPI 127 “Green intelligence awareness” – Educational activities.

Date	Type	Activity name	NBS/ Theme	Location	Nature	Attendes	Education level
dd/mm/yyyy	Classify: Course, conference, lecture, workshop, seminar, guided tours	Name of the activity	NBS	Address, city	I = International N = National R = Regional U = Local (Valladolid)	Number of people that attend to the activity	Type of attendee (Professional, University, schools)

2) Communication activities.

This second group considers publications in different communication means such as written press (newspaper, magazines, articles, brouchers), television, radio and social media.

- Editorial actions:
  - Articles, texts, photographs or videos published in magazines, newspapers, books with technical and educational content.

- Distribution of brochures, leaflets.

- Communication actions:
  - Online social networks campaigns (YouTube, Twitter, Facebook, other) with technical and educational content.

Table 3: Record table for KPI “Green intelligence awareness” – Editorial.

Partner	Type of Publication	Title	Date	Type of audience
Consortium partner or stakeholder	Type of publication (Newsletter, Articles, Press release, Interview, REport, Scientific paper, Video)	Name of the editorial	dd/mm/yyyy	Scientific community, industry, policy makers, civil society, investors, etc.

Table 4: Record table for KPI “Green intelligence awareness” – Communication.

Partner	Communication media	Title	Date	NBS/Theme	Impact
Consortium partner or stakeholder	YouTube, Twitter, Facebook	Name of the action, campaign	dd/mm/yyyy	NBS in URBAN GreenUP (VAcX) or Related theme.	

The measurability of KPI is also expressed as the size of the audience that is exposed to the communication activity impact (number of retweets and likes in Twitter, number of likes and shares in Facebook, number of plays in YouTube, etc.)
It is important to consider that all educational activities must be developed in the municipality of Valladolid, or must be dedicated about Valladolid (for instance, a magazine from other Spanish region that talks about Valladolid interventions in the URBAN GreenUP project).

Scale of measurement	City / neighbourhood
Data source	

Required data	This KPI is expressed as the Sum of the educational activities per year, and sum of the publications with educational content per year (editorial). The register is recorded separately, because the concept and magnitude of each result are different.
Data input type	Data collected manually by the project personnel.
Data collection frequency	The KPI is calculated monthly. There will be calculated a total KPI annually, with will generate at least three indicators (numbers): Number of activities per year, Number or people that attends to the educational activities and Number of publications per year. The result could be expressed as ratios, for a similar period of time (month, year) $$Green\ intelligence\ awareness = \frac{\text{Number of educational activities (nª)}}{\text{Number of publications (nº)}}$$ For instance, 12a/6p means 12 activities and 6 publications per year related to a NBS in particular.
Level of expertise required	Technical / Basic
Synergies with other indicators	
Connection with SDGs	SDG4 / SDG8 / **SDG10** / **SDG11**
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl

	URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl "Educating for a Sustainable Future: a Transdisciplinary Vision for Concerted Action". UNESCO, November 1997.

16.7 Positive environmental attitudes motivated by contact with NBS

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Positive environmental attitudes motivated by contact with NBS	Knowledge and Social Capacity Building
Description and justification	Positive environmental attitudes (EA) make for a significant part of the environmental education (EE) process/environmental literacy (EL) continuum. EE programs are expected to engage individuals in exploration of environmental issues, critical thinking, problem solving, and decision making to improve the environment (Kudryavtsev, Krasny and Stedman, 2012; Kudryavtsev, Stedman, & Krasny, 2012). Accordingly, attitudes of concern for the environment and motivation to improve or maintain environmental quality (U.S. EPA, n.d.) have been invested as an indicator of a finely tuned and efficient intervention through such transformative programs. Moreover, a number of studies have provided empirical support to the idea that exposure to nature is positively associated with constructive attitudes towards the environment (Baur, Tynon, Ries, & Rosenberger, 2014; Byrka, Hartig, & Kaiser, 2010; Tarrant & Green, 1999; Whitburn, Linklater, & Milfont, 2019; Williams, Jones, Gibbons, & Clubbe, 2015). In a quasi-experimental study with 423 urban residents in 20 neighborhoods in Wellington City, New Zealand, Whitburn et al. (2019) identified environmental attitudes as mediator of the relationship between exposure to nature/engagement with nature and pro-environmental behaviors. Baur et al. (2014) employed a general population survey of urban residents of four cities in Oregon (734 completed surveys returned), USA and found that increased visitation to urban parks, forest reserves or other urban and urban-proximate green spaces is strongly associated with greater public understanding and support for urban natural resource management. Along similar lines, Williams et al. (2015) interviewed 1054 visitors at five UK botanic gardens and found that environmental attitudes are more positive among respondents leaving a botanic garden, than among those about to enter one. In a systematic review of the existing literature on the benefits of children's engagement with nature, Gill (2015) finds support for the assertion that time spent in nature promotes positive

	environmental attitudes and values. The studies reviewed present solid evidence that "spending time in natural environments as child is associated with adult pro-environment attitudes and feelings of being connected with the natural world and is also associated with a stronger sense of place" (p. 18). Additionally, Soga et al. (2016) surveyed 397 Tokyo elementary schoolchildren and found that children's affective attitudes and willingness to conserve biodiversity were positively associated not only with the frequency of direct experiences of nature, but also with the frequency of vicarious manifestations of experience with nature (like reading books/watching TV about wildlife and nature, or talking with parents/friends about wildlife and nature). Schultz, Shriver, Tabanico, & Khazian (2004) defined EA as "the collection of beliefs, affect, and behavioral intentions a person holds regarding environmentally related activities or issues". The intricate nature of the construct as latent (i.e., cannot be observed directly) and multidimensional (i.e., values rooted in a concern for the self - egoistic, for other people – altruistic, or for the biosphere) has been a fertile ground for numerous studies attempting at consolidating the relevance of predicted connection between general environmental concern and ecological behavior (Bamberg, 2003; Bamberg & Rees, 2015; Milfont & Duckitt, 2006; Milfont, Duckitt, & Cameron, 2006; Milfont & Duckitt, 2010). Milfont and Duckitt (2006, 2010) have approached the challenge by departing from the traditional three-component model of attitude structure (i.e., cognitive, affective, and behavioral) to integrate the function of *evaluative tendencies* (i.e., values) which can both be inferred from and have an influence on beliefs, affects, and behaviors regarding human-environment relations. Subsequently, authors developed a multidimensional inventory to assess EA cross-culturally. Environmental Attitudes Inventory (EAI) is a collection of twelve specific scales that capture the main facets measured by previous research (Milfont & Duckitt, 2010). The twelve scales have shown high internal consistency, homogeneity, high test-retest reliability, and have also proven to be largely free from social desirability (Milfont, 2009; Milfont & Duckitt, 2010). Furthermore, their psychometric qualities have been supported in cross-cultural studies (Milfont, Duckitt, & Wagner, 2010). These attributes render authors' conceptual model empirically robust, thus relevant to our research objectives.
Definition	"Psychological tendency that is expressed by evaluating perceptions of or beliefs regarding the natural environment,

	including factors affecting its quality, with some degree of favor [...]" (Milfont, 2007 as quoted in Milfont, 2009). *See section "Measurement Procedure and Tool" below for construct definition of EAI Scales (i.e., constructs measured by previous research).*
Strengths and weaknesses	+indicator of resources (awareness, values, etc.) that create preconditions for environmentally responsible behaviors +indicator of successful impact of environmental education initiatives (longitudinal studies) -low relevance as predictors of actual behaviors; general agreement to treat them as general decisional preconditions for considering the potential environmental impact of decisions (Bamberg & Rees, 2015) -impact vs. intent – approach and risk for methodological bias: intent-oriented measures tend to neglect behavior patterns with a strong objective environmental impact (e.g., reducing CO_2 emissions) by omitting relevant structural/contextual factors (e.g., income, type of car, size of house) in favor of psychological variables like values or attitudes (Bamberg & Rees, 2015)
Measurement procedure (P) and tool (T)	☒ *Quantitative P – self-report measures*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: *Environmental Attitudes Inventory* (EAI – Milfont & Duckitt, 2010) assesses broad evaluating perceptions of or beliefs regarding the natural environment, including factors affecting its quality; EAI 24, the brief 24 items version of the instrument is included here; authors recommend use of a shortened Social Desirability Scale with the brief EAI. **Construct definition of EAI scales** (Milfont & Duckitt, 2010): Scale 1. Enjoyment of nature: Belief that enjoying time in nature is pleasant and preferred to spending time in urban areas, versus belief that enjoying time in nature is dull, boring and not enjoyable, and not preferred over spending time in urban areas. Scale 2. Support for interventionist conservation policies: Support for conservation policies regulating industry and the use of raw materials, and subsidising and supporting alternative ecofriendly energy sources and practices, versus opposition to such measures and policies.

	Scale 3. Environmental movement activism: Personal readiness to actively support or get involved in organized action for environmental protection, versus disinterest in or refusal to support or get involved in organized action for environmental protection. Scale 4. Conservation motivated by anthropocentric concern: Support for conservation policies and protection of the environment motivated by anthropocentric concern for human welfare and gratification, versus support for such policies motivated by concern for nature and the environment as having value in themselves. Scale 5. Confidence in science and technology: Belief that human ingenuity, especially science and technology, can and will solve all environmental current problems and avert or repair future damage or harm to the environment, versus belief that human ingenuity, especially science and technology, cannot solve all environmental problems. Scale 6. Environmental fragility: Belief that the environment is fragile and easily damaged by human activity, and that serious damage from human activity is occurring and could soon have catastrophic consequences for both nature and humans, versus belief that nature and the environment are robust and not easily damaged in any irreparable manner, and that no damage from human activity that is serious or irreparable is occurring or is likely. Scale 7. Altering nature: Belief that humans should and do have the right to change or alter nature and remake the environment as they wish to satisfy human goals and objectives, versus belief that nature and the natural environment should be preserved in its original and pristine state and should not be altered in any way by human activity or intervention. Scale 8. Personal conservation behaviour: Taking care to conserve resources and protect the environment in personal everyday behaviour, versus lack of interest in or desire to take care of resources and conserve in one's everyday behaviour. Scale 9. Human dominance over nature: Belief that nature exists primarily for human use, versus belief that humans and nature have the same rights.

	Scale 10. Human utilization of nature: Belief that economic growth and development should have priority rather than environmental protection, versus belief that environmental protection should have priority rather than economic growth and development. Scale 11. Ecocentric concern: A nostalgic concern and sense of emotional loss over environmental damage and loss, versus absence of any concern or regret over environmental damage. Scale 12. Support for population growth policies: Support for policies regulating the population growth and concern about overpopulation, versus lack of any support for such policies and concern. ☒ *Implicit measuring techniques that counterbalance limitations of self-report measures*: o T: case study methodology – interviews, unobtrusive observation o T: priming and response competition measures (Van Vugt & Samuelson, 1999)
Scale of measurement	▪ EAI 24 (Milfont & Duckitt, 2010) – 24 items *Please indicate the extent to which each of the following statements describes your beliefs by using the appropriate number from the scale below.* *1 - strongly disagree ...2...3...4 - neither agree nor agree...5...6...7 - strongly agree* *___1. I really like going on trips into the countryside, for example to forests or fields. [SCALE 01 - Enjoyment of nature]* *___2. I think spending time in nature is boring. (R) [SCALE 01 - Enjoyment of nature]* *___3. Governments should control the rate at which raw materials are used to ensure that they last as long as possible. [SCALE 02 - Support for interventionist conservation policies]* *___4. I am opposed to governments controlling and regulating the way raw materials are used in order to try and make them last longer. (R) [SCALE 02 - Support for interventionist conservation policies]* *___5. I would like to join and actively participate in an environmentalist group. [SCALE 03 - Environmental movement activism]*

	___6 would NOT get involved in an environmentalist organization. (R) [SCALE 03 - Environmental movement activism] *___7. One of the most important reasons to keep lakes and rivers clean+H17 is so that people have a place to enjoy water sports. [SCALE 04- Conservation motivated by anthropocentric concern]* *___8. We need to keep rivers and lakes clean in order to protect the environment, and NOT as places for people to enjoy water sports. (R) [SCALE 04- Conservation motivated by anthropocentric concern]* *___9. Modern science will NOT be able to solve our environmental problems. (R) [SCALE 05 - Confidence in science and technology]* *___10. Modern science will solve our environmental problems. [SCALE 05 - Confidence in science and technology]* *___11. Humans are severely abusing the environment. [SCALE 06 - Environmental threat]* *___12. I do not believe that the environment has been severely abused by humans. (R) [SCALE 06 - Environmental threat]* *___13. I'd prefer a garden that is wild and natural to a well groomed and ordered one. (R) [SCALE 07 - Altering nature]* *___14. I'd much prefer a garden that is well groomed and ordered to a wild and natural one. [SCALE 07 - Altering nature]* *___15. I am NOT the kind of person who makes efforts to conserve natural resources. (R) [SCALE 08 - Personal conservation behavior]* *___16. Whenever possible, I try to save natural resources. [SCALE 08 - Personal conservation behavior]* *___17. Human beings were created or evolved to dominate the rest of nature. [SCALE 09 - Human dominance over nature]* *___18. I DO NOT believe humans were created or evolved to dominate the rest of nature.(R) [SCALE 09 - Human dominance over nature]* *___19. Protecting peoples' jobs is more important than protecting the environment. [SCALE 10 - Human utilization of nature]* *___20. Protecting the environment is more important than protecting peoples' jobs. (R) [SCALE 10 - Human utilization of nature]* *___21. It makes me sad to see forests cleared for agriculture. [SCALE 11 - Ecocentric concern]* *___22. It does NOT make me sad to see natural environments destroyed. (R) [SCALE 11 - Ecocentric concern]*

	___23. Families should be encouraged to limit themselves to two children or less. [SCALE 12 - Support for population growth policies] *___24. A married couple should have as many children as they wish, as long as they can adequately provide for them. (R) [SCALE 12 - Support for population growth policies]*
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges ✓ Desirable: Data on environmental education programs which mediated contact with NBS, longitudinal evaluations of impact of programs (environmental literacy)
Data input type	Quantitative (quantitative and qualitative, if case study methodology is opted for)
Data collection frequency	After NBS implementation, longitudinally, over years, aligned with long-term objectives.
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection through case study methodology requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC6 Place attachment (Sense of Place): Place Identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC10 Environmental education opportunities SC11.2 Environmental Identity SC14 Social desirability
Connection with SDGs	Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts

	Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	-
Additional information	
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16.8 Urban farming educational and/or participatory activities

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Urban Farming Educative/ participate activities, Learning for producers	Knowledge and Social Capacity Building
Description and justification	Especially farmers living in the urban and peri-urban will be informed about climate change and its increasing affects, periodically. First of all, leading farmers living in the urban periphery (Çiğli and Menemen districts), agricultural cooperatives and students will be determined and training seminars will be organized. Secondly, the visitors of the Sasalı Natural Life Park where the Demo Site area is also located will also benefit from these seminars. Visitors to the natural life park (around 1.500.000) area will be able to visit climate sensitive greenhouse and its garden. All visitors will be counted for measuring. After each training seminar, the participants will complete detailed questionnaires and the success of the training will be measured. The results of the specially prepared questionnaires will be analyzed using statistical methods. Likewise, after analysing the questionnaires, the results will be shared by using ICT platforms.
Definition	In progress
Strengths and weaknesses	- This KPI will require citizens' collaboration, so recovering the data could be difficult.
Measurement procedure and tool	

Scale of measurement	City / neighbourhood
Data source	
Required data	In progress.
Data input type	In progress.
Data collection frequency	In progress
Level of expertise required	Technical / Basic
Synergies with other indicators	
Connection with SDGs	SDG4 / SDG8 / **SDG10** / **SDG11**
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl

PARTICIPATORY PLANNING AND GOVERNANCE

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17 RECOMMENDED INDICATORS OF PARTICIPATORY PLANNING AND GOVERNANCE

17.1 Openness of participatory processes

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Openness of participatory processes	**Participatory Planning and Governance**
Description and justification	Nature-Based Solutions require planning approaches and governance architectures that support accessibility to green spaces, while maintaining their quality for the provision of ecosystem services. Urban environmental problems are often difficult to handle and successful solutions require combined efforts of different scientific disciplines but also an active dialogue between stakeholders from policy and society (Lemos and Morehouse, 2005). In this context, transdisciplinary approaches for knowledge co-production provide insights about the ways and the rationale for engaging with multiple knowledge holders: experts and scientists as well as citizens and practitioners (Bergmann et al., 2012, Jahn et al., 2012). The scientific frameworks of

	urban ecosystem services were brought into the interface between policy and science to inform urban planning and governance (Frantzeskaki and Tilie, 2014). The quality of the URBAN GreenUP project implementation depends on social learning and adequate technical solutions. This is possible through the support and cooperation between the involved parties and the resulting input of knowledge (Luyet, 2012).
Definition	For this KPI definition "participation" is defined as "a process through which stakeholders influence and share control over development initiatives and the decision and resources which affect them" (World Bank definition, 1996). The stakeholder participation includes other stakeholders not mentioned in the other categories, such as civil society (individuals or organized society) and scientific community (the academia).
Strengths and weaknesses	Municipality data from different departments are needed
Measurement procedure and tool	Participation is often reduced to the dissemination of information and the holding of workshops. These approaches generally do not take into account either the heterogeneity of stakeholders, or the complexity of the decision making process (Luyet, 2012). The KPI "Openness of participatory processes" is based on the participation actions delivered in the city of Valladolid. There are defined two steps, data collection and data evaluation. ➢ <u>Step 1. Data collection and characterization.</u> The data collection about the participatory processes would have the following items: *Participation techniques*: Reports, Presentations, public hearings, Internet webpage, Interviews, questionnaires and surveys, Field visit and interactions, Workshop, Participatory mapping, Focus group, Citizen jury, Geospatial/ decision support system, Cognitive map, Role playing, Multicriteria analysis, Scenario analysis, Consensus conference. *Degrees of participation*: The participation action is classified into the following types. - Information: explanation of the project to the stakeholders. - Consultation: presentation of the project to stakeholders, collection of their suggestions, and then decision making with or without taking into account stakeholders input.

- Collaboration: presentation of the project to stakeholders, collection of their suggestions, and then decision making, taking into account stakeholders input.
- Co-decision: cooperation with stakeholders towards an agreement for solution and implementation.
- Empowerment: delegation of decision-making over project development and implementation to the stakeholders.

Co-creation & Co-production agent: There are identified the following stakeholders groups:

- Policy makers: The Valladolid City Council Departments, and other local entities.
- Experts: Scientific community and consultants, professionals, technicians.
- Community representatives: Economic agents. Civil society such as civil associations and local communities.

Table 1: Data collection record table for KPI CH0701 “Openness to participatory processes”.

		Openness to participatory processes			
Date	Communication model	Participation technique	Degree of participation	Co-creation & Co-production agent	Participation action
dd/mm/yyyy	Classify: In-person meeting. Video conference / Online meeting. Audio conference / Call.	Classify: Reports, Interviews, questionnaires, Workshop, others.	Classify: Information, Consultation, Collaboration, Co-decission, Empowerment	Policy maker, Scientific community, Civil society, Economic sector, Other stakeholder	Name of the participation action and short description

The following activities might be included to calculate this KPI: Single Desk actions, open days such as Mobility week or the

Day of the Earth, conferences about Smart city, environmental awareness, etc.

➢ Step 2. Evaluation of participatory processes.

How do we evaluate the stakeholder participation? There are defined two techniques, quantitative and qualitative.

Quantitative evaluation: The “Openness of participatory processes” indicator is expressed through quantitative techniques such as (nº processes/year/participation technique/stakeholder) and population reached (number of attendees/agent type)

Quantitative-Qualitative evaluation: There is also calculated a Global Indicator by a mix qualitative and quantitative technique. There will be assigned a final score from 1 to 5, depending on the following criteria (see next table for scoring criteria):

- The quality of the process (conflict resolution, early involvement, transparency, equity, influence, stakeholder representativeness, integration of all interests and definition of rules).
- The outcomes (capacity building, emergent knowledge, impacts and social learning)
- The political, social, cultural, historical and environmental context.

The qualitative score evaluates from 1-5 points, where 1-Low quality and 5-High quality.

Table 2. Qualitative scoring for indicator “Openness of participatory processes”

Criteria	Type of criteria	Scoring (points)
Scope	Quantitative	International, National, Regional = 1 point. Local = 0 points.
Communication model	Quantitative	In-person meeting = 1 point. Video conference/Online meeting/Audio conference/Call = 0,5 points. Email = 0 points.
Participation technique	Qualitative	From 0-1 depending on the quality and different types of participation techniques
Degree of participation	Quantitative	Information, Consultation = 0 points. Collaboration = 0,5 points. Co-decision, Empowerment = 1 point.

Attendees type	Quantitative	For >1 type = 1 point. Only 1 type = 0 points.

Table 3: Evaluation record table for indicator “Openness to participatory processes”.

		Evaluation of participatory processes	
Date	Participation action	Number of attendees	Qualitative score
dd/mm /yyyy	Name of the participation action and short description	Number of people that attend to the activity, for every stakeholder type (political, academia, citizens, etc.)	From 1-5 where 1- Low quality and 5- high quality.

Scale of measurement	City / neighbourhood
Data source	
Required data	Data are usually collected from the municipality participatory actions annually.
Data input type	▪ Participatory actions with the scientific community per year (#/month, #/year, n º attendees). This includes scientists, university students and scholars. ▪ Participatory actions with Other stakeholders (individuals and organized citizenship such as civic center’s board and neighbourhoods’ associations, as well as Local entities) per year (#/month, #/year, n º attendees). ▪ Participatory actions with economic agents per year. Economic agents involved such as technicians, specialists, consultants, enterprises, companies and others (#/month, #/year, nº attendees). ▪ Participatory Budgets: Number of NBS projects requested by the citizens per year. There will be identifies the NBS type.
Data collection frequency	Data are collected monthly. A global indicator is calculated annually. There will be included a statistic analysis of the participatory processes delivered.
Level of expertise required	Technical / Expert

Synergies with other indicators	
Connection with SDGs	SDG4 / SDG8 / **SDG10** / **SDG11**
Opportunities for participatory data collection	None identified.
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl Bhatnagar, Bhuvan; Williams, Aubrey C. [editors]; Bhatnagar, Bhuvan*Williams, Aubrey C. [editors]. 1992. Participatory development and the World Bank : potential directions for change (English). World Bank discussion papers ; no. WDP 183. Washington, DC : The World Bank. http://documents.worldbank.org/curated/en/789811468765616541/Participatory-development-and-the-World-Bank-potential-directions-for-change Luyet V1, Schlaepfer R, Parlange MB, Buttler A. (2012). A framework to implement Stakeholder participation in environmental projects. International Journal of Environmental Research and Public Health. Frantzeskaki, Niki & Kabisch, Nadja & McPhearson, Timon. (2016). Advancing urban environmental governance: Understanding theories, practices and processes shaping urban sustainability and resilience. Environmental Science & Policy. 62. 10.1016/j.envsci.2016.05.008.

17.1.1 Openness of participatory processes: proportion of citizens involved

Project Name: UNaLab (Grant Agreement no. 730052)

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Openness of participatory processes: proportion of citizens involved	**Participatory Planning and Governance**
Description and justification	Public participation in NBS projects encompasses a wide range of different opportunities for citizens, nongovernmental organizations, businesses, and other stakeholders co-create, co-implement and co-manage NBS, concomitantly creating a sense of ownership. The integral role of citizens and other stakeholders in NBS projects can influence the openness of other processes managed by the municipality. Increasing the openness of processes such as policy planning and implementation strengthens the connections between government agencies and the public they serve.
Definition	The proportion of public participation processes in a given municipality per 100 000 residents per year (expressed as %)
Strengths and weaknesses	+ Provides an indication of the alignment between citizens' need and desires and the decision-making processes in a municipality - - Does not provide information regarding the quality of participation processes
Measurement procedure and tool	Openness of participatory processes (%) is calculated as (Bosch et al., 2017): $\left(\frac{Total\ number\ of\ open\ public\ participation\ processes}{Population\ of\ city/100000}\right) \times 100$
Scale of measurement	District to municipality scale (project-based)
Data source	
Required data	Total number of open public participation processes, city population
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation

Level of expertise required	Low
Synergies with other indicators	Relation to *Design for sense of place* and *Participatory governance* indicators
Connection with SDGs	SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	
Additional information	
References	

17.2 Sense of empowerment: perceived control and influence over decision-making

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Perceived control and influence over NBS decision-making	**Participatory Planning and Governance**
Description and justification	Although generally recognized as a concept that bespeaks having, or taking, control over resources and decision-making processes that can affect one's quality of life (Carr, 2016), empowerment remains fairly ambiguous and debatable due to poor definitional clarity, followed by difficulties in measurement (Cross, Woodall, & Warwick-Booth, 2017). One of the most enduring problem arising from definitional diversity and differential understandings is the widespread use of a reductionist approach to its measurement (i.e., centered around individual/psychological empowerment) despite across-the-board acknowledgment that it can occur at different levels (individual, group, community or society) (Cross et al., 2017). Pratley (2016) emphasizes the five conceptual dimensions of empowerment commonly found throughout the literature (i.e., psychological, social, economic, legal, political), and states that the 'major challenges include complexity in measuring progress in several dimensions, and the situational, context dependent nature of the empowerment process' (p. 119). The fact that empowerment is a moving target (i.e., distinction between empowering processes and empowering outcomes, and

appreciation of the intricate interplay of their dynamics), and that its assessment is value-driven (i.e., culturally and ideologically molded) have added to measurement of empowerment often falling short of the range of expectations (Jupp, Ali, & Barahona, 2010).

In his delineation of a nomological network of empowerment at the individual level of analysis (i.e., psychological empowerment, PE), Zimmerman (1990) argues that 'PE may be an open-ended construct that is not easily reduced to a universal set of operational rules and definitions' (p. 583), and concedes that measures developed for one study may not be appropriate for another. One key component of empowerment targeted by NBS research is the participatory processes engaged in by individuals as they work to improve their quality of life (Cumbers, Shaw, Crossan & McMaster, 2018; Feldman & Westphal, 2000; Fernandez & Burch, 2003; Jennings & Bamkole, 2019; Westphal, 2003). Consequently, the theoretical work on empowerment from a psychological/individual perspective (Zimmerman, 1990a, 1990b, 1995; Zimmerman, Israel, Schulz, & Checkoway, 1992) has been valued for its insights into the active participation of individuals and groups in altering and shaping the socio-environmental context (Speer, Jackson, & Peterson, 2001).

Feldman and Westphal (2000) affirm the value of citizens' participation in environmental decision making and stress the importance of careful consideration of the *process* of participation through all the stages of an urban greening project in order to harness the individual and collective empowering potential of participatory practices. Drawing on case study, the authors illustrate how an open space revitalization project in a public housing development in Chicago contributed to empowerment by ultimately producing a useful and satisfying space, attracting other professional knowledge, and garnering economic resources.

Westphal (2003) brings forth more insight into the imperative of careful consideration of unique factors at play in the *process* of participatory planning and design on a case by case basis. The author designed a qualitative research founded on empowerment theory (Zimmerman, 1995) and collected data on indicators of empowerment like efficacy, mastery, control, new resources, participation, increased skills, proactive behavior, critical awareness, sense of competence, shared leadership, etc., from 4 sites involved in landscaping projects, approximately 2 years after their implementation. Two of the sites had been initially thought to greatly benefit from the greening project, while other two had not been foreseen as socially benefitting from it. The comparative analysis illustrates how "empowerment outcomes from urban and community forestry projects are possible but far from a given" (p.

	144), and how what might initially look as a success can end in utter failure, bringing empirical evidence to the notion that empowerment is “a possible, but not automatic” social benefit of urban and community NBS, and outlining recommendations for before, during, and after the project to guide the effective involvement of individuals and communities in urban forestry. Cumbers et al. (2018) carried out a qualitative research between February and July 2014 in 16 gardens across Glasgow and built on Massye’s (1991) notion of an active sense of place to find empirical support for the role of community gardening in advancing community empowerment by facilitating “the recovery of individual agency, construction of new forms of knowledge and participation, and renewal of reflexive and proactive communities that provide broader lessons for building more progressive forms of work in cities” (p. 133). Notably, Calvet-Mir and March (2019) analyse the meanings and politics of urban gardening in post-economic crisis Barcelona, and report data that support the assertion that urban gardens have proven successful as a source of collective empowerment promoting emancipatory and alternatives views about the right of citizen to the city and challenging speculative urban development.
Definition	PE is a process by which individuals gain mastery and control over their lives, and a critical understanding of their environment; it operates through intrapersonal, interactional, and behavioral components (Zimmerman et al., 1992; Zimmerman, 1995): - *The intrapersonal component (self-perception)* refers to how people think about their capacity to influence social and political systems important to them (i.e., domain-specific perceived control, domain-specific self-efficacy, motivation to exert control, perceived competence) - *The interactional component (information, knowledge, decision process)* refers to the transactions between persons and environments that enable one to successfully master social or political systems (i.e., knowledge about the resources needed to achieve goals, understanding causal agents, a critical awareness of one's environment, and the development of decision-making and problem-solving skills necessary to actively engage one's environment) - *The behavioral component (participation)* refers to the specific actions one takes to exercise influence on the social and political environment through participation in community organizations and activities (i.e., participation in community organizations such as neighborhood associations, political groups, and participation in community-related activities, like contacting public officials or organizing a neighborhood issue).

Strengths and weaknesses	+ reliable indicator of resources (psychosocial, etc.) that ground individual/group self-efficacy, self-esteem, and confidence, as well as sustain participation, pro-activeness and tenacity in the pursuit of goals that ultimately lead to socio-environmental change + oriented towards inclusiveness, high potential to further sense of belonging and trust within community, and to inculcate a community sense of pride -complex concept and ambiguous definitions, followed by considerable limitations in psychometric quality of measurement -individual (psychological) empowerment by itself does little to influence change in the political and social context in which people live (Woodall, Warwick-Booth, & Cross, 2012); research design and measurement has to depart from an understanding of the culture in which studies are carried out, and account for the economic, political, legal, and social dimensions (at least at the level of community members' understanding of their sociopolitical environment) in order to lend credence to data collected by quantitative measures of PE
Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: 3 items at measuring respondents' perception of their ability to make decisions that affect everyday activities and may change the course of their life from the *"Empowerment and Political Action" module* of Social Capital-Integrated Questionnaire (SC-IQ) (Grootaert et al., 2004) ☒ ***Qualitative*** *P*: o T: case study methodology – semistructured interviews, case study analysis, participant and non-participant observation (Calvet-Mir & March, 2019; Cumbers et al., 2018; Fernandez & Burch, 2003; Nikolaïdou, Klöti, Tappert, & Drilling, 2016) o T: participatory data collections methods, such as Community-based Participatory Research (Bateman et al., 2017), Stakeholder Analysis participatory or non-participatory methods (e.g., focus groups, Social Network Analysis, Q methodology, Knowledge Mapping, Interest-Influence Matrices, Actor-Linkage Matrices) (Reed, 2008; Reed, Graves, Dandy, Posthumus, Hubacek, Morris, Prell, Quinn & Stringer, 2009); collaborative participatory data collection - narrative study (communal narratives and personal stories) (Rappaport, 1995), photoelicitation and semistructured interview techniques (Westphal, 2003); participatory action research (PAR) to follow empowering processes in a community (Zimmerman, 1995); historical analysis of the process of creating

	just or unjust environmental conditions (Schönach, 2014); ethnographic accounts of justice (Checker, 2011, as quoted in Raymond et al., 2017); public participatory GIS to assess experiential qualities (Laatikainen et al., 2015; Raymond et al., 2016)
Scale of measurement	▪ Items aimed at empowerment from the *Empowerment and Political Action module* of SC-IQ (Grootaert et al., 2004) **1.** How much control do you feel you have in making decisions that affect your everyday activities? Do you have … 1.1 No control 1.2 Control over very few decisions 1.3 Control over some decisions 1.4 Control over most decisions 1.5 Control over all decisions **2.** Do you feel that you have the power to make important decisions that change the course of your life? Rate yourself on a 1 to 5 scale, where 1 means being totally unable to change your life, and 5 means having full control over your life. 1.1 Totally unable to change life 1.2 Mostly unable to change life 1.3 Neither able nor unable 1.4 Mostly able to change life 1.5 Totally able to change life **3.** Overall, how much impact do you think you have in making your street/ your neighborhood/ your city a better place to live? 1.1 A big impact 1.2 A small impact 1.3 No impact
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (long-term) and challenges ✓ Desirable: Data on empowerment processes and outcomes specifically related a certain NBS initiative in a community/city, and accounting for country/community-distinctive cultural, economic, legal, and political factors that play a role in empowerment dynamics (narrative studies, participatory data collection methods, participatory action research)
Data input type	Quantitative (quantitative and qualitative, if narrative studies, participatory data collection methods, and/or participatory action research are opted for)
Data collection frequency	Aligned with NBS implementation and timing of targeted objectives

Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection (case study and narrative study methodology, for example) requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC7 Geographical access to NBS SC8 Perceived access to NBS SC11.1 Positive environmental attitudes motivated by contact with NBS SC11.2 Environmental Identity SC12 Social desirability
Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods (e.g., narrative studies, participatory data collection methods, and/or participatory action research) may be applied to collect community-relevant information on empowerment processes and outcomes specifically related to a certain NBS/green space initiative in a community/city, and accounting for country/community-distinctive cultural, economic, legal, and political factors that play a role in empowerment dynamics
Additional information	
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17.3 Public-private partnerships activated

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Adoption of new forms of governance: Public-Private Partnership Activated	Participatory Planning and Governance
Description and justification	The level of cooperation between public and private sector in the Design Scenarios implementation should be taken into account in order to assess the quality of participation process. It should be estimated counting the number of partnership activated between public and private agencies.
Definition	The Indicator can be defined as the number of public-private partnerships activated in order to achieve the implementation of the Design Scenario. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenario computing the number of stakeholder taking part to the participatory process. In the Long-term scenario the indicators should be calculated considering data made available some years after NBS/Grey/Hybrid solutions have been implemented.

Strengths and weaknesses	Data mining could be time-consuming.
Measurement procedure and tool	The Indicator will be equal to the whole number of Public-Private Partnership activated in order to achieve the implementation of the Design Scenario
Scale of measurement	No.
Data source	Municipalities and other public agencies
Required data	Public-Private Partnerships data
Data input type	Documents
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	16, 17
Opportunities for participatory data collection	
Additional information	
References	

17.4 Policy learning for mainstreaming NBS

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Policies Set Up To Promote NBS	Participatory Planning and Governance
Description and justification	The level of involvement of public authorities in the Design Scenarios implementation should be taken into account in order to evaluate the quality of participation

	process. It should be assessed counting the number of policies set up to promote NBS.
Definition	The Indicator can be defined as the number of policies set up to promote NBS during the implementation of the Design Scenario. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenario computing the number of policies that public and/or private agencies have set up to promote NBS.
Strengths and weaknesses	Data mining could be time-consuming.
Measurement procedure and tool	The indicator will be equal to the whole number of policies that public and/or private agencies have set up to promote NBS, deduced by the consultation of public documents.
Scale of measurement	No.
Data source	Municipalities and other public agencies
Required data	Public policies documents
Data input type	Documents and reports
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	16
Opportunities for participatory data collection	
Additional information	
References	

17.5 Trust in decision-making procedure and decision-makers

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Trust in decision-making and decision-makers	**Participatory Planning and Governance**
Description and justification	'Political trust' is used as a common term to measure how positively citizens regard governmental decision-making actors, institutions and processes (Seyd 2016). Political trust is considered both an important prerequisite for as well as outcome of good governance. The absence of trust shows citizens' dissatisfaction and withdrawal from the political process, and it may result in citizens who do not want to pay taxes or follow rules (Bouckaert and van de Walle 2003; van Ryzin 2011). The same holds true for nature-based solutions planning, delivery and stewardship: citizens are more likely to actively participate when they trust local decision-making and decision-makers, while at the same time co-production of nature-based solutions might enhance trust (cf. Djenontin and Meadow 2018; Ferretti et al. 2018). However, political trust is a complex concept for which it is difficult to identify a commonly accepted definition (Bouckaert and van de Walle 2003; Seyd 2016; Parker et al. 2015). Trust has been the focus of multiple disciplines, including psychology, sociology, political science, economy and organisational science (Grimmelkhuijsen and Knies 2017). Despite the myriad of definitions and operationalisations of trust within and across disciplines, Grimmelkhuijsen and Knies (2017) identify agreement about two features related to trust: a degree of 'risk' and 'interdependence'. A trusts B to do X, which is in A's interest. This yields a risk because A cannot be certain as to whether B indeed carries out X. In the case of political trust, risk becomes relevant when governments exert a certain degree of power over citizens, which can be either used properly or abused. The condition of interdependence implies that the interests of one party cannot be achieved without reliance on the other party. In the case of trust in government, if citizens want the government to solve pressing social problems, they are dependent on government organisations to deliberate on decisions, carry out policy measures, and monitor their effects. Government, on the other hand, depends on citizens to cooperate and act according to certain rules for its policies to have any effect (ibid.). Based on these two conditions, definitions of political trust lean on Mayer et al.'s (1995, p. 712) definition of trust, which originates from organisational science literature (Seyd 2016; Grimmelkhuijsen and Knies 2017): trust is "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action

important to the trustor, irrespective of the ability to monitor or control that other party". In this definition, the expectation of the vulnerable party (i.e. citizen) is central: the trust of person A in another person or organisation B rests on a judgement by A about how far B will act in a way consistent with their (A's) interests (Seyd 2016). This expectation is based on the perceptions that people have of 'the other': trust in government consists of the extent to which it is considered 'worthy of trust' by its citizens (Grimmelkhuijsen and Knies 2017). Accordingly, trust is often measured via beliefs or judgements on A's part that B manifests particular features or qualities that induce trust (or distrust) in A – rather than an intention or behaviour (Seyd 2016). The content of a trust belief relates to A's judgement that B possesses the qualities that render them worthy of trust (ibid.; Grimmelkhuijsen and Knies 2017).

Based on this, and to gain a more specific understanding of how trust works and can be measured, Grimmelkhuijsen and Knies (2017) devised a 'citizen trust in government organisations scale'. The scale distinguishes between different dimensions to determine a governmental organisation's perceived trustworthiness: (1) perceived competence (the extent to which a citizen perceives a government organisation to be capable, effective, skilful and professional), (2) perceived benevolence (the extent to which a citizen perceives a government organisation to care about the welfare of the public and to be motivated to act in the public interest); and (3) perceived integrity (the extent to which a citizen perceives a government organisation to be sincere, to tell the truth, and to fulfil its promises). These dimensions respond to criticism about conventional measures of political trust, which employ single-item survey measures (ibid.; Seyd 2016). To trust rests on judgements about a number of different considerations, rather than comprising a singular, generalised evaluation.

Another concern is that survey items that squeeze a range of potential evaluations into a single expressed opinion risk understate the level of uncertainty and ambivalence in people's attitudes towards different governmental bodies or even people. Along these lines, scholars emphasise that the object of political trust (who/what is trusted) needs to be clearly defined. Political trust can relate to different levels and bodies of government, e.g. national, regional and local governments, the parliament or the civil service (Bouckaert and van de Walle 2003; Parker et al. 2015). Political trust can also relate to different type of people or office holders – politicians or public officials – as well as individual persons, e.g. the president or prime minister (Parker et al. 2015). Accordingly, Parker et al. (2015) contend that trust in government reflects trust in the federal or national government, which can be distinguished from trust in incumbent political leaders, trust in state government and presidential job evaluations.

In addition, there needs to be a clear separation between its components and its potential causes – especially when aiming to establish causal relations. Findings reveal that levels of trust

	cannot simply be attributed to the good or bad functioning of an institution; they may in fact be entirely unrelated to what government is or does (Bouckaert and van de Walle 2003). Economic and political performance, institutional context, political culture, changing behaviours and values, citizen-state relationships, opportunities for citizen participation and critical events might all be important factors influencing political trust (ibid.; Kim and Lee 2012; Parker et al. 2015). Thus, if one also aims to explain the feelings of (dis)trust that A has for B, the antecedents of that trust lie in three places: (a) the characteristics of A, notably their propensity to trust; (b) the characteristics or past behaviour of B, notably the extent to which these reveal trustworthy qualities; and (c) the context in which B operates, notably whether they are faced with appropriate incentives and sanctions. Importantly, the indicators to capture levels of trust must be clearly distinguished from those to capture the reasons for that trust (Seyd 2016).
Definition	Political trust is defined as the willingness of citizens to be vulnerable to the actions of governmental decision-making and decision-makers based on their expectation that governments perform a particular action important to them, irrespective of their ability to monitor or control that other party (cf. Mayer et al. 1995). Political trust comprises evaluations of the trustworthiness of governmental decision-making and decision-makers, based on three dimensions (Grimmelkhuijsen and Knies 2017): **1) perceived competence:** the extent to which a citizen perceives a government organisation to be capable, effective, skilful and professional; **2) perceived benevolence:** the extent to which a citizen perceives a government organisation to care about the welfare of the public and to be motivated to act in the public interest; **3) perceived integrity:** the extent to which a citizen perceives a government organisation to be sincere, to tell the truth, and to fulfil its promises.
Strengths and weaknesses	+ Important measure of citizens' perceptions of and satisfaction with local government related to the nature-based solution implementation - Difficult to establish causal relations between measures of political trust and nature-based solutions implementation - Data collection could be time-consuming
Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: 9 items at measuring respondents' perception of policies adapted or implemented ☒ *Qualitative P*:

	o T: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation o T: participatory data collections methods, such as focus group
Scale of measurement	The levels of political trust can be evaluated based on responses to survey questions using a five-point Likert scale: strongly disagree, disagree, neutral, agree, and strongly agree (Seyd 2016; Grimmelkhuijsen and Knies 2017). **(1) Perceived competence** 1.a) The municipality of XX is capable. 1.b) The municipality of XX wastes a lot of public money. 1.c) Local politicians generally know what they are doing. **(2) Perceived benevolence** 2.a) Local politicians act in the interest of citizens. 2.b) The municipality of XX carries out its duty very well. 2.c) Local politicians keep their commitments. **(3) Perceived integrity** 3.a) In the main, local politicians tell the truth. 3.b) Governmental officials (e.g., civil servants)* tell us as little about what they get up to as they can. 3.c) When things go wrong, local politicians admit their mistakes. *Civil servants are higher level non-political government paid officials. They are not elected to office—they applied for their posts and are senior public servants or government administrators.
Data source	
Required data	✓ Essential: questionnaire scoring on trust ✓ Desirable: qualitative data on nature-based solutions governance processes and underlying determinants of levels of trust
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for)
Data collection frequency	Aligned with NBS implementation and timing of targeted objectives
Level of expertise required	☒ Methodology and data analysis requires medium level expertise in social science research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection requires medium level expertise in social science research
Synergies with other indicators	

Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions governance processes and underlying reasons of levels of trust to reveal underlying challenges and opportunities.
Additional information	
References	Bouckaert, G., van de Walle, S. (2003) Comparing measures of citizen trust and user satisfaction as indicators of 'good governance': difficulties in linking trust and satisfaction indicators. International Review of Admoinistrative Sciences, 69: 329-343. Djenontin, I.N.S., Meadow, A.M. (2018) The art of co-production of knowledge in environmental sciences and management: lessons from international practice. Environmental Management, 61: 885-903. https://doi.org/10.1007/s00267-018-1028-3 Grimmelkhuijsen, S., Knies, E. (2017) Validating a scale for citizen trust in government organizations. International Review of Administrative Sciences, 83(3): 583-601. DOI: 10.1177/0020852315585950 Kim, S., Lee, J. (2012) E-participation, transparency, and trust in local government. Public Administration Review, 72(6): 819-828. DOI: 10.111/j.1540-6210.2012.02593.x. Mayer, Roger C et al. (2995) An Integrative Model of Organizational Trust. Academy of Management Review, 20:3, 709-34. Parker, S.L., Parker, G.R., Towner, T.L. (2015) Rethinking the meaning and measurement of political trust. In: Eder, C., Mochmann, I.C., Quandt, M. (eds.) Political trust and disenchantment with politics: International perspectives, Leiden: Brill, pp. 85-115. Seyd, B. (2016) How should we measure political trust? Paper for PSA annual conference, Brighton March 21-23, 2016. https://www.psa.ac.uk/sites/default/files/conference/papers/2016/Paper.v2.pdf van Ryzin, G. (2011) Outcomes, process, and trust of civil servants. Journal of Public Administration Research and Theory, 21: 745-760. doi:10.1093/jopart/muq092

18 Additional Indicators of Participatory Planning and Governance

18.1 Community involvement in planning

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Openness of participatory processes: Community involvement in planning	**Participatory Planning and Governance**
Description and justification	Public participation in NBS projects encompasses a wide range of different opportunities for citizens, nongovernmental organizations, businesses, and other stakeholders co-create, co-implement and co-manage NBS, concomitantly creating a sense of ownership. The integral role of citizens and other stakeholders in NBS projects can influence the openness of other processes managed by the municipality. Stakeholder involvement has been shown to positively influence agreement on solutions and acceptance of policy interventions, largely through raising citizens' awareness (Driessen, Glasbergen and Verdaas 2001).
Definition	The extent to which citizens and other stakeholders have been involved in the planning phase of a given project (unitless)
Strengths and weaknesses	+ Few data necessary - Difficult to understand the level of all citizens' involvement
Measurement procedure and tool	A five-point Likert scale based on the ladder of citizen participation (Arnstein, 1969) can be used to qualitatively assess the success of community involvement in NBS planning. The Likert scale follows Arnstein's ladder from non-participation (1) through degrees of tokenism (2-3) to citizen empowerment via partnership (4) or citizen control (5): **No involvement — 1 — 2 — 3 — 4 — 5 — High involvement** 1. Not at all: No community involvement. 2. Inform and consult: A relatively complete project plan is announced to the community for information only, or for the purpose of receiving community feedback. The

	consultation process primarily seeks community acceptance of the plan. 3. Advise: A project plan is drafted by a project team then presented to community actors, who are invited to ask questions, provide feedback and give advice. Based on this input the planners may alter the project plan. 4. Partnership: Community actors are invited by project planners to participate in the planning process by prioritising issues and planning actions. The local community is able to influence the planning process. 5. Community self-development: Project planners empower community actors to outline their needs and to make actionable plans.
Scale of measurement	District to municipality scale (project-based)
Data source	
Required data	Information on public participation processes during the planning phase of NBS project
Data input type	Qualitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Relation to *Design for sense of place, Participatory governance* indicators and *Green Space Management* indicator group
Connection with SDGs	SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	Participatory data collection is the core of this metric
Additional information	
References	Arnstein, S.R. (1969). A ladder of citizen participation. Journal of the American Planning Association, 35(4), 216-224. Driessen, P.P.J., Glasbergen, P., & Verdaas, C. (2001.) Interactive policy-making: A model of management for public works. European Journal of Operational Research, 128, 322-337.

18.1.1 Citizen involvement in co-creation/co-design of NBS

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[2] *University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy*

[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

Openness of participatory processes: Citizens Involved	**Participatory Planning and Governance**
Description and justification	The amount of local actors in the Design Scenarios implementation should be taken into account in order to evaluate the quality of participation process. It should be assessed counting the number of citizen involved
Definition	The Indicator can be defined as the number of people involved in participatory process set up during the implementation of the Design Scenario. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenario computing the number of people taking part to the participatory process.
Strengths and weaknesses	It could be difficult to estimate the exact number of people involved.
Measurement procedure and tool	At the beginning of the meetings organized during the participatory process, citizens should be invited to sign a timesheet. The Indicator will be equal to the whole number of people involved during these meetings. Other proxy data could be used, such as number of visits to the website of the participatory process.
Scale of measurement	No.
Data source	Participatory Process Planning Committee
Required data	Time-sheet
Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	

Connection with SDGs	17
Opportunities for participatory data collection	This Indicator could only be calculated through a participatory data collection.
Additional information	
References	

18.1.2 Stakeholder involvement in co-creation/co-design of NBS

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

[1] *Aalto University, Department of Built Environment, Espoo, Finland (gerardo.caroppi@aalto.fi)*

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Openness of participatory processes: Stakeholders Involved	Participatory Planning and Governance
Description and justification	The amount of local actors in the Design Scenarios implementation should be taken into account in order to evaluate the quality of participation process. It should be assessed counting the number of stakeholder involved
Definition	The indicator can be defined as the number of stakeholders involved in participatory process set up during the implementation of the Design Scenario. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenario computing the number of stakeholders taking part to the participatory process.
Strengths and weaknesses	It could be difficult to estimate the exact number of stakeholders involved.
Measurement procedure and tool	At the beginning of the meetings organized during the participatory process, stakeholder should be invited to sign a timesheet. The Indicator will be equal to the whole number of stakeholder involved during these meetings.
Scale of measurement	No.
Data source	Participatory Process Planning Committee
Required data	Time-sheet

Data input type	Quantitative
Data collection frequency	
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	17
Opportunities for participatory data collection	This Indicator could only be calculated through a participatory data collection.
Additional information	
References	

18.2 Community involvement in implementation

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Openness of participatory processes: Community involvement in implementation	**Participatory Planning and Governance**
Description and justification	Public participation in NBS projects encompasses a wide range of different opportunities for citizens, nongovernmental organizations, businesses, and other stakeholders co-create, co-implement and co-manage NBS, concomitantly creating a sense of ownership. The integral role of citizens and other stakeholders in NBS projects can influence the openness of other processes managed by the municipality. Involvement of citizens and other stakeholders during project implementation ensures establishment of a common understanding of the project's longer-term maintenance or management needs, and provides NBS managers and developers with critical input regarding the NBS project's performance relative to stakeholder expectations.

Definition	The extent to which citizens and other stakeholders have been involved in the implementation phase of a given project (unitless)
Strengths and weaknesses	+ Few data necessary - Difficult to understand the level of all citizens' involvement
Measurement procedure and tool	A five-point Likert scale based on Arnstein's (1969) ladder of citizen participation can be used to evaluate the extent of citizen's power in determining the implementation program: **No involvement — 1 — 2 — 3 — 4 — 5 — High involvement** 1. Not at all: No community involvement. 2. Inform and consult: An essentially complete project is presented to the community for information only, or in order to receive community feedback. The consultation process primarily seeks community acceptance of the project at the implementation stage. 3. Advise: The project implementation is done by a project team. Community actors are invited to ask questions, provide feedback and give advice. Based on this input the planners may alter how the project is implemented. 4. Partnership: Community actors are invited by project managers and developers to participate in the implementation process. The local community is able to influence the implementation process. 5. Community self-development: The project planners empower community actors to manage the project implementation and evaluate the results.
Scale of measurement	District to municipality scale (project-based)
Data source	
Required data	Information on public participation processes during the implementation phase of NBS project
Data input type	Qualitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Relation to *Design for sense of place*, *Participatory governance* indicators and *Green Space Management* indicator group

Connection with SDGs	SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	Participatory data collection is the core of this metric
Additional information	
References	Arnstein, S.R. (1969). A ladder of citizen participation. Journal of the American Planning Association, 35(4), 216-224.

18.3 Involvement of citizens from traditionally under-represented groups

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Participation of vulnerable or traditionally under-represented groups	**Social Justice and Social Cohesion** **Participatory Planning and Governance**
Description and justification	Definitions of "vulnerable" and "under-represented" groups in society vary somewhat, but in general the following groups can be considered vulnerable to discrimination and/or under-represented: Women and girls Children Refugees Internally displaced persons Stateless persons National minorities Indigenous peoples Migrant workers Disabled persons Elderly persons HIV positive persons and those suffering from AIDS Roma/Gypsies/Sinti

	Lesbian, gay, bisexual, transgender, queer, and differently gendered people (LGBTQ+) Particular effort is necessary to ensure that these groups receive equal representation and opportunity to become involved in NBS projects. Specifically engaging vulnerable and/or under-represented groups in NBs projects enhances social cohesion and diversity whilst tapping into underdeveloped social capital.
Definition	The extent to which the NBS project has led to the increased participation by groups of people who are typically not well represented in the society.
Strengths and weaknesses	+ The indicator gives useful data for reducing inequalities + Easy to use - May not provide a holistic assessment
Measurement procedure and tool	The participation of vulnerable or traditionally under-represented groups in NBS projects or specific NBS project activities can be qualitatively assessed using a five-point Likert scale: **Not at all – 1 — 2 — 3 — 4 — 5 — Excellent** 1. Not at all: the project has not increased participation of groups not well represented in society. 2. Poor: the project has achieved little when it comes to participation of groups not well represented in society. 3. Fair: the project has somewhat increased the participation of groups not well represented in society. 4. Good: the project has significantly increased the participation of groups not well represented in society. 5. Excellent: Participation of groups not well represented in society has clearly been hugely improved due to the project. Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).
Scale of measurement	District to metropolitan scale

Data source	
Required data	Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).
Data input type	Qualitative
Data collection frequency	Before and after implementation of the NBS project
Level of expertise required	Moderate
Synergies with other indicators	Synergies with indicator group *Participatory Planning and Governance* indicators
Connection with SDGs	SDG 10 Reduced inequalities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeys D14Indicatorsforsmartcityprojectsandsmartcities.pdf

18.4 Active engagement of citizens in decision-making

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Active engagement of citizens in decision-making	**Participatory Planning and Governance**
Description and justification	Participatory or inclusive governance, wherein municipalities partner with citizens to develop and manage solutions to contemporary challenges, focuses on

	enhancing citizen engagement in municipal governance by providing opportunity for citizens to play a direct role in public decision-making. The increased engagement of citizens in urban governance and decision-making is a primary objective of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC).
Definition	The extent to which the NBS project has contributed to the active engagement of citizens in public decision-making (unitless)
Strengths and weaknesses	+ Straightforward assessment - Records may not reflect the true situation
Measurement procedure and tool	The proportion (%) of citizens involved in participatory governance is calculated on an annual basis, as: $\left(\frac{No. of\ citizens\ enaged\ in\ relevant\ projects\ in\ a\ given\ year}{Total\ population\ of\ the\ city}\right) \times 100$
Scale of measurement	Municipality scale
Data source	
Required data	Municipalities maintain records of the number of citizens involved in face-to-face meetings or other activities. Evaluation of citizen engagement should take into account online (internet- or app/smartphone-based) engagement. Software providers and/or platform hosts can provide metrics related to the number of unique visitors for use in calculating digital citizen engagement.
Data input type	Qualitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group
Connection with SDGs	SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	European Innovation Partnership on Smart Cities and Communities (EIP SCC). (2013.) Strategic Implementation Plan. Issues

	14.10.2013. Brussels: EIP SCC. https://smartcities.at/assets/Uploads/sip-final-en2.pdf

18.5 Consciousness of citizenship

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Consciousness of citizenship	**Participatory Planning and Governance** **Social Justice and Social Cohesion**
Description and justification	Consciousness of citizenship can be described as an individual's awareness of their community, civic rights and responsibilities and their relationship with the community, state or nation. An individual with consciousness of citizenship is aware of how the community functions and their respective role in the community. As such, consciousness of citizenship contributes to a sense of community. According to Ng (2015), civic consciousness includes the following elements: • Personal identity and citizenship: characteristics such as personal awareness, pride, obedience to the law, and a sense of equality • National identity: respect for national authorities, belief in the legitimacy of the current political system, sense of the nation as a cohesive whole • Moral consciousness: upholding family and social normative values in public and in private, willingness to promote public welfare • Ecological consciousness: awareness of the finite nature of natural resources, consideration of the environmental consequences of personal actions • Global citizenship: actively concerned with others at home and abroad
Definition	The extent to which the NBS project has contributed in increasing consciousness of citizenship (qualitative, unitless)

Strengths and weaknesses	+ The indicator gives useful data for urban planning but the data collecting and evaluation might be challenging - May not provide the holistic picture
Measurement procedure and tool	The extent to which an NBS project seeks to contribute to the local consciousness of citizenship can be qualitatively rated on a five-point Likert scale, from no effort to substantial effort: **No increase – 1 — 2 — 3 — 4 — 5 — High increase** 1. None: The NBS project has made no effort to increase civic consciousness. 2. Little: The NBS project has made a small effort to increase civic consciousness. 3. Somewhat: The NBS project has developed some initiatives to increase civic consciousness. 4. Significant: The NBS project has executed several activities to increase civic consciousness 5. High: increasing civic consciousness was (one of) the main goals of the NBS project and substantial effort has been made to enhance civic consciousness.
Scale of measurement	District to metropolitan scale
Data source	
Required data	Project documentation and/or interviews during the NBS project
Data input type	Qualitative
Data collection frequency	Before and after implementation of the NBS project
Level of expertise required	Moderate
Synergies with other indicators	Synergies with indicator group *Participatory Planning and Governance* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, and SDG 16 Peace, justice and strong institutions
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4.

	http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf Ng, J.A.I. (2015). Scale on Civic Consciousness (SCC) for the National Service Training Program. International Journal of Humanities and Management Sciences, 3(3), 161-165.

18.6 Number of governance innovations adopted

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Katharina Hölscher[1]

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Governance innovation	Participatory Planning and Governance
Description and justification	The planning, delivery and stewarding of nature-based solutions requires participatory governance approaches (Frantzeskaki et al. 2020; Hölscher et al. 2019; van der Jagt et al. 2017). Participatory governance will enhance the social support of the nature-based solution and awareness of its changing functional design over time. Moreover, the engagement of a large variety of actors is also a matter of creating economic insurance, where different financial resources can be activated to sustain functionality over time. For these reasons, participatory approaches to co-design, co-creation and co-management ('co-co-co') of NBS are advocated (European Commission, 2016). For example, Buijs et al. (2018) show how active citizens can significantly contribute to urban green infrastructure planning and implementation, for example by developing large parks with volunteers or designing a network of green corridors. As they show a large diversity of citizen-local government collaborations and different pathways for upscaling innovative discourses and practices, they term this 'mosaic governance' that can facilitate a combination of long-term, more formalised strategic approaches with more incremental approaches that correspond with localised, fragmented and informal efforts of local communities. Generally speaking, participatory governance is embodied in processes that empower citizens to participate in public decision-making. Around the world, a growing number of local governments are experimenting with innovative practices that seek to expand the space and mechanisms for citizen participation in governance processes beyond elections. Putting in place the mechanisms for participatory governance requires governance innovations. In general terms,

	governance innovations can be diverse – they refer to novel rules, regulations and approaches, as well as skills, competencies and structural capacities of actors to address a public problem in more efficacious and effective ways, lead to better policy outcomes and enhance legitimacy (Hertie School of Governance 2017; Anheier and Korreck 2013; OECD 2018). Governance innovations that facilitate participatory governance refer to the creation of those novel conditions (e.g. resources, cognitive, social and normative capacities) that support collaborative decision-making (cf. Kerkhoff and Lebel 2015; Wyborn 2015). Innovative governance conditions for participatory governance refer to the provision and institutionalisation of participatory mechanisms in city governance. Pieterse (2000) provides an overview of participatory governance methods and tools, including citizen juries, referenda and participatory diagnostic tools. Similarly, the Hertie School of Governance (2017) identifies several democratic innovations, which refer to new mechanisms for citizens' engagement in decision-making (e.g. referendums, citizens' assemblies, participatory budgeting). The institutionalisation of participatory governance will depend on political will, establishing an accurate picture of the variety of urban stakeholders and formulating a policy on participation for the municipality (Pieterse 2000). Such conditions also include the extent to which information is readily available and citizens are aware of opportunities for participation (Pieterse 2000; Galukande-Kiganda and Boitumelo Mzini 2019). In addition, several authors identify capacities for co-production, or co-productive capacities (Hölscher et al. 2019b; Kerkhoff and Lebel 2015; Wyborn 2015). Next to strategies, programmes and goals that are in place, these capacities also address which type of knowledge and skills existing for participatory governance. For example, Frantzeskaki et al. (2020) highlight that for collaborative decision-making, specific skills such as negotiation and collaboration are needed.
Definition	Governance innovations for participatory governance refer to the creation of those novel mechanisms, processes and rules that support participation.
Strengths and weaknesses	+ Provides insights into extent to which nature-based solutions process contributed to governance innovations for particiaption -Difficult to assess and data collection could be time consuming -Does not address the quality of participation and issues of power and equity
Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

	o T: 1 item at measuring respondents' perception of governance innovations. ☒ *Qualitative P*: o T: participatory data collection methods, such as focus groups, semi-structured interviews, case study analysis, participant and non-participant observation
Scale of measurement	A five-point Likert scale can be used to evaluate the extent of governance innovations for participation: **No innovations for participation — 1 — 2 — 3 — 4 — 5 — Very high level of innovation for participation** 1. Not innovation: No innovation for participation 2. Low level of innovation: Participation is considered as hoc in few governance activities in projects of the city 3. Moderate level of innovation: Participation is embedded in city strategies, but not required as part of city projects and activities 4. High level of innovation: Participation is embedded in city strategies and required for any type of city project and activity 5. Very high level of innovation: Participation is embedded and mainstreamed in city strategies, projects and activities and capacities (knowledge, skills) for ensuring good participation are supported and ensured
Data source	
Required data	✓ Essential: questionnaire to collect different perspectives on the governance innovations for participation ✓ Desirable: qualitative data on nature-based solutions governance processes to reveal challenges and opportunities for governance innovations, as well as reflect on outcomes.
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for)
Data collection frequency	Aligned with NBS implementation and timing of targeted objectives
Level of expertise required	☒ Methodology and data analysis requires medium level expertise in social science research and the governance of the city in question ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection requires medium level expertise in social science research
Synergies with other indicators	

Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions governance processes to reveal challenges and opportunities for governance innovations, as well as reflect on outcomes.
Additional information	
References	Anheier, H., Korreck, S. (2013) Governance innovations. In: Herti School of Governance (ed.) The Governance Report 2013. Oxford University Press: Oxford, pp. 83-116. Buijs, A., Hansen, R., Van der Jagt, S., Ambrose-Oji, B., Elands, B., Rall, E. L., ... & Møller, M. S. (2018). Mosaic governance for urban green infrastructure: Upscaling active citizenship from a local government perspective. Urban Forestry & Urban Greening. Frantzeskaki, N., Vandergert, P., Connop, S., Schipper, K., Zwierzchowska, I., Collier, M., Lodder, M. (2020) Examining the policy needs for implementing nature-based solutions in cities: Findings from city-wide transdisciplinary experiences in Glasgow (UK), Genk (Belgium) and Poznan (Poland). Land use Policy 96: 104688. Hertie School of Governance (2017) The Governance Report 2017. An overview of democratic innovations highlighted in the report. Oxford University Press. https://hertieschool-f4e6.kxcdn.com/fileadmin/2_Research/1_About_our_research/4_The_Governance_Report/2017/GovReport2017_InnovationOverview.pdf Hölscher, K., et al. (2019) Deliverable 4: Report on outcomes of meetings, consultations, webinars and workshops leading to the publication of a 'Co-creation for cities' guidebook and infographics. Connecting Nature Deliverable 4. Pieterse, E. (2000) Participatory urban governance. Practical approaches, regional trends and UMP experiences. Urban Management Programme UNCHS/UNDP/World Bank: Nairobi, Kenya. OECD (2018) Implementing the OECD Principles on Water Governance Indicator Framework and Evolving Practices. OECD Studies on Water.

18.7 Adoption of new forms of NBS (co-)financing

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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New forms of financing	Participatory Planning and Governance
Description and justification	Despite widespread recognition of the multiple co-benefits offered by NBS, financing for urban green spaces remains a common barrier to NBS implementation. Close partnerships between municipal governments, businesses and citizens (public-private-people partnerships, PPPPs) are one example of a new business and financing model that yields resource and governance synergies that can support NBS implementation. Other examples include new financial products such as 'green mortgages' or revolving funds for sustainable investments.
Definition	The extent to which the NBS project has contributed to, or inspired, the development of new forms of financing (unitless)
Strengths and weaknesses	+ Easy and straightforward assessment - The results may not be holistic
Measurement procedure and tool	This metric uses a five-point Likert scale to evaluate the extent to which a given NBS project has contributed to the development of innovative forms of financing (Bosch et al., 2017): **No impact on new forms of financing — 1 — 2 — 3 — 4 — 5 — High impact** 1. No impact: the project used a new form of financing but this is not known to the outside world. 2. Little impact: the project used a new form of financing but is hardly known for this 3. Some impact: the project used a new form of financing and received some professional attention because of this. 4. Notable impact: the project is (one of the first) to develop and use a new form of financing and has attracted a lot of professional attention because of this, which has led to a few further experiments with the new way of financing. 5. High impact: the project developed and used a new form of financing and has attracted a lot of public and

	professional attention because of this, which has led to several further experiments with the new way of financing.
Scale of measurement	Municipality scale
Data source	
Required data	Information on the development of innovative forms of financing related to a NBS project
Data input type	Qualitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group
Connection with SDGs	SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., … Bonn, A. (2016). Nature-based solutions to climate change adaptation and mitigation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecology and Society, 21(2), 39.

18.8 Development of a climate resilience strategy (extent)

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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<table>
<tr><th colspan="2">Degree of development of climate resilience strategy</th><th>Participatory Planning and Governance</th></tr>
<tr><td colspan="2">Description and justification</td><td>Many climate resilience strategies are linked with disaster and risk reduction as the impacts of climate change are commonly experienced in urban areas as flooding and/or drought, and over-heating (urban heat island effect). Nature-based solutions are a key tool for use in urban climate change mitigation and adaptation efforts.</td></tr>
<tr><td colspan="2">Definition</td><td>The extent to which the city has developed and implemented a climate resilience strategy</td></tr>
<tr><td colspan="2">Strengths and weaknesses</td><td>+ Projects involving NBS can increase awareness of ecosystem based adaptation to climate change and encourage the development of municipal climate resilience strategies that incorporate natural solutions to climate change impacts
+ Increased awareness of NBS benefits
+ Easy to evaluate
- An overly simple assessment</td></tr>
<tr><td colspan="2">Measurement procedure and tool</td><td>The metric is evaluated using a seven-point Likert scale based on the steps suggested by the “Mayors adapt” initiative for climate change adaptation in urban areas (Bosch et al., 2017; Climate Adapt, n.d.):
No action – 1 — 2 — 3 — 4 — 5 — 6 — 7 — Implementation, monitoring and evaluation
1. No action has been taken yet
2. The ground for adaptation has been prepared (the basis for a successful adaptation process)
3. Risks and vulnerabilities have been assessed
4. Adaptation options have been identified
5. Adaptation options have been selected
6. Adaptation options are being implemented
7. Monitoring and evaluation is being carried out.</td></tr>
</table>

Scale of measurement	Municipal scale
Data source	
Required data	Information on the development and implementation of climate resilience strategy in the city
Data input type	Qualitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Relation to *Openness of participatory processes, Policy learning concerning adapting policies and strategic plans, New forms of financing* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf Climate Adapt. (n.d.). About the Urban Adaptation Support Tool. https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-0-1

18.9 Alignment of climate resilience strategy with UNISDR-defined elements

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Maria Dubovik[1], Ville Rinta-Hiiro[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Silvia Vela[3], Margherita Cioffi[3]

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Alignment of climate resilience strategy with UNISDR-defined elements	Participatory Planning and Governance
Description and justification	Many climate resilience strategies are linked with disaster and risk reduction as the impacts of climate change are commonly experienced in urban areas as flooding and/or drought, and over-heating (urban heat island effect). Nature-based solutions are a key tool for use in urban climate change mitigation and adaptation efforts. The evaluation of Climate Resilience Strategy Development can rely on the assessment proposed by the United Nations Office for Disaster Risk Reduction (UNISDR) that allows local governments and to assess their disaster resilience and to enable the development of a local disaster risk reduction strategy (resilience action plans).
Definition	The extent to which the city has implemented the “Ten Essentials for Making Cities Resilient” included in the Sendai Framework for Disaster Risk Reduction
Strengths and weaknesses	+ Essentials are able to cover many of the issues that cities need to address to become more disaster resilient and they are able to address multiple perspectives, such as governance and financial capacity, planning and disaster preparation and disaster response and post-event recovery (United Nations Office for Disaster Risk Reduction [UNISDR], 2017) - Requires a substantial amount of external information
Measurement procedure and tool	The metric is evaluated using UNISDR Disaster Resilience Scorecard for Cities, which is a tool that allows local governments to monitor and review progress and challenges in the Implementation of the Sendai Framework for Disaster Risk Reduction and to enable the development of a local disaster risk reduction strategy. The assessment is performed with respect to a selected climate hazard (e.g., the most severe, the most probable) and can be made at two levels: preliminary and detailed.

	In detail, for each of the Essentials, a number of issues is identified within the tool, and for each of the issue a score must be assigned. Final results include an overall score, a representation of results focused on the score obtained for each essential in graphical form and also a representation of results focused on the score obtained for each sub-issue of each essential in graphical form.
Scale of measurement	Municipal scale
Data source	
Required data	Information on the progress and challenges in the Implementation of the Sendai Framework for Disaster Risk Reduction and the development of a local disaster risk reduction strategy
Data input type	Qualitative
Data collection frequency	Annually
Level of expertise required	Low
Synergies with other indicators	Relation to *Openness of participatory processes, Policy learning concerning adapting policies and strategic plans, New forms of financing* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	United Nations Office for Disaster Risk Reduction (UNISDR). (2017). Disaster Resilience Scorecard for Cities – Preliminary level assessment. Retrieved from https://www.unisdr.org/campaign/resilientcities/toolkit/article/disaster-resilience-scorecard-for-cities

18.10 Adaptation of local plans and regulations to include NBS

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Policy learning concerning adapting policies and strategic plans	**Participatory Planning and Governance**
Description and justification	Policy learning to systemically incorporate ecosystem-based adaptation into climate change strategies and ecosystem services into municipal planning is a critical step in shifting the prevailing paradigm of dealing with risk and disaster (Wamsler, Luederitz & Brink, 2014).
Definition	The extent to which the NBS project has contributed to, or inspired, changes in municipal rules, regulations and behavioural change instruments to support implementation and "mainstreaming" of NBS (unitless)
Strengths and weaknesses	+ Policy learning can create windows of opportunity for other, similar urban innovations + Diffusion of good policies to increase NBS implementation and maintenance and, hence, urban resilience - Implementation of NBS in the absence of policy and planning support may be challenging, as bottom-up and decentralised processes are inherent within the concept
Measurement procedure and tool	The extent of policy learning during or as a result of an NBS project can be evaluated using a five-point Likert scale (Bosch et al., 2017): **No impact — 1 — 2 — 3 — 4 — 5 — High impact** 1. No impact: the NBS project has not, at any level, inspired changes in municipal rules and regulations. 2. Little impact: the NBS project has led to localised discussion about the suitability of the current municipal rules and regulations. 3. Some impact: the NBS project has led to public discussion, leading to a change in municipal rules and regulations. 4. Notable impact: the NBS project has led to public discussion, leading to a change in municipal rules and regulations. This, in turn, has sparked discussion amongst other administrations about the suitability of current rules and regulations.

	5. High impact: the NBS project has led to public discussion, leading to a change in municipal rules and regulations. This, in turn, has inspired other administrations to reconsider their respective rules and regulations
Scale of measurement	Municipal scale
Data source	
Required data	Information on changes in municipal rules and regulations to support implementation and "mainstreaming" of NBS as a result of a NBS project
Data input type	Qualitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 7 Clean and affordable energy, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf Wamsler, C., Luederitz, C., & Brink, E. (2014). Local levers for change: Mainstreaming ecosystem-based adaptation into municipal planning to foster sustainability transitions. Global Environmental Change, 29, 189-201.

18.11 Perceived ease of governance of NBS

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Perceived ease of governance of NBS	**Participatory Planning and Governance**
Description and justification	Existing municipal rules and regulations based upon centralised or top-down systems of management, traditional construction processes, etc., may serve as a barrier to innovations like NBS. Projects may be able to forge a new path, or shift the paradigm within which municipalities operate in order to better support innovative actions that challenge the status quo. There is growing recognition of the critical importance of citizen engagement in sustainable urban development. Long-term climate change mitigation and adaptation planning has been identified as a key area for participatory or inclusive governance, wherein municipalities partner with citizens to develop and manage solutions (Brink & Wamsler, 2018).
Definition	The extent to which the NBS project has contributed to, or inspired, the development of new forms of NBS governance in the form of changes to rules or regulations (unitless).
Strengths and weaknesses	+ Easy and straightforward assessment - The results may not be holistic
Measurement procedure and tool	The extent to which an NBS project has contributed to, or inspired, the development of new forms of NBS governance in the form of changes to rules or regulations can be evaluated using a five-point Likert scale (Bosch et al., 2017): **No impact — 1 — 2 — 3 — 4 — 5 — High impact** 1. No impact: the project has not, at any level, inspired changes in rules and regulations. 2. Little impact: the project has led to a localised discussion about the suitability of the current rules and regulations. 3. Some impact: the project has led to a public discussion, leading to a change in rules and regulations. 4. Notable impact: the project has led to a public discussion, leading to a change in rules and regulations. This in its turn has sparked a discussion amongst other

	administrations about the suitability of the current rules and regulations. 5. High impact: the project has led to a public discussion, leading to a change in rules and regulations. This in turn has inspired other administrations to reconsider their rules and regulations
Scale of measurement	Municipality scale
Data source	
Required data	Information on changes to rules or regulations based on contribution or inspiration from an NBS project
Data input type	Qualitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Low
Synergies with other indicators	Relation to *Openness of participatory processes, Design for sense of place* indicators and *Green Space Management* indicator group
Connection with SDGs	SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	Questionnaires
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf Brink, E., & Wamsler, C. (2018). Collaborative governance for climate change adaptation: Mapping citizen-municipality interactions. Environmental Policy & Governance, 28, 82-97.

18.12 Diversity of stakeholders involved

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Diversity of stakeholders involved	**Participatory Planning and Governance**
Description and justification	Co-production is all about diversity, meaning that diverse actors need to be involved on an equal basis (Bussu and Galanti 2018; Frantzeskaki and Kabisch 2016). Co-production in nature-based solution projects encompasses a wide range of opportunities for citizens, nongovernmental organisations, businesses and other stakeholders to co-design, co-implement and co-manage a nature-based solution. Including different perspectives, needs and knowledges does not only produce a more creative output but also ensures their accountability and applicability (Frantzeskaki and Kabisch 2016). Actor mapping tools facilitate the identification of suitable participants based on different types of knowledge and backgrounds (van der Jagt et al. 2019; Hölscher et al. 2018; Wittmayer et al. 2012). While recognising the importance of other requirements, the diversity indicator looks at the diversity of knowledge and backgrounds rather than e.g. gender (see Indicator on social equity). Avelino and Wittmayer (2016) introduced the Multi-actor Perspective (MAP) (Figure 1). The MAP draws on work by institutional scholarship, particularly the 'Welfare Mix' scheme by Evers and Laville (2004: 1740) and Pestoff (1992: 2537). This scheme distinguishes between four different sectors: state, market, community and third sector. The distinction of sectors is based on general characteristics and 'logics' of a sector (i.e. formal vs. informal, for-profit vs. non-profit, public vs. private). Notable is the category of 'third sector' as an intermediary sector between state, market and community. It includes the non-profit sector that is formalised and private, but also intermediary organisations that cross the boundaries between profit and non-profit, private and public, formal and informal (e.g. 'not-for-profit' social enterprises, universities, or cooperatives). The consideration of the third sector enables to more sharply specify what is usually referred to as 'civil society' (Avelino and Wittmayer 2016). Even if a co-production process includes actors from NGOs, citizens or grassroots initiatives can still remain underrepresented. The MAP takes the Welfare Mix scheme further and distinguishes between different individual and

organisational actors that can take up different roles in relation to different sectors. The MAP can be used as an actor mapping tool in co-production processes, enabling to be more explicit about which actor categories and roles are included and to overcome a bias towards certain (groups of) actors and sector logics (Hölscher et al. 2018).

Figure 1: MAP: level of individual actors per sector (source: Avelino and Wittmayer 2016, p. 637)

Similarly, the Quintuple Helix model helps to identify five key audiences to be targeted as part of a co-production process (Carayannis et al. 2012; Figure 2): 1) Education system (e.g. academia, higher education, schools, kindergartens); 2) Economic system (e.g. industry(ies), firms, services, banks, entrepeneurs); 3) Political system (e.g. national/local governments, policymakers, law makers, politicians); 4) Civil society and media (e.g. local communities, community groups, NGO's, mainstream and local media, environmental media); 5) Natural environments of society (e.g. NBS experts from NGO's, policy makers, political bodies, experts and opinion leaders on NBS).

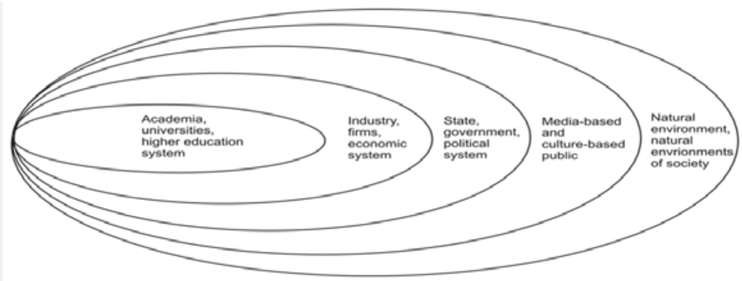

Figure 2: Quintuple Helix (Carayannis et al. 2012, p. 6)

Definition	The indicator is defined in terms of the mix of stakeholders involved in a co-production process, based on their backgrounds and sectoral logics.
Strengths and weaknesses	+ relatively easy-to-measure indicator + helps understanding whether a co-production process included a balanced participation of different stakeholders, views and perspectives - Does not explicitly consider other forms of diversity and inclusivity related to social equity (e.g. representation of underrepresented groups, gender equality)
Measurement procedure and tool	*Quantitative P*: Scale inventory of types of actors per co-production/participatory process T: MAP or Quintuple helix model. The numbers per category are added up and the proportion of each group is calculated. What is considered a good spread across the different groups often depends on the type of participation process. *Qualitative P*: T: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation T: participatory data collections methods, such as focus groups
Scale of measurement	At the beginning of the meetings organized during a co-production/participatory process, stakeholders should be invited to sign a timesheet. The Indicator will be equal to the whole number of stakeholders involved during these meetings. In a second step, the stakeholders are categorised based on the role/position they took in the process. There are two options to categorise the diversity of stakeholders: Option A) Multi-Actor Perspective (MAP) State: e.g. policymaker, politician, bureaucrat Community: e.g. resident, neighbour Market: e.g. firm, entrepreneur

	Third Sector: e.g. activist, volunteer, researcher Option B) Quintuple Helix Education system: e.g. academia, higher education, schools, kindergartens Economic system: e.g. industry(ies), firms, services, banks, entrepeneurs Political system: e.g. national/local governments, policymakers, law makers, politicians Civil society and media: e.g. local communities, community groups, NGO's, mainstream and local media, environmental media Natural environments of society: e.g. NBS experts from NGO's, policy makers, political bodies, experts and opinion leaders on NBS In a third step, the numbers per category are added up and the proportion of each group is calculated. What is considered a good spread across the different groups often depends on the type of participation process.
Data source	
Required data	Essential: Time-sheets for each meeting/activity per participatory process Essential: knowledge about stakeholder backgrounds/category Desirable: reflective notes from organisers about reasons for over-/underrepresentation of certain groups
Data input type	Quantitative, qualitative if linked to reflections about reasons for over-/underrepresentation
Data collection frequency	Every six months, aligned with co-production / participatory processes Most desirable after each meeting to reflect on diversity
Level of expertise required	Low
Synergies with other indicators	
Connection with SDGs	Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

	Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	This Indicator can only be calculated through a participatory data collection (timesheets). Participatory methods (e.g., focus groups, narrative studies, participatory data collection methods, and/or participatory action research) may be applied to collect community-relevant information on over-/underrepresentation.
Additional information	
References	Avelino, F. and Wittmayer, J.M. (2016). Shifting Power Relations in Sustainability Transitions: A Multi-actor Perspective. Journal of Environmental Policy & Planning, 18(5): 628-649. DOI: 10.1080/1523908X.2015.1112259. Bussu, S., Galanti, M.T. (2018) Facilitating coproduction: the role of leadership in coproduction initiatives in the UK, Policy and Society, 37:3, 347-367, DOI: 10.1080/14494035.2018.1414355 Carayannis, E.G., Barth, T.D., Campbell, D.F.J. (2012) The Quintuple Helix innovation model: global warming as a challenge and driver for innovation. Journal of Innovation and Entrepreneurship, 1:2. DOI: 10.1186/2192-5372-1-2 Evers, A. and Laville, J.L. (Eds.) (2004). The third sector in Europe. Edward Elgar Publishing Ferlie, E., Pegan, A., Pluchinotta, I., Shaw, K. (2019) Co-production and co-governance: strategic management, public value and co-creation in the renewal of public agencies across Europe. COGOV Deliverable 1.1. Frantzeskaki, N., & Kabisch, N. (2016). Designing a knowledge co-production operating space for urban environmental governance—Lessons from Rotterdam, Netherlands and Berlin, Germany. Environmental Science & Policy, 62, 90-98. Hölscher, K., Avelino, F., & Wittmayer, J. M. (2018). Empowering actors in transition management in and for cities. In Co-creating Sustainable Urban Futures (pp. 131-158). Springer, Cham. Pestoff, V. (1992). Third Sector and Co-Operative Services – An Alternative to Privatization. Journal of Consumer Policy, 15:21-45. Van der Jagt, A.P.N., Smith, M., Ambrose-Oji, B. et al. (2019) Co-creating urban green infrastructure connecting people and nature: A guiding framework and approach. Wittmayer, J., Frantzeskaki, N., van Steenbergen, F., Roorda, C. and Henneman, P. (2012). Introducing a profile for urban change agents: Experiences from five European cities, Drift Working Paper, Erasmus University Rotterdam, Rotterdam, Creative Commons.

18.13. Transparency of co-production

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Transparency of co-production	**Participatory Planning and Governance**
Description and justification	Transparency is one of the basic dimensions of good co-production and participatory governance processes. It especially important to ensure the legitimacy of the process, to create co-ownership over process and results and facilitate trust-building (Djenontin and Meadow 2018; Hölscher et al. 2019). In general terms, transparency means operating in such a way that it is easy for others to see what actions are performed. The relationship between transparency and participation is assumed to be reciprocal: while transparency is a requirement for 'good' participation, collaborative governance and co-production are a means to enhance transparency (Campanale et al. 2020). Participatory approaches reduce the information asymmetry and align preferences and incentives between service recipients and providers (Eriksson 2012, cf. Campanale et al. 2020). The concept of transparency is most commonly used in literature as a key principle of 'good governance'. The normative belief is that governments should report about the 'why, how, what, and how' of their activities, through information made available to citizens in the most convenient way. As such, transparency is a way to show integrity, performance and accountability, and recently became a vehicle to increase legitimacy, trust in government, improve citizen engagement and participation, and curb corruption and maladministration (da Cruz 2015; Wu et al. 2015; Council of Europe 2017). Transparency in this context is more about how willing a government is to allow citizens to monitor its performance, processes and internal workings, rather than citizen participation therein. While there are many definitions of transparency in this context, all of them hold the role of **information accessibility** at their core. For instance, Kaufmann and Kraay (2002) define transparency as "the increased flow of timely and reliable economic, social, and political information, accessible to all relevant stakeholders" (cf. del Sol 2013). In that sense, transparency is closely related to accountability: "Information should be available to those who can be affected by the decision-making and be understandable by its users. Accountability can be defined as the obligation of public sector organizations to account for their decisions and actions to the citizens and other

stakeholders” (Campton et al. 2020; see also Wu et al. 2015). There are several indicators and frameworks to compare and promote best practices in transparency among public institutions such as municipalities and regional and national governments (Campanale et al. 2020). An example of an extensive framework was developed by da Cruz (2015). It includes a participatory approach for selecting indicators, metrics, and the weighting scheme to assess governments or public authorities. It includes 76 indicators grouped by seven dimensions, including organizational information and operation of the municipality, relationship with citizens, public procurement and economic and financial transparency (ibid.).

From the uses of transparency within participatory governance and planning literature it becomes clear that transparency also relates to a **process dimension**. In this perspective, transparency is about the provision of information about how such processes are being structured and communicated. The participatory process should be transparent so that the participants and the wider public can see what is going on and how decisions are being made (Rowe and Frewer 2000). In a general sense, this type of transparency has an internal and external implication. The internal implication relates to the transparency towards the participants of the collaborative process. The external implications relate to the transparency of how the process and results are communicated to the broader audience. Information should be communicated through a variety of online and offline means (Rosenström and Kyllonen 2006). A genuine attempt to share information means that organisers actively ensure that all stakeholders are aware of, and understand, the relevant information (Laktić and Malovrh 2018). If any information needs to be withheld from the participants or the wider public, for reasons of sensitivity or security, it is important to admit the nature of what is being withheld and why, “rather than risking the discovery of such secrecy, with subsequent adverse reactions” (Rowe and Frewer 2000, p. 15).

A first condition for process transparency is i**nformation about the purpose of the process and the participation**. Stakeholders should be informed about what the purpose of their participation and involvement is, who can participate and how, what they can influence and how the results will be used (Laktić and Malovrh 2018). This also includes the provisioning of relevant background materials (Rowe and Frewer 2000).

A second condition for process transparency is **information about the process decision-making structure**. Relevant information includes the manner of participants selection, decision-making procedures (Rowe

	and Frewer 2000; Laktić and Malovrh 2018; Rosenström and Kyllonen 2006). Specifically, the documentation of the process of reaching a decision (as well as the outcome) is liable to increase transparency (and hence the perceived credibility of the exercise) as well as the efficiency of the process (Rowe and Frewer 2000). Another condition relates to the **clarity of roles**. The (co-)definition of roles and responsibilities in the process gives clarity about what is expected from actors and help them feel comfortable in and adopting their (new) roles and functions (Ferlie et al. 2019). There are typically different, but sometimes overlapping roles in participatory processes, including participants, facilitators, technical experts and initiators (Hölscher et al. 2019). Goals and roles need to be continually deliberated and adjusted (Djenontin and Meadow 2018). A final condition for process transparency is the provisioning of **information about the content and results**, including relevant background materials, meeting minutes, updates about progress and changes within the process and well as results (Rowe and Frewer 2000; Laktić and Malovrh 2018; Rosenström and Kyllonen 2006). Evaluating this type of process transparency is difficult, mainly because transparency is difficult to isolate (Rowe and Frewer 2000; Laktić and Malovrh 2018). Transparency also becomes blurred, relating to questions about transparency by whom, to whom (Campanale et al. 2020). While we define transparency as a responsibility mainly on the part of the organisers, also participants need to ideally be transparent about their motivations and interests, which they bring into such processes.
Definition	This indicator is defined as the extent to which the co-production process is transparent about the purpose, decision-making structure, roles, content and results.
Strengths and weaknesses	+ Provides insights into the way co-production processes are structured and communicated + Creates space and opportunity to reflect on co-production process - Indicator veils complexity and multiple perceptions of transparency - Qualitative data mining could be time-consuming
Measurement procedure and tool	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: 4 items at measuring respondents' perception of transparency ☒ *Qualitative P*: o T: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation o T: participatory data collections methods, such as focus groups

Scale of measurement	The levels of transparency can be evaluated based on responses to survey questions using a five-point Likert scale. (1) The stakeholders/I was aware about the goals of the process. a. Strongly disagree b. Disagree c. Not sure d. Agree e. Strongly agree (2) The stakeholders were/I was informed about how the results would be used. a. Strongly disagree b. Disagree c. Not sure d. Agree e. Strongly agree (3) The procedures and rules for decision-making and changes in the process were openly communicated. a. Strongly disagree b. Disagree c. Not sure d. Agree e. Strongly agree (4) The results of the process were regularly disseminated to a wider audience – via online and offline channels. a. Strongly disagree b. Disagree c. Not sure d. Agree e. Strongly agree
Data source	
Required data	✓ Essential: questionnaire scoring on transparency ✓ Desirable: qualitative data on reasons and causes for (in-)transparency, and implications for how the process and results are perceived
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for)
Data collection frequency	Aligned with NBS co-production process, at least at the end of a co-production process or every 6 months if the process is longer
Level of expertise required	☒ Quantitative data collection requires no expertise ☒ Qualitative data collection requires medium level expertise in social science research
Synergies with other indicators	
Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

	Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on reasons and causes for (in-)transparency, and implications for how the process and results are perceived.
Additional information	
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18.14. Activation of public-private collaboration

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Activation of public-private collaboration	Participatory Planning and Governance
Description and justification	Traditionally, most urban green initiatives were, and still are, initiated and governed by local governments (Sekulova and Anguelovski 2017; Dushkova and Haase 2020). However, public agencies tend to withdraw in long-term managing and financing, making interventions one-off measures or leaving them without maintenance funds (Nesshöver et al. 2017; Young and McPherson 2013). Meanwhile, the number of green spaces, especially community gardens, initiated and managed in a bottom-up fashion is increasing (Buijs et al. 2018; Sekulova and Anguelovski, 2017). The private sector has started to be dominant driving force in implementing nature-based solutions, particularly for green roofs and facades. Private initiatives often still need support from local governments in the form of land permits, funding, knowledge and linking to other practitioners (Frantzeskaki 2019). Collaboration between various public and private actors can help overcoming fragmentation, disengagement and social exclusion girdling nature-based solutions planning through integrating multiple perspectives, needs and knowledges and opening up opportunities for innovation with multiple ecological, social and economic gains (Frantzeskaki 2019; Davies and Lafortezza 2019). Collaboration can be of importance for the social support of the nature-based solutions over time. Involvement of citizens and other stakeholders during project implementation ensures establishment of a common understanding of the project's longer-term maintenance or management needs, and provides managers and developers with critical input regarding the project's performance relative to stakeholder expectations. It can also be a matter of creating economic insurance, where different financial resources can be activated to sustain functionality over time. For these reasons, public-private collaboration and co-management of nature-based solutions are advocated (European Commission, 2016; Pauleit et al., 2017; Kabisch et al. 2017). Often, the term public-private partnership (PPP) is employed to refer to a more or less formalised relationship formed between public and private sectors, with different levels of responsibilities, to deliver public services (Ahmadabadi and Heravi 2019; Chan et al. 2010). Collaborations between public and private actors in nature-

	based solutions planning, delivery and stewarding can however be much more diverse. They can involve formal and informal government-industry, government-research or citizen-government collaborations – to name but a few. For example, Buijs et al. (2018) show how active citizens can significantly contribute to urban green infrastructure planning and implementation, by developing large parks with volunteers or designing a network of green corridors (Buijs et al. 2018). These collaborations can also be short-term or long-term – important is that at least one public and one private party is involved with the aim to collaborate on the planning, delivery and/or stewarding of a nature-based solution. It is important to note that public-private collaborations are no magical recipe to overcome typical governance problems. Research on PPPs has focused on unveiling various reasons for pitfalls and shortcomings, including regulatory issues, inappropriate and complex financing structures (Ahmadabadi and Heravi 2019; Benítez-Ávila et al. 2018). While this indicator suggests to estimate the level of collaboration by counting the number of collaborations activated, it is therefore important to also consider the (reasons for) success and failure of these collaborations.
Definition	The indicator is defined as the number of collaborations between public and private actors activated for the planning, delivery and/or stewarding of a nature-based solution.
Strengths and weaknesses	+ Easy measure of public-private collaboration + Creates space and opportunity to reflect on collaboration (goals, outcomes, interests etc.) - Does not reveal the quality of the collaboration and diversity in terms of (especially private) actors involved - (Qualitative) data mining could be time-consuming
Measurement procedure and tool	*Quantitative P*: number (counting number of collaborations activated) *Qualitative P*: T: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation T: participatory data collections methods, such as focus groups
Scale of measurement	Number
Data source	
Required data	Essential: Information on public-private collaborations activated throughout each nature-based solution project planning, delivery and stewardship Recommended: Data on the types of public-private collaboration, including what type of actors were involved, what were the actors' respective goals and individual roles

	in the collaboration, how was the collaboration structured and how satisfied were the actors
Data input type	Quantitative (number of collaboration) and qualitative if data on the types of public-private collaboration is considered
Data collection frequency	Aligned with NBS implementation and timing of targeted objectives; at minimum before and after NBS implementation
Level of expertise required	Medium: data collection on collaborations requires knowledge about existing and new collaborations
Synergies with other indicators	
Connection with SDGs	Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	Participatory methods (e.g., focus groups, participatory data collection methods, and/or participatory action research) may be applied to collect information on the types of public-private collaboration, including what type of actors were involved, what were the actors' respective goals and individual roles in the collaboration, how was the collaboration structured and how satisfied were the actors
Additional information	
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18.15. Reflexivity: identified learning outcomes

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Reflexivity: identified learning outcomes	**Participatory Planning and Governance**
Description and justification	Conventional governance, policy-making, planning and project management approaches aim to optimize existing processes starting from pre-defined problems and solutions. Only after a problem or solution is identified, a monitoring and evaluation process is designed. For example, indicators are selected to measure the effectiveness of the project(s) after implementation. This is done by experts and involves little participation of other actors. However, implementing nature-based solutions – especially on a large scale in cities – is complex: it touches on multiple goals and interests and requires innovative processes for collaboration, financing and design etc. It cannot be 'blueprint' planned beforehand. In addition, the context might change, new opportunities and barriers may

	present themselves. Therefore, the existing evaluation methods are not sufficient because they leave little room for collaborative learning, experimentation and adaptations during the planning, delivery and stewardship phase of the nature-based solution. Nature-based solutions planning, delivery and stewardship requires ongoing reflection about who is involved, who isn't, and who benefits and who doesn't, as well as adaptability to respond to new insights, demands and needs (Chatterton, Owen, Cutter, Dymski, & Unsworth, 2018; Ferlie, Pegan, Pluchinotta, & Shaw, 2019; Muñoz-Erickson, Miller, & Miller, 2017). This learning process is reflexive when participants are self-critical and reflect on the inherent political nature of how they build knowledge, the assumptions they make and the normative premises that guide them (Miller & Wyborn, 2018; Muñoz-Erickson et al., 2017). This requires a process of learning-by-doing and doing-by-learning in terms of goals achievement, adopt lessons learned into new or existing structures, strategies or practices and identify needs for adaptation (Beers & van Mierlo, 2017; Dentoni, Bitzer, & Pascucci, 2016; Frantzeskaki, Kabisch, & McPhearson, 2016). To support this process reflexive monitoring was developed as a method with specific tools developed for practitioners (van Mierlo et al., 2010), but there are other ways to increase the reflexivity of a learning process. The learning process results in 'reflexive learning outcomes' when knowledge (the what), actions (the how) and relations (the who) become substantively interwoven (Beers, Van Mierlo, & Hoes, 2016) as a result of a shared experience in how to overcome barriers or use opportunities and learning about how to deal with them. Thus, learning outcomes are reflexive, when not only new insights are gained, but when these insights are implemented into the context within which the learning actors operate. Reflexive learning outcomes can be operationalized in terms of changes in the existing 1) rules guiding actors' practices, 2) relations between actors, and between the initiative and context, 3) practices as the common ways of working and 4) discourse related to the future of the initiative's sector (Beers & van Mierlo, 2017). For application by the cities in the Connecting Nature project we developed a method to track and distill learning outcomes and reflect upon their reflexivity (Lodder, Sillen, Frantzeskaki, Hölscher, & Notermans, 2019).
Definition	This indicator is defined in terms of the number of reflexive learning outcomes identified throughout nature-based solutions process. Reflexive learning outcomes are changes in the existing 1) rules guiding actors' practices, 2) relations

	between actors, and between the initiative and context, 3) practices as the common ways of working and 4) discourse related to the future of the initiative's sector (Beers & van Mierlo, 2017).
Strengths and weaknesses	+ The learning process that results in reflexive learning outcomes is a practice-driven process in which the involved actors steer the direction in which the changes are needed. + Harvesting learning outcomes can work empowering for practitioners as these illustrate the innovative processes in the achievements in terms of barriers that are overcome, or opportunities taken. + Learning outcomes are rich qualitative data sources as they describe not only one experience but also how the experience influenced its context. - The learning process and creating space for reflection to formulate learning outcomes can be challenging and complex to manage. - The process can be a time intensive process for practitioners, facilitators and experts involved. - Formulating reflexive learning outcomes requires practice from practitioners and facilitators.
Measurement procedure and tool	*Quantitative P*: number (counting number of learning outcomes identified) T: Involved actors can start to list experiences in terms of how they overcame the barriers and used the opportunities they encountered. Then they can organise time to reflect upon the changes they established in terms of novel rules, relations, practices and discourses. In this way they can be reformulate their experiences as reflexive learning outcomes. This can be done by the practitioners themselves or by (external) experts who facilitate the learning process. The number of learning outcomes can then be counted per month or year. *Qualitative P*: T: Practitioners could apply reflexive monitoring tools to structure their learning process and integrate it in their daily activities. By working with tools as a 'Dynamic Learning Agenda' actors map the continuous and ongoing flow of decisions, observations, actions, thoughts, reflections, interactions, adjustments, etc. (Regeer, Hoes, van Amstel-van Saane, Caron-Flinterman, & Bunders, 2009). This agenda can serve as a data source for tracking and formulating reflexive learning outcomes in a structured way. This can be done by the practitioners themselves or by (external) experts who facilitate the learning process. T: Case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation – can be used as a data source to formulate reflexive learning outcomes by (external) experts.

	T: Other participatory data collections methods, such as focus groups can also be organised to collectively reflect upon the learning process and to formulate reflexive learning outcomes facilitated by (external) experts if needed.
Scale of measurement	Number of identified reflexive learning outcomes per month or year that can be specified in number of changes in the context based on reflexivity type (rules, and/or relations, and/or practices and/or discourse).
Data source	
Required data	Essential: Group of practitioners with experiences in implementing the large-scale nature-based solution Goals they want to achieve with their nature-based solution Barriers and opportunities they faced and what they did to overcome or take them Desirable: Participatory identification of learning outcomes and the assessment of the type of reflexivity
Data input type	Quantitative (number of learning outcomes) and qualitative if data on the types and implications of learning outcomes are considered
Data collection frequency	Depending on experience of actors involved they can organize time to reflect upon their experiences and formulate learning outcomes themselves ones every 1-3 months to identify and every 6 months to revisit. When other methods are selected, and the analysis is done by experts, every 6 months to once a year is possible too.
Level of expertise required	Methodology and data analysis require high expertise understanding of reflexivity and analytical skills but also knowledge about the context to ensure the changes are reflexive and not optimizing existing structures, cultures and practices. Quantitative data collection (counting number of learning outcomes and innovations) requires no expertise Qualitative data collection (facilitation of participatory sessions to identify reflexive learning outcomes) require high expertise in action-research and basic training in participatory data collection, appreciative inquiry and critical analysis.
Synergies with other indicators	
Connection with SDGs	Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

	Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	Participatory methods (e.g., narrative studies, participatory data collection methods, and/or participatory action research) are crucial for this indicator to collect relevant information on learning outcomes and how these affect the context and different types of actors.
Additional information	
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18.16. Facilitation skills for co-production

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Facilitation skills for co-production	**Participatory Planning and Governance**
Description and justification	Workshops and interactive meetings with multiple actors are at the core of co-production processes. A workshop can be generally viewed as a structured meeting that is led by a facilitator and that emphasises participatory involvement (Weyers and Rankin 2007). One of the salient characteristics of such events is that the facilitator plays a pivotal role in their ultimate success or failure. Thus, facilitation skills are a key precondition for co-production (Reed and Abernethy 2018; Djenontin and Meadow 2018; Chatterton et al. 2018). Facilitation is about making meetings participative and more effective: "Facilitation is the art of leading people through processes towards agreed-upon objectives in a manner that encourages participation, ownership and creativity by all those involved" (Cserti 2019). Bens (2009) defines a facilitator as someone "who contributes structure and process to interactions so groups are able to function effectively and make high-quality decisions. A helper and enabler whose goal is to support others as they achieve exceptional performance." A facilitator has a wide range of tasks to perform in co-production processes. Cserti (2019) summarise three key roles of facilitators: A 'catalyst' that makes possible the transformation of input (ideas, opinions) to desired outcome without being an active part of the conversation itself. A 'conductor' of an orchestra who synchronises all participants, optimally guiding the use of their instruments toward the desired result – a harmonic musical expression of the musicians' complex interactions, creativity, and expertise. A 'coach' who helps the group form a constructive way of working together, identify its needs and wishes, and reach the outcome they would jointly like to achieve.

In line with these roles, facilitation skills are complex (ibid.; Bens 2009). They involve skills for designing, planning and preparing a workshop or meeting (e.g. asking the right questions, process design, agenda planning, communication with stakeholders), running the process and facilitating a workshop or meeting (e.g. creating an inclusive environment, communicating clear guidelines and instructions, empathy, active listening, consensus-building, managing time, flexibility), and recording results (e.g. recording and keeping visible agreements made, points of consensus, decisions and action item).

For co-production processes, facilitation skills need to be ensured by those initiating and guiding the process; they can emerge from the initiating team (e.g. city government) or participants composition, they can be mobilised elsewhere (e.g. by hiring a professional facilitator), and fostered by institutional support (e.g. professional development training) (Hölscher et al. 2018; Djenontin and Meadow 2018). 'Skill' in this context can be defined as "personal qualities" (Green 2013 p. 5). Skills are acquired through both experience and training and represent the power of an individual to make that knowledge investment productive in the job or in real life (OECD 2017).

Bens (2009) developed a Facilitator Self-Assessment checklist that can be applied for different levels of skills and allows people identify both current competences and skills they need to acquire most. Level I consists of core skills required to lead routine discussions and manage meetings effectively. Level II consists of the ability to design complex decision processes and manage difficult situation. Level III involves designing and leading activities that are part of a planned change efforts. The questions for each level cover different levels of facilitation skills related to the ability to manage a group discussion, effective meeting design, fostering participation and making clear and accurate summaries and notes.

Weyers and Rankin (2007) developed a Facilitation Assessment Scale (FAS) to measure and analyse the impact of the facilitator and facilitation process on the outcomes of workshops. The assessment questionnaire consists of four compulsory categories of effective workshop facilitation: Firstly, the facilitator's aptitude focuses on the extent to which they can be viewed as both content experts and as skilled interpreters and promoters of the data and ideas. Secondly, his/her presentation skills refer to the presentation of data and the facilitator's ability to involve participants. Thirdly, the learning process assesses the quality of the communication and appropriateness of the material and data that was communicated. Fourthly, the workshop context focuses on the contextual elements that might have a positive or

	negative impact on goal attainment, including quality of the venue, the learning material and educational aids and tools.
Definition	Facilitation skills for co-production refer to the availability of personal qualities of an individual to lead groups through key meetings and gatherings towards intended outcomes. The Indicator will be equal to the sum of the average number of each question (sum of responses per question divided by respondents), divided by number of questions. The facilitator skills can be evaluated using a five-point Likert scale (Weyers and Rankin 2007): *Poor — 1 — 2 — 3 — 4 — 5 — Very good / excellent* 1. Poor (1 – 1.79) 2. Fair (1.8 – 2.59) 3. Average (2.6 – 3.39) 4. Good (3.4 – 4.19) 5. Very good / excellent (4.2 – 5)
Strengths and weaknesses	+ Provides detailed overview of available facilitation skills and whether additional skills need to be sourced + Can give explanation into impact of co-production processes + Easy to implement ex ante and ex post (e.g. selection of questions integrated in questionnaire after a workshop) - Risk of stakeholder fatigue when there are multiple questionnaires after a workshop
Measurement procedure and tool	*Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) T: 8 items at measuring respondents' perception of their/the facilitator's facilitation skills for co-production. *Qualitative P*: T: participatory data collection methods, such as focus groups, semi-structured interviews, case study analysis, participant and non-participant observation T: When looking for a candidate who could facilitate a co-production process, s/he could use the questionnaire as a self-assessment. In addition, the employees could look at their past experiences, who they have worked with and for specific facilitation training.
Scale of measurement	Items aimed at assessing facilitator's skills (Weyers and Rankin 2007; Bens 2009): 1. The facilitator is knowledgeable about the subjects/issues to be/that were covered *Strongly disagree – Disagree - Not sure – Agree - Strongly agree* 2. The facilitator can/could link the material to the participants' level of knowledge *Strongly disagree – Disagree - Not sure – Agree - Strongly agree* 3. The facilitator is/was skilled at active listening, paraphrasing, questioning and summarising key points.

	Strongly disagree – Disagree - Not sure – Agree - Strongly agree 4. The facilitator is/was able to manage time and maintain a good pace. *Strongly disagree – Disagree - Not sure – Agree - Strongly agree* 5. The facilitator knows/knew techniques for encouraging active participation and generating ideas. *Strongly disagree – Disagree - Not sure – Agree - Strongly agree* 6. The facilitator encourages/encouraged participant involvement. *Strongly disagree – Disagree - Not sure – Agree - Strongly agree* 7. The facilitator is/was able to organise workshops *Strongly disagree – Disagree - Not sure – Agree - Strongly agree* 8. The facilitator is/was able to help a group achieve consensus and gain closure even in polarized situations. *Strongly disagree – Disagree - Not sure – Agree - Strongly agree*
Data source	
Required data	Essential: Questionnaire of facilitation (self-)assessment Desirable: Qualitative data on how the facilitation was perceived, what could be done better and how it affected the co-production process/outcomes
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for)
Data collection frequency	Aligned with NBS implementation, especially the implementation of workshops. Assessment can be done before or after workshops. Before: (self-)assessment of facilitator and/or initiating/organising team. After: Let each participant complete the facilitation assessment questionnaire at the end of a workshop.
Level of expertise required	Quantitative data collection requires no expertise Qualitative data collection (case study and participatory methodology, for example) requires medium level expertise in social science research
Synergies with other indicators	
Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Opportunities for participatory data collection	Participatory methods (e.g., focus groups, participatory data collection methods, and/or participatory action research) may be applied to collect community-relevant information on facilitator's skills and how it affected their perception of the co-production process.
Additional information	
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18.17. Procedural fariness

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Procedural fairness	**Participatory Planning and Governance**
Description and justification	Procedural fairness refers to "the fairness of the processes used to produce [...] decisions" (Lauber et al, 2010). It is important in relation to participatory planning and

	governance of nature-based solutions as it gives interested or affected parties the opportunity to take any legitimate role in a decision-making process. This implies that all stakeholders have equal opportunities to express and defend opinions as well as to request evidence and justification from other stakeholders (Rosentröm and Kyllönen 2007; Laktic and Malovrh 2018). Procedural fairness requires basic ground rules (e.g. on timetables, procedures) that ensure legitimacy, accountability and inclusivity of the process, treat everyone as equals and give clarity to how discussions and data are treated can build trust (Ferlie et al. 2019; Frantzeskaki 2019; Ferretti et al. 2018; Chatterton et al. 2018).
Definition	The extent to which the decision-making process was perceived as fair by the participants.
Strengths and weaknesses	+ easy measure of how process was organized and perceived by participants -simplified measure with little information about what kind of groups were involved, and what it implies for roles, relationships and empowerment
Measurement procedure and tool	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: Six items at measuring procedural fairness ☒ *Qualitative P*: o T: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation o T: participatory data collections methods, such as focus groups
Scale of measurement	Responses to survey questions using a five-point Likert scale based on (Lauber et al 2010): *strongly disagree, disagree, neutral, agree, and strongly agree* (1) Impartiality Whether organising party/decision-maker was impartial during the process (2) Honesty Whether organising party/decision-maker was honest during the process (3) Equal opportunity whether all participants had an equal opportunity to participate in the process (4) Representation whether all viewpoints were adequately represented during the process (5) Voice whether all participants had the opportunity to voice their opinions during the process

	(6) Influence whether participants influenced the final decision
Data source	
Required data	✓ Essential: questionnaire scoring on procedural fairness ✓ Desirable: qualitative data on reasons and causes for procedural fairness or lack hereof, and implications for how the process and results are perceived
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for)
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	☒ Quantitative data collection requires no expertise ☒ Qualitative data collection requires medium level expertise in social science research
Synergies with other indicators	
Connection with SDGs	Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	Participatory methods may be applied to collect information about perceptions of diverse actors to reveal challenges and opportunities, power dynamics, as well as reflect on outcomes with regards to procedural fairness
Additional information	
References	Ferlie, E., Pegan, A., Pluchinotta, I., Shaw, K. (2019) Co-production and co - governance: strategic management, public value and co-creation in the renewal of public agencies across Europe. COGOV Deliverable 1.1. Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. Environmental Science & Policy, 93, 101–111. https://doi.org/10.1016/J.ENVSCI.2018.12.033 Laktić, T., & Malovrh, Š.P. (2018). Stakeholder participation in Natura 2000 management program: case study of Slovenia. Forests, 9(10), 599. Lauber, B. (1999) Measuring Fairness in Citizen Participation: A Case Study of Moose Management, Society & Natural Resources, 12:1, 19-37, DOI: 10.1080/089419299279867 Rosenström, U. & Kyllönen, S. (2007). Impacts of a participatory approach to developing national level sustainable development indicators in Finland. Journal of Environmental Management 84: 282-298. doi:10.1016/j.jenvman.2006.06.008

18.18. Strategic alignment

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Strategic alignment	Participatory Planning and Governance
Description and justification	As complex societal problems cannot be addressed through siloed approaches but require the active search for synergies in terms of how different problems relate to one another and how addressing one problem might reproduce another. Multifunctional solutions like nature-based solutions offer the potential to address multiple policy priorities and goals simultaneously. Therefore, the governance of nature-based solutions cannot be separated from urban governance of other policy priorities and goals such as mobility, health, climate resilience etc., and requires cross-sectoral, multi-scale and inclusive approaches in terms of who is best placed to ensure development, delivery and ongoing sustainability of the nature-based solution and how effective governance networks can be fostered (Buijs et al., 2018; Pauleit et al., 2016; Kabisch et al., 2017). This requires alignment with broader social, political and business priorities and goals of a city and of a city region. Strategic alignment is widely discussed in organisation and business management literatures. In general terms, strategic alignment is the process of aligning an organisation's decisions, actions and resources such that they support the achievement of strategic goals. In other words, it means that all elements of an organisation, and each activity and project are arranged in such a way as to best support the fulfilment of its long-term purpose (Trevor and Varcoe 2016). Strategic alignment also means fit between an organisation's strategic priorities and its environment (Walter et al. 2012). In relation to urban governance, Hölscher et al. (2019) define strategic alignment as the orientation towards shared sustainability and resilience goals in the long-term that provide common reference points for concerted action and helps to move from problem-focused to solution-oriented approaches. This means, essentially, that every task should be able to be linked to an overarching vision. Strategic alignment with regard to nature-based solutions means that nature-based solutions are strategically linked to the city governments' goals, strategies and agendas, and vice versa. Strategic alignment has many benefits for nature-based solutions implementation. Overall, several studies found that the level of strategic alignment of an

organisation explains a large degree of the difference in performance between organisations (Al Khalifa 2016; Walter et al. 2012). Positioning individual issues and priorities such as nature-based solutions within broader goals serves to identify synergies and trade-offs across sectors, scales and time (McPhearson et al. 2017). It also helps local policymakers or practitioners build the case and communicate how nature-based solutions can generate wider benefit. In turn, this will help build alliances with different partners who have different interests (Loorbach et al. 2015). For example, a nature-based solution could support people getting healthier by providing space for exercise and help to increase biodiversity and stormwater management. These benefits could be communicated to organisations working to improve residents health and wellbeing, to those working to improve the natural environment, to maintaining open spaces and to development planning organisations.

Strategic alignment builds on buy-in and support (Walter et al. 2012). Thus, it needs to be co-created to ensure that all interests are heard, increase ownership, deal with conflicts, safeguard against overlooking issues of social justice and mediate good compatibility between knowledge and different contexts (Loorbach et al. 2015; Wittmayer et al. 2014). Strategic alignment also implies that resources are deployed towards new behaviours, processes and practices (and way from older, less strategic areas) (Myler 2013). This means that a vision is also translated into (political, financial and institutional) incentives and conditions for working towards the vision, and that the contribution of each project to the strategic goals is evaluated. This involves incorporating long-term and multi-scale thinking into decision-making, implementation processes and performance reviews as well as decisively clarifying costs, benefits and responsibilities at systemic levels for taking up action in alignment with the long-term goals (Loorbach 2014; Hodson and Marvin 2010).

Trevor and Varcoe (2016) present a simple test to evaluate strategic alignment of an organization, based on two crucial dimensions: *(1) Fit between strategy and organisation's purpose*. Purpose is what the organisation is trying to achieve. Strategy is how the organisation will achieve it. Purpose is enduring – it is the north star towards which the company should point. Strategy involves choices about what activities and projects to do to achieve the purpose. In relation to nature-based solutions, this question means how well the nature-based solutions are linked to fulfil the city's goals. (*2) Organisational support for the achievement of the strategy*. This includes all of the required capabilities, resources (including human), and management systems necessary to implement the strategy. If nature-based solutions are a key strategic priority, the

	organisational structure needs to facilitate this. To maintain strategic alignment, an organisation's people, culture, structure and processes have to flex and change as the strategy itself shifts.
Definition	Strategic alignment means that nature-based solutions are strategically linked to the city governments' goals, decisions, actions and resources, and vice versa. The Indicator will be equal to the sum of the average number of each question (sum of responses per question divided by respondents), divided by number of questions. The strategic alignment can be evaluated using a five-point Likert scale: *Poor — 1 — 2 — 3 — 4 — 5 — Very good / excellent* 1. Poor (1 – 1.79) 2. Fair (1.8 – 2.59) 3. Average (2.6 – 3.39) 4. Good (3.4 – 4.19) 5. Very good / excellent (4.2 – 5)
Strengths and weaknesses	+ Innovative measure to check how well an organization (city government) is supportive of nature-based solutions and able to establish synergies across different priorities and departments - Complex concept and measure, followed by considerable limitations in quality of measurement - Measure does not account for identifying synergies and trade-offs between nature-based solutions and priorities and goals
Measurement procedure and tool	*Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) T: 3 items at measuring respondents' perception of strategic alignment *Qualitative P*: T: case study methodology – semistructured interviews, case study analysis, participant and non-participant observation T: participatory data collections methods, focus groups, collaborative participatory data collection, semistructured interviews
Scale of measurement	Items aimed at strategic alignment (based on Trevor and Varcoe 2016; Hölscher et al. 2019): 1. Nature-based solutions are linked to other city strategic priorities, strategies and goals. *Strongly disagree – Disagree - Not sure – Agree - Strongly agree* 2. The city government supports the implementation of nature-based solutions by providing and investing in capabilities, resources and management systems necessary. *Strongly disagree – Disagree - Not sure – Agree - Strongly agree*

	3. The city government supports innovative ways to cooperate, pool resources and build synergies across sectors for nature-based solutions implementation. *Strongly disagree – Disagree - Not sure – Agree - Strongly agree*
Data source	
Required data	Essential: Questionnaire of strategic alignment assessment Desirable: Data on processes of strategic alignment, perceived opportunities and barriers for collaboration and alignment, and outcomes related to a nature-based solution implementation in a city
Data input type	Quantitative (quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for)
Data collection frequency	Aligned with NBS implementation and timing of targeted objectives
Level of expertise required	Methodology and data analysis requires medium level expertise in the city's policy and governance processes and conditions Quantitative data collection requires no expertise Qualitative data collection requires medium level expertise in social science research and the city's policy and governance processes and conditions
Synergies with other indicators	
Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 13. Take urgent action to combat climate change and its impacts Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	Participatory methods may be applied to collect data on nature-based solutions governance processes to reveal challenges and opportunities for strategic alignment, as well as to reflect on outcomes.
Additional information	
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18.19. Reflexivity: time for reflection

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Reflexivity: time for reflection	**Participatory Planning and Governance**
Description and justification	Conventional governance, policy-making, planning and project management approaches aim to optimize existing processes starting from pre-defined problems and solutions. After a problem or solution is identified a monitoring and evaluation process is designed by selecting suitable evaluation methods. For example, by selecting indicators to measure the effectiveness of the project(s) after implementation. This is done by experts and requires a low level of participation of other actors. Implementing large-scale nature-based solutions is a complex process that includes innovative processes that are hard to oversee and plan on beforehand. Therefore, time for reflection is needed to create room for collaborative learning, experimentation and adaptations during the planning, delivery and stewardship phase of the nature-based solution.

	Time for reflection can contribute to increase the reflexivity of the actors when they reflect on how their daily activities contribute to systemic change and why this is needed. Beers & van Mierlo (2017) studied the relation between learning in and reflexivity of system innovation (in this case a nature-based solution) and argue that collective reflection on changing context helps to increase its reflexivity. Time for reflection includes the interweaving of knowledge (the what), actions (the how) and relations (the who) (Beers, Van Mierlo, & Hoes, 2016). It builds on a shared experience of involved actors in how to identify and overcome barriers or use opportunities. Specifically, spending time on reflection means constantly reflecting about who is involved, who isn't, and who benefits and who doesn't, as well as adaptability to respond to new insights, demands and needs (Chatterton, Owen, Cutter, Dymski, & Unsworth, 2018; Ferlie, Pegan, Pluchinotta, & Shaw, 2019; Muñoz-Erickson et al., 2017). Thus, investing time in reflection is not only about generating new insights, but also on how these insights are influencing their context. Time for reflection can be facilitated through various methods. Reflexive monitoring is a concrete method to structure and guide the learning process embodied in time for reflection in the context of system innovations such as nature-based solutions (Sol, van der Wal, Beers, & Wals, 2018; van Mierlo, 2012; van Mierlo, Arkesteijn, & Leeuwis, 2010; van Mierlo, Leeuwis, Smits, & Woolthuis, 2010). Reflexive monitoring allows to capture and assess processes of learning-by-doing and doing-by-learning in terms of goals achievement, adopt lessons learned into new or existing structures, strategies or practices and identify needs for adaptation (Beers & van Mierlo, 2017; Dentoni, Bitzer, & Pascucci, 2016; Frantzeskaki, Kabisch, & McPhearson, 2016). Herewith, reflexive monitoring can also involve developing institutional mechanisms to include outside actors to be part of the design and review process (Muñoz-Erickson, Miller, & Miller, 2017).
Definition	This indicator is defined as the sum of the time invested in reflection on how implementing nature-based solutions contributes to changing its context (e.g. the spatial planning system) by taking a step back from the daily activities to look the bigger picture. Reflection time is defined in terms of time spent participating in reflection meetings and sessions as well as learning about the methods and tools (e.g., reflexive monitoring tools, but other methods can be applied as well) that support this process and practicing with the skills.
Strengths and weaknesses	+ it is easy to track the time simply given to reflection - the amount of time does not say anything about the quality of how the time was spend (e.g. what was the result in terms of learning, skills of insights though analysis and quality of reflexive learning outcomes)

Measurement procedure and tool	*Quantitative P*: number (counting number of hours spent on reflection per week/month) *Qualitative P*: T: reflexive monitoring tools (see e.g. van Mierlo, Regeer, et al., 2010) or the Connecting Nature reflexive monitoring process for cities (Lodder et al., 2019) T: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation T: participatory data collections methods, such as focus groups
Scale of measurement	Hours or days per week or month
Data source	
Required data	Essential: Timesheets of total amount of time spent on reflection Desirable: Overview of reflexive monitoring activities How much time was spent per activity Reflection about barriers and opportunities for, gains etc. from spending time reflecting
Data input type	Quantitative (time for reflection) and qualitative if data on barriers, opportunities etc. are considered.
Data collection frequency	Monthly
Level of expertise required	Tracking time for reflection require medium level expertise in terms of understanding of reflexivity Quantitative data collection (listing activities and counting number of hours/days spent on them) requires no expertise Qualitative data collection (facilitation of participatory sessions to identify reflexive learning outcomes) require high expertise in action-research and basic training in participatory data collection, appreciative inquiry and critical analysis.
Synergies with other indicators	
Connection with SDGs	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development
Opportunities for participatory data collection	Participatory methods (e.g., narrative studies, participatory data collection methods, and/or participatory action research) are crucial for this indicator to collect relevant

	information on reflexive learning processes and how these affect the context and different types of actors.
Additional information	
References	Beers, P. J., & van Mierlo, B. (2017). Reflexivity and Learning in System Innovation Processes. Sociologia Ruralis, 57(3), 415–436. https://doi.org/10.1111/soru.12179 Beers, P. J., Van Mierlo, B., & Hoes, A. C. (2016). Toward an integrative perspective on social learning in system innovation initiatives. Ecology and Society, 21(1). https://doi.org/10.5751/ES-08148-210133 Chatterton, P., Owen, A., Cutter, J., Dymski, G., & Unsworth, R. (2018). Recasting Urban Governance through Leeds City Lab: Developing Alternatives to Neoliberal Urban Austerity in Co-production Laboratories. International Journal of Urban and Regional Research, 42(2), 226–243. https://doi.org/10.1111/1468-2427.12607 Dentoni, D., Bitzer, V., & Pascucci, S. (2016). Cross-Sector Partnerships and the Co-creation of Dynamic Capabilities for Stakeholder Orientation. Journal of Business Ethics, 135(1), 35–53. https://doi.org/10.1007/s10551-015-2728-8 Ferlie, E., Pegan, A., Pluchinotta, I., & Shaw, K. (2019). Co-Production and Co-Governance : Strategic Management , Public Value and Co-Creation in the Renewal of Public Agencies across Europe Deliverable 1 . 1 : Literature Review. (770591), 1–60. Retrieved from www.cogov.eu Frantzeskaki, N., Kabisch, N., & McPhearson, T. (2016). Advancing urban environmental governance: Understanding theories, practices and processes shaping urban sustainability and resilience. Environmental Science and Policy, 62, 1–6. https://doi.org/10.1016/j.envsci.2016.05.008 Lodder, M., Sillen, D., Frantzeskaki, N., Hölscher, K., & Notermans, I. (2019). Reflexive Monitoring of Co-producing Nature-based Solutions : A Guidebook for Policymakers and Practitioners to " Learn-by-Doing ." Muñoz-Erickson, T. A., Miller, C. A., & Miller, T. R. (2017). How cities think: Knowledge co-production for urban sustainability and resilience. Forests, Vol. 8. https://doi.org/10.3390/f8060203 Regeer, B. J., Hoes, A. C., van Amstel-van Saane, M., Caron-Flinterman, F. F., & Bunders, J. F. G. (2009). Six guiding principles for evaluating mode-2 strategies for sustainable development. American Journal of Evaluation, 30(4), 515–537. https://doi.org/10.1177/1098214009344618 Sol, J., van der Wal, M. M., Beers, P. J., & Wals, A. E. J. (2018). Reframing the future: the role of reflexivity in governance networks in sustainability transitions. Environmental Education Research, 24(9), 1383–1405. https://doi.org/10.1080/13504622.2017.1402171 van Mierlo, B. (2012). Convergent and divergent learning in photovoltaic pilot projects and subsequent niche development. Sustainability: Science, Practice, and Policy, 8(2), 4–18. van Mierlo, B., Arkesteijn, M., & Leeuwis, C. (2010). Enhancing the reflexivity of system innovation projects with system analyses. American Journal of Evaluation, 31(2), 143–161. https://doi.org/10.1177/1098214010366046 van Mierlo, B., Leeuwis, C., Smits, R., & Woolthuis, R. K. (2010). Learning towards system innovation: Evaluating a systemic instrument. Technological Forecasting and Social Change,

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SOCIAL JUSTICE AND SOCIAL COHESION

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19 Recommended Indicators of Social Justice and Social Cohesion

19.1 Bridging and bonding – quality of interactions within and between social groups

19.1.1 Bridging

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Bridging Social Capital	**Social Justice and Social Cohesion**
Description and justification	Social capital is largely conceived in terms of the nature, extent, and outcomes of networks and associated norms of reciprocity, thus generally seen as a contributor to individual and group (community, nation) growth, well-being, and progress (Szreter & Woolcock, 2004). Social capital enables individuals to gain access to resources (ideas, information, money, services, and favours) and to have accurate expectations regarding the behaviour of others by virtue of their participation in relationships that are themselves the product of networks of association (Claridge, 2018; Szreter & Woolcock, 2004). Data on bridging social capital (BrSC) can provide an indication of associations between groups, communities, or organisations that link people across a cleavage that typically divides society (like race, class, or religion) (Claridge, 2018). These connections of respect and mutuality function as a social lubricant leading to an increased ability to gather information, ability to gain access to power or better placement within the network, or ability to better recognize new opportunities (Claridge, 2018). Nature-based solutions (NBS) have been linked to the notion of environmental justice across studies that explore the role of supporting urban processes involving equal access to neighborhood green space in fostering social cohesion (e.g., bridging social capital) towards the cultural integration of typically-excluded social groups, like elderly, immigrants, persons with disabilities, etc. (i.e., recognition-based justice) (Ibes, 2015; Kweon, Sullivan & Wiley, 1998; Raymond et al., 2017; Raymond, Gottwald, Kuoppa & Kyttä, 2016; van Den Berg et al., 2017). BrSc's beneficial impact on collective initiatives like NBS can be far-reaching, as it allows different groups to share and exchange information, ideas and innovation and builds consensus among the groups representing otherwise diverse interests.
Definition	Social relationships of exchange, often of associations between people with shared interests or goals but contrasting social identity (socio-demographics); BrSC is essentially the result of networking outside normal social groupings (Claridge, 2018; Szreter & Woolcock, 2004).

Strengths and weaknesses	+ reliable indicator of resources that encourage reciprocity and collaboration between groups/communities/organisations + mostly inclusive, fosters tolerance and acceptances of different people, values, and beliefs through contact with diverse others (Claridge, 2018; Szreter & Woolcock, 2004) + Putnam saw it as a resource that helps one "get ahead" (as quoted in Claridge, 2018), facilitates swifter recognition of new opportunities, and promotes social change, innovation and consensus among groups/communities/organisations + can improve economic development, growth, and employment (Claridge, 2018) - may enable collusion, price fixing, or corruption (Claridge, 2018; Szreter & Woolcock, 2004) *+/- general agreement as to the importance of a balance of bonding (see SC1) and bridging social capital, in that neither is negative per se but can be negative depending on the balance and context. The precise nature of the social identity boundaries, and the political salience of bonding and bridging groups are highly context specific (Claridge, 2018; Szreter & Woolcock, 2004).*
Measurement procedure (P) and tool (T)	☒ P: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) ☒ T: Scale consisting of 2 items measuring the presence of BrSC type of connections, and respondent's perception of quality of interactions within BrSC type of connections (Anucha et al., 2006 – item 1 adapted to purposes of current study; item 2 formulated for the purposes of current study)
Scale of measurement	1. Thinking about people you interact with … (e.g., in your community garden, in your local park), are most of them of ...mixed occupations (coded as [1] yes or [0] no), ...mixed religion (coded as [1]yes or [0]no), ...mixed ethnic or linguistic group/race/caste/tribe (coded as [1]yes or [0]no), ...mixed educational backgrounds or levels (coded as [1] yes or [0] no), ...and/or mixed income levels (coded as [1] yes or [0] no)? 2. Thinking about these same people, how would you rate the quality of your interactions with them? 1 ...2....3...4...5...6...7 extremely dissatisfied (1)... extremely satisfied (7)
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges
Data input type	Quantitative (quantitative and qualitative, if participatory data collection is opted for)
Data collection frequency	Before and after NBS implementation, then aligned with timing of targeted objectives.

Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1. Bonding social capital SC3. Linking social capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC5.1 Perceived safety SC5.2 Actual/real safety SC6 Place attachment (Sense of place): Place Identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC12 Social desirability
Connection with SDGs	Goal 1. End poverty in all its forms everywhere Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 5. Achieve gender equality and empower all women and girls Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 12. Ensure sustainable consumption and production patterns Goal 13. Take urgent action to combat climate change and its impacts Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection) may be applied to garner community-relevant information on BrSC's role in NBS implementation and expansion.
Additional information	
References	Anucha, U., Diamini, N.S., Yan, M.C., & Smylie, L. (2006). *Social capital and the welfare of immigrant women: A multi-level study of four ethnic communities in Windsor.* Status of Women Canada's Policy Research Fund. Retrieved from http://www.researchgate.net Claridge, T. (2018). Functions of social capital – bonding, bridging, linking. *Social Capital Research*, 1-7. Retrieved from

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Granovetter, M.S. (1973). The strength of weak ties. *The American Journal of Sociology*. 78(6), 1360-1380. Retrieved from http://www.jstor.org

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19.1.2 Bonding

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Bonding Social Capital	Social Justice and Social Cohesion
Description and justification	Social capital is largely conceived in terms of the nature, extent, and outcomes of networks and associated norms of reciprocity, thus generally seen as a contributor to individual and group (community, nation) growth, well-being, and progress (Szreter & Woolcock, 2004). Social capital enables individuals to gain access to resources (ideas, information, money, services, and favours) and to have accurate expectations regarding the behaviour of others by virtue of their participation in relationships that are themselves the product of networks of association (Claridge, 2018; Szreter & Woolcock, 2004). Data on bonding social capital (BoSC) can provide an indication of connections within a group or community characterised by high levels of similarity in demographic characteristics, attitudes, and available information and resources (Claridge, 2018). These connections foster social support by allowing people to access favors, information, and emotional support (Claridge, 2018). BoSC fulfils an important social function by providing the norms and trust that facilitate the kind of collaborative action required by initiatives like NBS/Nature-based Infrastructure. Conversely, Nature-based solutions have been hailed as beneficial to social cohesion and social capital (Ibes, 2015; Low, Taplin & Scheld, 2005; Volker, Flap & Lindenburg, 2007; Oldenburg, 1989). Oldenburg (1989) analyses the unique role of outdoor spaces as “third places” with significant value in the well-being of urban existence in that they supply community members with publicly accessible spaces for gathering, socializing, and recreating (as quoted in Ibes, 2015).
Definition	Trusting and co-operative relations between members of a network who see themselves as being similar, in terms of their shared social identity (socio-demographics) (Claridge, 2018; Szreter and Woolcock, 2004).

Strengths and weaknesses	+ reliable indicator of resources that encourage reciprocity and collaboration within community/group/organization - tightly structured and mostly exclusive - networks with excessive levels of bonding tend to breed bias and racism, creating out-groups and exclusion (Claridge, 2018; Szreter & Woolcock, 2004) - Putnam (2000) described it as a source of support to people "getting by" (as quoted in Claridge, 2018) – more impactful as a source of support to people who suffer from socio-economic hardship or poor health, than as a resource for initiatives that challenge the status-quo (e.g., NBS) - several studies have found that bonding social capital has either no effect or a negative effect on economic outcomes (Claridge, 2018) *+/- general agreement as to the importance of a balance of bonding and bridging social capital (see SC2), in that neither is negative per se but can be negative depending on the balance and context. The precise nature of the social identity boundaries, and the political salience of bonding and bridging groups are highly context specific (Claridge, 2018; Szreter & Woolcock, 2004).*
Measurement procedure (P) and tool (T)	☒ P: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) ☒ T: Scale consisting of 2 items measuring the presence of BoSC type of connections, and respondent's perception of quality of interactions within BoSC type of connections (Anucha et al., 2006 – item 1 adapted to purposes of current study; item 2 formulated for the purposes of current study)
Scale of measurement	1. Thinking about people you interact with … (e.g., in your community garden, in your local park), are most of them of ...the same family or kin group (coded as [1]yes or [0]no), ...the same religion (coded as [1]yes or [0]no), ...the same gender (coded as [1]yes or [0]no), ...the same age (coded as [1]yes or [0]no), ...the same ethnic or linguistic group/race/caste/tribe (coded as [1]yes or [0]no), ...the same occupation (coded as [1]yes or [0]no), ...the same educational background or level (coded as [1]yes or [0]no), ...and/or mostly the same income (coded as [1]yes or [0]no)? 2. Thinking about these same people, how would you rate the quality of your interactions with them? 1 ...2....3...4...5...6...7 extremely dissatisfied (1)... extremely satisfied (7)
Data source	

Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges
Data input type	Quantitative (quantitative and qualitative, if participatory data collection is opted for)
Data collection frequency	Before and after NBS implementation, then aligned with timing of targeted objectives.
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC2. Bridging Social Capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC5.1 Perceived safety SC5.2 Actual/real safety SC6 Place attachment (Sense of place): Place Identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC12 Social desirability
Connection with SDGs	Goal 1. End poverty in all its forms everywhere Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 3. Ensure healthy lives and promote well-being for all at all ages
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection) may be applied to garner community-relevant information on BoSC's role in NBS implementation and expansion.
Additional information	

References	

Anucha, U., Diamini, N.S., Yan, M.C., & Smylie, L. (2006). *Social capital and the welfare of immigrant women: A multi-level study of four ethnic communities in Windsor.* Status of Women Canada's Policy Research Fund. Retrieved from http://www.researchgate.net

Claridge, T. (2018). Functions of social capital – bonding, bridging, linking. *Social Capital Research*, 1-7. Retrieved from https://d1fs2th61pidml.cloudfront.net/wp-content/uploads/2018/11/Functions-of-Social-Capital.pdf?x96784

Fonseca, X., Lukosch, S., & Brazier, F. (2018). Social cohesion revisited: a new definition and how to characterize it, Innovation. *The European Journal of Social Science Research*. doi: 10.1080/13511610.2018.1497480

Granovetter, M.S. (1973). The strength of weak ties. *The American Journal of Sociology*. 78(6), 1360-1380. Retrieved from http://www.jstor.org

Ibes, D.C. (2015). A multi-dimensional classification and equity analysis of an urban park system: A novel methodology and case study application. *Landscape and Urban Planning*,137, 122–137. doi:10.1016/j.landurbplan.2014.12.014

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Szreter, S., & Woolcock, M. (2004). Health by association? Social capital, social theory, and the political economy of public health. *International Journal of Epidemiology*, 33(4), 650–667.

19.2 Inclusion of different social groups in NBS projects

Project Name: UNaLab (Grant Agreement no. 730052)

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Participation of vulnerable or traditionally under-represented groups	**Participatory Planning and Governance** **Social Justice and Social Cohesion**
Description and justification	Definitions of "vulnerable" and "under-represented" groups in society vary somewhat, but in general the following groups can be considered vulnerable to discrimination and/or under-represented: Women and girls Children Refugees Internally displaced persons Stateless persons National minorities Indigenous peoples Migrant workers Disabled persons Elderly persons HIV positive persons and those suffering from AIDS Roma/Gypsies/Sinti Lesbian, gay, bisexual, transgender, queer, and differently gendered people (LGBTQ+) Particular effort is necessary to ensure that these groups receive equal representation and opportunity to become involved in NBS projects. Specifically engaging vulnerable and/or under-represented groups in NBs projects enhances social cohesion and diversity whilst tapping into underdeveloped social capital.
Definition	The extent to which the NBS project has led to the increased participation by groups of people who are typically not well represented in the society.

Strengths and weaknesses	+ The indicator gives useful data for reducing inequalities + Easy to use - May not provide a holistic assessment
Measurement procedure and tool	The participation of vulnerable or traditionally under-represented groups in NBS projects or specific NBS project activities can be qualitatively assessed using a five-point Likert scale: **Not at all – 1 — 2 — 3 — 4 — 5 — Excellent** 1. Not at all: the project has not increased participation of groups not well represented in society. 2. Poor: the project has achieved little when it comes to participation of groups not well represented in society. 3. Fair: the project has somewhat increased the participation of groups not well represented in society. 4. Good: the project has significantly increased the participation of groups not well represented in society. 5. Excellent: Participation of groups not well represented in society has clearly been hugely improved due to the project. Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).
Scale of measurement	District to metropolitan scale
Data source	
Required data	Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).
Data input type	Qualitative
Data collection frequency	Before and after implementation of the NBS project

Level of expertise required	Moderate
Synergies with other indicators	Synergies with indicator group *Participatory Planning and Governance* indicators
Connection with SDGs	SDG 10 Reduced inequalities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeys D14Indicatorsforsmartcityprojectsandsmartcities.pdf

19.3 Trust within the community

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Trust within the community	Social Justice and Social Cohesion
Description and justification	Trust, solidarity, tolerance, and respect are generally understood as manifestations of a cohesive society, one that works towards the well-being of all the members, i.e., towards the common good. Although the benefits of communitarian social capital (BoSC, BrSC, LSC) depend upon more basic structural factors of which inequality, level of education of the population and its ethnic-racial composition are considered as the most important, trust, solidarity, tolerance, and respect are core elements in the process of creating or building social capital which enables people to expect good from others (reciprocity) and to act on behalf of others in order to create a better future for all (Cloete, 2014). Moreover, whilst good governance has a significant impact on social cohesion by increasing trust, tolerance, and acceptance of diversity, it is in fact each individual who actually create trust and guarantee reciprocity through concurrent values and by abiding to norms that guide the process of participation in networks. It seems that people with values like honesty, trustworthiness, integrity, who care for their fellow humans, are likely to create social capital that could lead to the formation of public good (Cloete, 2014). Therefore, trust, solidarity, tolerance, and respect are considered fundamental resources in the inception, implementation, and potential success of any collective initiatives like NBS. Moreover, social cohesion has been proven to represent an important resource for long-term environmental sustainability in that socially cohesive communities tend to be more supportive of environmentally sustainable attitudes and behaviors compared with those communities where social cohesiveness is weaker (Uzzell, Pol & Badenas, 2002). The cognitive components of social cohesion, like trust, tolerance or respect, attachment, reflect the quality of social interactions which take place within neighborhoods or cities (Stafford et al., 2003), and can be particularly relevant as both precursors and mediators of community response to environmental planning decision and change (Mihaylov & Perkins, 2014).

Definition	Perception that members of one's community are trustworthy and trust each other, as well as perception of how trust within community has changed over time.
Strengths and weaknesses	+ reliable indicator of solid premises for collaboration and reciprocity among members of a community + evolution of perception of trust can be traced back into the history of a community, and events that either decreased or boosted trust can be integrated as "lessons learnt" in the process of design and implementation of NBS + provides consistent information about the values that lay the foundation of both explicit and implicit norms within a community - highly context-dependent, its actual benefits for a local NBS can be foreseen through a good understanding of the values that shore up perceived trust, and of the recent history of the community (i.e., through qualitative methods like case studies, focus groups, and/or participatory data collection)
Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: items measuring perception of trust from "Trust and Solidarity" scale of the *Integrated Questionnaire for the Measurement of Social Capital* (SC-IQ) (Grootaert et al., 2004) adapted to purposed of NBS research o T: Trust Scale in *Neighbourhood Social Cohesion* measurement tool (Stafford et al., 2003) ☒ *Qualitative P*: o T: case study methodology – structured interviews, focus-groups, case study analysis o T: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation
Scale of measurement	▪ SC-IQ (Grootaert et al., 2004) – 4 items measuring perception of trust from "Trust and Solidarity" scale *In every community, some people get along with others and trust each other, while other people do not. Now, I would like to talk to you about trust and solidarity in your community.* **1.** Generally speaking, would you say that most people can be trusted, or that you can't be too careful in your dealings with other people? 1 Most people can be trusted 2 You can't be too careful **2.** In general, do you agree or disagree with the following statements? 1. Agree strongly 2. Agree somewhat 3. Neither agree nor disagree 4. Disagree somewhat 5. Disagree strongly A. Most people who live in this city/neighborhood can be trusted. B. In this city/neighborhood, one has to be alert or someone is likely

	to take advantage of you. C. Most people in this city/neighborhood are willing to help if you need it. D. In this city/neighborhood, people generally do not trust each other in matters of lending and borrowing money. **3.** Now I want to ask you how much you trust different types of people. On a scale of 1 to 5, where 1 means a very small extent and 5 means a very great extent, how much do you trust the people in that category? 1. To a very small extent 2. To a small extent 3. Neither small nor great extent 4. To a great extent 5. To a very great extent A. People from your ethnic or linguistic group/race/caste/tribe B. People from other ethnic or linguistic groups/race/caste/tribe C. Shopkeepers D. Local government officials E. Central government officials F. Police G. Teachers H. Nurses and doctors I. Strangers **4.** Do you think that over the last five years*, the level of trust in this city/neighborhood has gotten better, worse, or stayed about the same? [* ENUMERATOR: TIME PERIOD CAN BE CLARIFIED BY SITUATING IT BEFORE/AFTER MAJOR EVENT] 1 Gotten better 2 Gotten worse 3 Stayed about the same ▪ Neighbourhood Social Cohesion (Stafford et al., 2003) – Trust Scale *Trust is measured by the use of a series of opposing statements at either end of a row of seven boxes; respondents are asked to place a tick in the one box which best represents their agreement with the following statements:* 1. People in this area would do something if a house was being broken into 2. In this area people would stop children if they saw them vandalising things 3. People would be afraid to walk alone after dark 4. People in this area will take advantage of you 5. If you were in trouble, there are lots of people in this area who would help you 6. Most people in this area can be trusted.
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges ✓ Desirable: Data on significant events in the recent history of the community with implications for the evolution of a sense of shared trust among its members
Data input type	Quantitative (quantitative and qualitative, if case study methodology and/or participatory data collection are opted for)

Data collection frequency	Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection through case study methodology requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC5.1 Perceived safety SC5.2 Actual/real safety SC6 Place attachment (sense of place): Place identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC12 Social desirability
Connection with SDGs	Goal 1. End poverty in all its forms everywhere Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all Goal 5. Achieve gender equality and empower all women and girls Goal 6. Ensure availability and sustainable management of water and sanitation for all Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 12. Ensure sustainable consumption and production patterns Goal 13. Take urgent action to combat climate change and its impacts Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all

	and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community-relevant information on the evolution of a sense of shared trust among its members; they present the opportunity to perform a gap analysis, if needed, in order to address (diagnosed) breaches of trust that could negatively impact NBS implementation and expansion.
Additional information	
References	Cloete, A. (2014). Social cohesion and social capital: Possible implications for the common good. *Verbum et Ecclesia*, 35(3). doi:10.4102/ve.v35i3.1331 Grootaert, C., Narayan, D., Jones, V.N., & Woolcock, M. (2004). *Measuring Social Capital: An Integrated Questionnaire*. World Bank Working Paper 18. Washington D.C.: World Bank. Retrieved from http://documents.worldbank.org/curated/en/515261468740392133/Measuring-social-capital-an-integrated-questionnaire Mihaylov, N., & Perkins, D.D. (2014). Community Place Attachment and its Role in Social Capital Development in Response to Environmental Disruption. In L. Manzo & P. Devine-Wright (Eds.), *Place Attachment: Advances in Theory, Methods and Research* (pp. 61-74). Routledge. Stafford, M., Bartley, M., Sacker, A., Marmot, M., Wilkinson, R., Boreham, R., & Thomas, R. (2003). Measuring the Social Environment: Social Cohesion and Material Deprivation in English and Scottish Neighbourhoods. Environment and Planning A: Economy and Space, 35(8), 1459–1475. doi:10.1068/a35257 Uzzell, D., Pol, E., & Badenas, D. (2002). Place identification, social cohesion, and environmental sustainability. *Environment and Behavior,* 34(1), 26-53. doi: 10.1177/0013916502034001003

19.4 Solidarity among neighbours

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Solidarity among neighbours	Social Justice and Social Cohesion
Description and justification	Trust, solidarity, tolerance, and respect are generally understood as manifestations of a cohesive society, one that works towards the well-being of all the members, i.e., towards the common good. Although the benefits of communitarian social capital (BoSC, BrSC, LSC) depend upon more basic structural factors of which inequality, level of education of the population and its ethnic-racial composition are considered as the most important, trust, solidarity, tolerance, and respect are core elements in the process of creating or building social capital which enables people to expect good from others (reciprocity) and to act on behalf of others in order to create a better future for all (Cloete, 2014). Moreover, whilst good governance has a significant impact on social cohesion by increasing trust, tolerance, and acceptance of diversity, it is in fact each individual who actually create trust and guarantee reciprocity through concurrent values and by abiding to norms that guide the process of participation in networks. It seems that people with values like honesty, trustworthiness, integrity, who care for their fellow humans, are likely to create social capital that could lead to the formation of public good (Cloete, 2014). Therefore, trust, solidarity, tolerance, and respect are considered fundamental resources in the inception, implementation, and potential success of any collective initiatives like NBS. Moreover, social cohesion has been proven to represent an important resource for long-term environmental sustainability in that socially cohesive communities tend to be more supportive of environmentally sustainable attitudes and behaviors compared with those communities where social cohesiveness is weaker (Uzzell, Pol & Badenes, 2002). The cognitive components of social cohesion, like trust, tolerance or respect, attachment, reflect the quality of social interactions which take place within neighborhoods or cities (Stafford et al., 2003), and can be particularly relevant as both precursors and mediators of community response to environmental planning decision and change (Mihaylov & Perkins, 2014). Solidarity is a particularly elusive concept, like most important concepts in our lives, such as health, love, or happiness (Prainsack & Buyx, 2012). Social solidarity as a practice requires contributions

	in terms of time, effort and emotional investments, or money that groups or individuals make to assist others. Prainsack and Buyx (2012) underline the notion that motivations, feelings such as empathy, etc., are not sufficient to satisfy the operationalization of solidarity as practice, unless they manifest themselves in acts. Individuals come to engage in solidarity practices through recognition of similarity with one (or more) other people in a relevant aspect (interpersonal level), forms of solidarity institutionalization defined by social norms of 'good conduct' (group practices), and/or highly institutionalized structures (contractual and legal manifestations) (Prainsack and Buyx, 2012). Authors make plain that not every practice of solidarity at interpersonal and/or group level solidifies into contractual and legal manifestations, and the former can exist without highly institutionalized structures. In contrast, interpersonal and group practices may change (i.e., break away) following the institutionalization into contractual and legal manifestations of solidarity (i.e., the welfare society arrangements). Accordingly, collecting data on the typical manifestations of solidarity within a certain community and society (state, nation – the wider culture) (i.e., through qualitative research approaches) can best inform NBS initiatives on both existing resources and pitfalls when it comes to this complex layer of enacted values.
Definition	A shared practice (or a cluster of such practices) reflecting a collective commitment to carry 'costs' (financial, social, emotional, or otherwise) to assist others (Prainsack & Buyx, 2012).
Strengths and weaknesses	+ reliable indicator of solid premises for partnership around and towards the common good (i.e., awareness of sameness/similarity with fellow community members) + evolution of solidarity practices can be traced back into the history of a community, and events that either endangered or inspired solidarity can be integrated as "lessons learnt" in the process of design and implementation of NBS + provides consistent information about the values that lay the foundation of both explicit and implicit norms within a community - highly abstract a concept that requires attention to operationalization so as to distinguish it from empathy, friendship, charity, dignity, reciprocity, altruism, and trust - highly context-dependent, its actual benefits for a local NBS can be foreseen through a good understanding of the existing structures for enactment of a core value like solidarity within a certain community, and of its recent history (i.e., through qualitative methods like case studies, focus groups, and/or participatory data collection)

Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: items measuring perception of solidarity from "Trust and Solidarity" scale of the *Integrated Questionnaire for the Measurement of Social Capital* (SC-IQ) (Grootaert et al., 2004) adapted to purposed of NBS research ☒ *Qualitative P*: o T: case study methodology – structured interviews, focus-groups, case study analysis o T: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation *Quantitatively measured as perception of own willingness to manifest solidarity (i.e., elusive, idealized, abstract), and perception of solidarity manifested by fellow community members (a closer fit to the understanding of the concept as a practice). Consequently, qualitative methods are valuable to capturing idiosyncratic manifestations of solidarity within a certain community that could inform NBS implementation and successful development.*
Scale of measurement	▪ SC-IQ (Grootaert et al., 2004) – 2 items measuring perception of own willingness to manifest solidarity, and perception of solidarity manifested by fellow community members from "Trust and Solidarity" scale *In every community, some people get along with others and trust each other, while other people do not. Now, I would like to talk to you about trust and solidarity in your community.* **5.** How well do people in your city/neighborhood help each other out these days? Use a five point scale, where 1 means always helping and 5 means never helping. 1 Always helping 2 Helping most of the time 3 Helping sometimes 4 Rarely helping 5 Never helping **6.** If a community project does not directly benefit you, but has benefits for many others in the city/neighborhood, would you contribute time or money to the project? A. Time B. Money 1 Will not contribute time 1 Will not contribute money 2 Will contribute time 2 Will contribute money.
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges ✓ Desirable: Data on significant events in the recent history of the community with implications for the evolution of solidarity practices and relevant structures
Data input type	Quantitative (quantitative and qualitative, if case study methodology and/or participatory data collection are opted for)

Data collection frequency	Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection through case study methodology requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.1 Trust in community SC4.3 Tolerance and respect SC5.1 Perceived safety SC5.2 Actual/real safety SC6 Place attachment (sense of place): Place identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC12 Social desirability
Connection with SDGs	See 4.1. Trust in community
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community-relevant information on past and present enactments of solidarity (layers, structures); they present the opportunity to grasp both existing resources and potential pitfalls of relevance to emergent NBS initiatives within a certain community and culture of social solidarity.
Additional information	
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19.5 Tolerance and respect

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Tolerance and respect	Social Justice and Social Cohesion
Description and justification	Trust, solidarity, tolerance, and respect are generally understood as manifestations of a cohesive society, one that works towards the well-being of all the members, i.e., towards the common good. Although the benefits of communitarian social capital (BoSC, BrSC, LSC) depend upon more basic structural factors of which inequality, level of education of the population and its ethnic-racial composition are considered as the most important, trust, solidarity, tolerance, and respect are core elements in the process of creating or building social capital which enables people to expect good from others (reciprocity) and to act on behalf of others in order to create a better future for all (Cloete, 2014). Moreover, whilst good governance has a significant impact on social cohesion by increasing trust, tolerance, and acceptance of diversity, it is in fact each individual who actually create trust and guarantee reciprocity through concurrent values and by abiding to norms that guide the process of participation in networks. It seems that people with values like honesty, trustworthiness, integrity, who care for their fellow humans, are likely to create social capital that could lead to the formation of public good (Cloete, 2014). Therefore, trust, solidarity, tolerance, and respect are considered fundamental resources in the inception, implementation, and potential success of any collective initiatives like NBS. Moreover, social cohesion has been proven to represent an important resource for long-term environmental sustainability in that socially cohesive communities tend to be more supportive of

	environmentally sustainable attitudes and behaviors compared with those communities where social cohesiveness is weaker (Uzzell, Pol & Badenes, 2002). The cognitive components of social cohesion, like trust, tolerance or respect, reflect the quality of social interactions which take place within neighborhoods or cities (Stafford et al., 2003), and can be particularly relevant as both precursors and mediators of community response to environmental planning decision and change (Mihaylov & Perkins, 2014). Significantly, tolerance and respect is linked to social capital in that they reflect urban community's capacity for inclusion of diverse members or struggle thereof with a strong sense of identity which limits the access of minority members to decisional processes and shared resources (Cook & Swyngedouw, 2012, Stafford et al., 2003).
Definition	Attitudes that manifest as acceptance of the very things one disagrees with, disapproves of or dislikes, and of the differences between others and ourselves we would rather fight, ignore or overcome (van Doorn, 2012, 2014). These attitudes are paramount to overcoming or avoiding conflict, and often reached only after controversy or conflict (van Doorn, 2012, 2014).
Strengths and weaknesses	+ reliable indicator of capacity to overcome differences (i.e., tolerance and respect are important resources in conflict management) + evolution of these attitudes can be traced back into the history of a community, and events that challenged tolerance or brought forth deep-seated prejudices can be integrated as "lessons learnt" in the process of design and implementation of NBS + provides consistent information about the values that lay the foundation of both explicit and implicit norms within a community - highly context (culture)-dependent, its actual benefits for a local NBS can be foreseen through a good understanding of the evolution of tolerance and respect within a certain community, and of its recent history (i.e., through qualitative methods like case studies, focus groups, and/or participatory data collection) - highly vulnerable to social desirability bias

Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: 'Tolerance or Respect' Scale in Neighbourhood Social Cohesion measurement tool (Stafford et al., 2003) ☒ *Qualitative P*: o T: case study methodology – structured interviews, focus-groups, case study analysis o T: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation *Quantitatively measured as perception of tolerance or respect as present and manifest in one's neighborhood. Consequently, qualitative methods are valuable to capturing idiosyncratic manifestations of tolerance/respect within a certain community that could inform NBS implementation and successful development.*
Scale of measurement	▪ Neighbourhood Social Cohesion (Stafford et al., 2003) – 'Tolerance or Respect' Scale *A 7-point Likert scale to measure respondents' agreement with each of these statement was developed for the purposes of this study - full agreement, 2- moderate agreement, 3 - slight agreement, 4 - neutral, 5 - slight disagreement, 6 - moderate disagreement, 7 - full disagreement* 1.Everybody in this area should have equal rights and an equal say 2.People in this area treat each other with respect 3.People in this area are tolerant of others who are not like them 4.People in this area respect one another's privacy 5.In this area there are some people who belong and some who don't (R) 6.In this area there is pressure to behave like everyone else (R)
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges ✓ Desirable: Data on significant events in the recent history of the community with implications for the evolution of tolerance and respect, as well as for the presence of deep-seated prejudice
Data input type	Quantitative (quantitative and qualitative, if case study methodology and/or participatory data collection are opted for)

Data collection frequency	Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection through case study methodology requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC5.1 Perceived safety SC5.2 Actual/real safety SC6 Place attachment (sense of place): Place identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC11.2 Environmental Identity SC12 Social desirability
Connection with SDGs	See 4.1. Trust in community
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community-relevant information on past and present experiences with tolerance and/or prejudice; they present the opportunity to grasp both existing resources and potential pitfalls of relevance to emergent NBS initiatives within a certain community/culture.
Additional information	

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19.6 Availability and equitable distribution of blue-green space

Project Name: UNaLab (Grant Agreement no. 730052)

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Availability and equitable distribution of blue-green space	**Social Justice and Social Cohesion**
Description and justification	It is widely accepted that access to urban green space improves the quality of life for urban residents, facilitating social cohesion, democracy, and equity whilst enhancing physical and psychological health and well-being. Urban green spaces also contribute to the economic vitality of urban neighbourhoods by increasing property values and encouraging tourism (Ibes, 2015). A number of recent studies have highlighted inequitable access to green space in cities around the world. Spatial analysis of metropolitan areas can reveal the relationship between green space access and socio-economic status.
Definition	The availability and distribution of blue-green space with respect to specific individual or household socioeconomic profiles and landscape design
Strengths and weaknesses	+ Provides useful data for urban city planning - Needs expert users and a lot of input data
Measurement procedure and tool	The overall methodology involves selecting relevant characteristics and datasets, then overlaying these dataset using a geographic information system (GIS). Statistical analyses of spatially-explicit variables are then used to explore the relationship between urban green space availability and selected socio-economic characteristics. Additional factors, such as size or type of green space, biodiversity value, etc. can also be evaluated. Steps of the process are given below: Step 1: Separate the metropolitan area of interest into its respective spatial/administrative units which provide clearly defined areas with readily available data regarding population density, demographics, median household income, level of home ownership, etc. Additional information regarding dominant building type (single family and multi-family residences, buildings for retail or commercial/industrial use, mean or maximum building

	height etc.) can be obtained from municipality records for each spatial/administrative unit. Step 2: Using GIS, overlay the spatial units with available urban landscape data. For example, Cohen et al. (2012) obtained high resolution urban landscape data (1 m) from the Paris Urban Planning Agency that described the spatial distribution of: vegetation patches per strata (i.e., <1 m, 1–10 m, >10 m); (2) water bodies, bare soil and asphalt; and, built up areas based on the median height of buildings and the period of construction. This layer was intersected with the census block group data to view distribution patterns of urban landscapes. Step 3: Statistically analyse spatially-explicit data to evaluate green space availability (and green space type and size and/or biodiversity value, if desired) as a function of socio-economic factors in order to determine equity of green space distribution). A number of different statistical methods may be employed to evaluate the equity of public green space distribution. For example, Cohen et al. (2012) used available botanical information for each of the census block groups, calculating the mean household income per botanical and landscape class cluster. They also assessed the correlation between mean revenue, floral richness, the ecological diversity index and building density.
Scale of measurement	Metropolitan scale
Data source	
Required data	Spatial/administrative data regarding population density, demographics, median household income, level of ownership, etc. Also urban landscape data with green spaces and green space characteristics.
Data input type	Qualitative and quantitative
Data collection frequency	Before and after NBS implementation
Level of expertise required	Moderate to high
Synergies with other indicators	Synergies with *Distribution of public green space* and *Accessibility of urban green spaces*
Connection with SDGs	SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	

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20 Additional Indicators of Social Justice and Social Cohesion

20.1 Linking social capital

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Linking social capital	Social Justice and Social Cohesion
Description and justification	Social capital is largely conceived in terms of the nature, extent, and outcomes of networks and associated norms of reciprocity, thus generally seen as a contributor to individual and group (community, nation) growth, well-being, and progress (Szreter & Woolcock, 2004). Social capital enables individuals to gain access to resources (ideas, information, money, services, and favours) and to have accurate expectations regarding the behaviour of others by virtue of their participation in relationships that are themselves the product of networks of association (Claridge, 2018; Szreter & Woolcock, 2004). Data on linking social capital (LSC) inform on norms of respect and networks of trusting relationships between people who are interacting across explicit, formal or institutionalized power or authority gradients in society (Claridge, 2018). These relationships are described as 'vertical' and the key feature is differences in social position or power (Claridge, 2018). An example could be relationships between a community-based organisation and government or other funders (Claridge, 2018). Relationships that connect people across explicit 'vertical' power differentials, particularly as it pertains to accessing public and private services that can only be delivered through on-going face-to-face interaction, such as classroom teaching, general practice medicine, and agricultural extension, are central to shaping welfare and well-being (especially in poor communities) (Claridge, 2018). Consequently, LSC has many benefits on collective initiatives like NBS by connecting government officials and specialists (doctors, teachers, etc.) with people in the community, and by opening up economic opportunities to those belonging to less powerful or excluded groups. Nature-based Infrastructure has been linked to the notion of environmental justice across studies that explore the role of supporting urban processes involving equal access to neighborhood green space in fostering social cohesion

	(e.g., bridging social capital) towards the cultural integration of typically-excluded social groups, like elderly, immigrants, persons with disabilities, etc. (i.e., recognition-based justice) (Ibes, 2015; Kweon, Sullivan & Wiley, 1998; Raymond et al., 2017; Raymond, Gottwald, Kuoppa & Kyttä, 2016; van Der Berg et al., 2017).
Definition	Social relations with those in authority that can be used to access resources or power (Claridge, 2018; Szreter & Woolcock, 2004).
Strengths and weaknesses	+ reliable indicator of resources that encourage reciprocity and collaboration among people or institutions at different levels of societal power hierarchy + indicator central to welfare and wellbeing (Claridge, 2018) + networks and ties with individuals, groups or corporate actors represented in public agencies, schools, business interests, legal institutions and religious/political groups are of paramount importance to economic progress, or to the implementation of initiatives that promote social change and innovation (Claridge, 2018; Szreter & Woolcock, 2004) + oriented towards inclusiveness, high potential to further trust within community, to ground tolerance and respect, and to inculcate a community sense of safety (Claridge, 2018) - can be put to unhappy purposes—e.g., nepotism, corruption, and suppression (Szreter & Woolcock, 2004) *+/- It is important to have an appropriate balance of all types of social capital. Research has found that without linking types of social capital, bonding social capital alone may not be sufficient for community development to occur (Claridge, 2018; Szreter & Woolcock, 2004).*
Measurement procedure (P) and tool (T)	☒ P: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) ☒ T: Scale consisting of 2 items measuring the presence of LSC type of connections, and respondent's perception of quality of interactions within LSC type of connections (Anucha et al., 2006 – item 1 adapted to purposes of current study; item 2 formulated for the purposes of current study)

Scale of measurement	1. Thinking about people you interact with ... (e.g., meetings to define the open-space strategy, interactions in participatory sessions), are some of them of ...higher social status (coded as [1] yes or [0] no), ...higher public/political power (coded as [1] yes or [0] no) ...higher financial capability (coded as [1] yes or [0] no)? 2. Thinking about these same people, how would you rate the quality of your collaborative interactions with them? 1 ...2....3...4...5...6...7 extremely dissatisfied (1)... extremely satisfied (7)
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges
Data input type	Quantitative (quantitative and qualitative, if participatory data collection is opted for)
Data collection frequency	Before and after NBS implementation, then aligned with timing of targeted objectives.
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1. Bonding social capital SC2. Bridging social capital SC4.1 Trust in community SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC5.1 Perceived safety SC5.2 Actual/real safety SC9 Empowerment: Perceived control and influence over NBS decision-making SC10 Environmental education opportunities SC12 Social desirability

Connection with SDGs	Goal 1. End poverty in all its forms everywhere Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all Goal 5. Achieve gender equality and empower all women and girls Goal 6. Ensure availability and sustainable management of water and sanitation for all Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation Goal 10. Reduce inequality within and among countries Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 12. Ensure sustainable consumption and production patterns Goal 13. Take urgent action to combat climate change and its impacts Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection) may be applied to garner community-relevant information on LSC's role in NBS implementation and expansion.
Additional information	
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20.2 Perceived social interaction

Project Name: CLEVER Cities (Grant Agreement no. 776604)

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Perceived social interaction	Social Justice and Social Cohesion
Description and justification	Social relationships are a special case of social relations that can exist without any communication taking place between the actors involved. Categorizing social interactions enables observational and other social research, such as Gemeinschaft and Gesellschaft (lit. 'community and society'), collective consciousness, etc. However different schools and theories of sociology and other social sciences dispute the methods used for such investigations.
Definition	In social science, a social relation or social interaction is any relationship between two or more individuals. Social relations derived from individual agency form the basis of social structure and the basic object for analysis by social scientists. Fundamental inquiries into the nature of social relations feature in the work of sociologists such as Max Weber in his theory of social action.
Strengths and weaknesses	+ Direct information from people (perception, valuation...) - Need for rigorous methodology to avoid response bias
Measurement procedure and tool	CLEVER-Social Survey Questionnaire (CLEVER-SSQn) : *How much you / What extent did you agree or disagree with following statements before the COVID-19 crisis? [* *1. Generally, I borrow things and exchange favours with my neighbours/building when I live/people who I work/study.* *7. I am content with my friendships and relationships.* *8. I have enough people I feel comfortable asking for help at any time.* *9. My relationships are as satisfying as I would want them to be.*
Scale of measurement	☒ Neighbourhood ☒ Space ☒ Building
Data source	

Required data	The participant response The response is rated on a 5-point *(Dis)Agree scale: 1. Strongly/Definitely disagree; 2. Disagree; 3. Neither agree nor disagree / Undecided; 4. Agree; 5. Strongly/definitely Agree; 9. Don´t know / Prefer not to answer*
Data input type	Qualitative: the response of the participant on a Differential Semantic scale of 5 points (from 1 to 5)
Data collection frequency	Annually or at minimum, before and after NBS implementation.
Level of expertise required	Moderate – Social research experts needed
Synergies with other indicators	Relation to Sociocultural inclusiveness (*Connectedness to nature,* Perceived social support, cohesion, and interaction…), Pro-environmental identity and behaviour, Sense of empowerment, Place identity, *Population dynamics, Participatory planning and governance,* Trust in decision-making procedure,
Connection with SDGs	SDG 3 Good health and wellbeing, SDG 5 Gender equality, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	The questionnaires are in themselves a tool for the participation of both citizens and other actors or stakeholders.
Additional information	
References	Allport, G. W (1985). "The Historical Background of Social Psychology". In G. Lindzey and E. Aronson (ed.). The Handbook of Social Psychology. New York: McGraw Hill. p. 5. Herranz-Pascual et al. (2020) CLEVER Social Survey Questionnaire (CLEVER-SSQn) In Zorita et al. D4.3 Monitoring strategy in the FR interventions. Deliverable 4.3, CLEVER Cities Project, 6th July 2020. Moscovici, S; Markova, I (2006). The Making of Modern Social Psychology. Cambridge, UK: Polity Press.

20.3 Quantity and quality of social interaction

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Giuseppina Spano[1], Yole de Bellis[1], Giovanni Sanesi[1]

[1] *Università degli Studi di Bari Aldo Moro, Bari, Italy*

Perceived quantity and quality of social interaction	**Health and Wellbeing** **Social Justice and Social Cohesion**
Description and justification	The need to communicate between human beings is innate and it represents the foundation of society. The quantity and quality of social interaction is related to several health outcomes. This indicator is of paramount importance since it shows Whether and to what extent an implemented NBS affect the quality and quantity of social interactions among users.
Definition	Sequence of social actions between individuals or groups who modify their actions and reactions due to actions by their interaction partner(s)
Strengths and weaknesses	Strengths: Easy to assess. Weaknesses: Potential biases in self-reported data
Measurement procedure and tool	NBS users are asked to answer to a number of questions about any social activities they might have done in the NBS spot.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions (baseline) and once after (follow-up).
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness and to indicators on mental health.
Connection with SDGs	• Good health and wellbeing • Reduced inequalities • Sustainable cities and communities • Peace, justice and strong institutions

Opportunities for participatory data collection	The questionnaires can be both self-reported and administrable in an interview method.
Additional information	
References	Baumeister, R. F., & Leary, M. R. (1995). The need to belong: desire for interpersonal attachments as a fundamental human motivation. Psychological bulletin, 117(3), 497.

20.4 Perceived social support

20.4.1 Perception of socially supportive network

Project Name: CLEVER Cities (Grant Agreement no. 776604)

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[2] *UKE – University Hospital Essen, Institute for Urban Public Health (InUPH), Essen, Germany*

Perceived social support	**Social Justice and Social Cohesion**
Description and justification	Social support is studied across a wide range of disciplines including psychology, medicine, sociology, nursing, public health, education, rehabilitation, and social work. Social support has been linked to many benefits for both physical and mental health, but "social support" (e.g., gossiping about friends) is not always beneficial.
Definition	Social support is the perception and actuality that one is cared for, has assistance available from other people, and most popularly, that one is part of a supportive social network. These supportive resources can be emotional (e.g., nurturance), informational (e.g., advice), or companionship (e.g., sense of belonging); tangible (e.g., financial assistance) or intangible (e.g., personal advice). Social support can be measured as the perception that one has assistance available, the actual received assistance, or the degree to which a person is integrated in a social network. Support can come from many sources, such as family, friends, pets, neighbors, coworkers, organizations, etc.
Strengths and weaknesses	+ Direct information from people (perception, valuation...) - Need for rigorous methodology to avoid response bias

Measurement procedure and tool	CLEVER-Social Survey Questionnaire (CLEVER-SSQn) : *How much you / What extent did you agree or disagree with following statements before the COVID-19 crisis?* *2. People in this neighbourhood can be trusted.* *3. People around here are willing to help their neighbours.* *4. People in this neighbourhood generally don't get along with each other.* *5. This local area is a place where people from different backgrounds get on well together* *6. People in this neighbourhood pull together to improve the neighbourhood*
Scale of measurement	☒ Neighbourhood ☒ Space ☒ Building
Data Source	
Required data	The participant response The response is rated on a 5-point *(Dis)Agree scale: 1. Strongly/Definitely disagree; 2. Disagree; 3. Neither agree nor disagree / Undecided; 4. Agree; 5. Strongly/definitely Agree; 9. Don´t know / Prefer not to answer*
Data input type	Qualitative: the response of the participant on a Differential Semantic scale of 5 points (from 1 to 5)
Data collection frequency	Annually or at minimum, before and after NBS implementation.
Level of expertise required	Moderate – Social research experts needed
Synergies with other indicators	Relation to Sociocultural inclusiveness (*Connectedness to nature,* Perceived social support, cohesion, and interaction…), Pro-environmental identity and behaviour, Sense of empowerment, Place identity, *Population dynamics, Participatory planning and governance,* Trust in decision-making procedure,
Connection with SDGs	SDG 3 Good health and wellbeing, SDG 5 Gender equality, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	The questionnaires are in themselves a tool for the participation of both citizens and other actors or stakeholders.
Additional information	
References	Drennon-Gala, D. (1995). Drennon-Gala, D. (1995). Delinquency and high school dropouts: reconsidering social correlates.

	Maryland: University Press of America; a member of the Rowan & Littlefield Publishing Group. Herranz-Pascual et al. (2020) CLEVER Social Survey Questionnaire (CLEVER-SSQn) In Zorita et al. D4.3 Monitoring strategy in the FR interventions. Deliverable 4.3, CLEVER Cities Project, 6th July 2020. Racino, J. (2006). Social support. In: G. Albrecht, Encyclopedia on Disability, 1470-1471. Thousand Oaks, CA: SAGE. Vaux, A. (1988). Social Support: Theory, Research and Interventions. My, NY: Praeger.

20.4.2 Perceived social support

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Giuseppina Spano[1], Yole de Bellis[1], Giovanni Sanesi[1]

[1] *Università degli Studi di Bari Aldo Moro, Bari, Italy*

Perceived social support	**Health and Wellbeing** **Social Justice and Social Cohesion**
Description and justification	Empirical evidences showed that supportive social groups and effective and helpful social networks are associated with a good mental and physical health. This indicator is measured in the neighbourhood context since a perception of high social support fosters social inclusion and justice.
Definition	Perception of various ways in which individuals aid others.
Strengths and weaknesses	Strengths: Reliable measurement tool; easy to assess. Weaknesses: Potential biases in self-reported data.
Measurement procedure and tool	This indicator is obtained using a 8-point scale on general social support and a 6-point scale on social support in the neighborhood. Participants are required to complete the scales before and after the NBS implementation.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions (baseline) and once after (follow-up).

Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness and to indicators on mental health.
Connection with SDGs	• Good health and wellbeing • Reduced inequalities • Sustainable cities and communities • Peace, justice and strong institutions
Opportunities for participatory data collection	The questionnaires can be both self-reported and administrable in an interview method.
Additional information	
References	Pearson, J. E. (1986). The definition and measurement of social support. Journal of Counseling & Development.

20.5 Perceived social cohesion

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Giuseppina Spano[1], Yole de Bellis[1], Giovanni Sanesi[1]

[1] *Università degli Studi di Bari Aldo Moro, Bari, Italy*

Perceived social cohesion	Social Justice and Social Cohesion
Description and justification	Social cohesion is strongly related to social equality and social inclusion. This indicator measure the degree of trust that the individual has towards other people, and in particular towards his / her neighbourhood.
Definition	Social cohesion indicates the set of behaviors and bonds of affinity and solidarity between individuals or groups
Strengths and weaknesses	Strengths: Reliable measurement tool; easy to assess. Weaknesses: Potential biases in self-reported data
Measurement procedure and tool	This indicator is obtained using a 8-point scale on general social support and a 6-point scale on social support in the neighborhood. Participants are required to complete the scales before and after the NBS implementation.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables

Data collection frequency	Twice; once before the implementation of the nature-based solutions (baseline) and once after (follow-up).
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness.
Connection with SDGs	• Good health and wellbeing • Reduced inequalities • Sustainable cities and communities • Peace, justice and strong institutions
Opportunities for participatory data collection	The questionnaires can be both self-reported and administrable in an interview method.
Additional information	
References	Stanley, D. (2003). What do we know about social cohesion: The research perspective of the federal government's social cohesion research network. Canadian Journal of Sociology/Cahiers canadiens de sociologie, 5-17.

20.6 Perceived ownership of space and sense of belonging to the community

Project Name: UNaLab (Grant Agreement no. 730052) and CLEVER Cities (Grant Agreement no. 776604)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Karmele Herranz-Pascual[3], Julita Skodra[4], Saioa Zorita[3], Igone García[3]

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Sense of belonging to the community / Consciousness of citizenship	**Social Justice and Social Cohesion** **Participatory Planning and Governance**
Description and justification	Consciousness of citizenship can be described as an individual's awareness of their community, civic rights and responsibilities and their relationship with the community,

	state or nation. An individual with consciousness of citizenship is aware of how the community functions and their respective role in the community. As such, consciousness of citizenship contributes to a sense of community. According to Ng (2015), civic consciousness includes the following elements: • Personal identity and citizenship: characteristics such as personal awareness, pride, obedience to the law, and a sense of equality • National identity: respect for national authorities, belief in the legitimacy of the current political system, sense of the nation as a cohesive whole • Moral consciousness: upholding family and social normative values in public and in private, willingness to promote public welfare • Ecological consciousness: awareness of the finite nature of natural resources, consideration of the environmental consequences of personal actions • Global citizenship: actively concerned with others at home and abroad
Definition	The extent to which the NBS project has contributed in increasing consciousness of citizenship (qualitative, unitless)
Strengths and weaknesses	+ The indicator gives useful data for urban planning but the data collecting and evaluation might be challenging - May not provide the holistic picture
Measurement procedure and tool	The extent to which an NBS project seeks to contribute to the local consciousness of citizenship can be qualitatively rated on a five-point Likert scale, from no effort to substantial effort: **No increase – 1 — 2 — 3 — 4 — 5 — High increase** 1. None: The NBS project has made no effort to increase civic consciousness. 2. Little: The NBS project has made a small effort to increase civic consciousness. 3. Somewhat: The NBS project has developed some initiatives to increase civic consciousness. 4. Significant: The NBS project has executed several activities to increase civic consciousness 5. High: increasing civic consciousness was (one of) the main goals of the NBS project and substantial effort has been made to enhance civic consciousness.

	In addition, a single-question survey can be used to assess citizens' feeling of belonging. CLEVER-Social Survey Questionnaire (CLEVER-SSQn): *Before the COVID-19 crisis, how strongly do you feel you belong to your immediate neighbourhood/local area? Please think of the area within a few minutes walking distance from your home.* The response is rated on a 5-point (Dis)Agree scale: 1. Strongly/Definitely disagree; 2. Disagree; 3. Neither agree nor disagree / Undecided; 4. Agree; 5. Strongly/definitely Agree; 9. Don´t know / Prefer not to answer
Scale of measurement	Neighbourhood – district - metropolitan scale
Data source	
Required data	Project documentation and/or interviews during the NBS project. The participant response to questionnaire: The response is rated on a 5-point (*1. Strongly/Definitely disagree; 2. Disagree; 3. Neither agree nor disagree / Undecided; 4. Agree; 5. Strongly/definitely Agree; 9. Don´t know / Prefer not to answer)*
Data input type	Qualitative: the response of the participant on a Likert scale of 5 points (from 1 to 5)
Data collection frequency	Before and after implementation of the NBS project
Level of expertise required	Moderate
Synergies with other indicators	Synergies with indicator group *Participatory Planning and Governance* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 12 Responsible consumption and production, and SDG 16 Peace, justice and strong institutions
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

	Herranz-Pascual et al. (2020) CLEVER Social Survey Questionnaire (CLEVER-SSQn) In Zorita et al. D4.3 Monitoring strategy in the FR interventions. Deliverable 4.3, CLEVER Cities Project, 6th July 2020. Ng, J.A.I. (2015). Scale on Civic Consciousness (SCC) for the National Service Training Program. International Journal of Humanities and Management Sciences, 3(3), 161-165.

20.7 Proportion of community who volunteer

Project Name: CLEVER Cities (Grant Agreement no. 776604)

Author/s and affiliations: Karmele Herranz-Pascual[1], Julita Skodra[2], Saioa Zorita[1]

[1] *TECNALIA, Basque Research and Technology Alliance (BRTA), Mikeletegi Pasealekua 2, 20009 Donostia-San Sebastián, Spain*

[2] *UKE – University Hospital Essen, Institute for Urban Public Health (InUPH), Essen, Germany*

Number and type of residents who have actively volunteered in maintaining the garden	**Social Justice and Social Cohesion**
Description and justification	There are many proven personal benefits of community volunteerism. Working together with a group of people who have different ethnicity, backgrounds, and views reduces stereotypes. Environmental volunteering refers to the volunteers who contribute towards environmental management or conservation. Volunteers conduct a range of activities including environmental monitoring, ecological restoration such as re-vegetation and weed removal, protecting endangered animals, and educating others about the natural environment.
Definition	Volunteering is generally considered an altruistic activity where an individual or group freely gives time "to benefit another person, group or organization". Volunteering is also renowned for skill development and is often intended to promote goodness or to improve human quality of life. Volunteering may have positive benefits for the volunteer as well as for the person or community served. Community volunteering refers globally to those who work to improve their local community. This activity commonly occurs through not for profit organizations, local governments and churches; but also encompasses ad-hoc or informal groups such as recreational sports teams.
Strengths and weaknesses	+ Direct information from people (perception, valuation...) - Need for rigorous methodology to avoid response bias

Measurement procedure and tool	CLEVER-Social Survey Questionnaire (CLEVER-SSQn) → see «required data»
Scale of measurement	Qualitative
Required data	The participant response to following questions: Local community participation (CLEVER-SSQn): *Before the COVID-19 crisis, did you currently participate in any association or entity of any kind (cultural, neighbourhood, sports, political...)?* • *Yes. [Could you indicate in which one or which ones and what is your participation? ______________________]* • *No* *During the last 12 months before the COVID-19 crisis, have you done any voluntary work?* *A volunteer is a person who, free of charge, contributes his or her collaboration in favour of others through some organisation of general interest.* • *Yes* • *No* *[OR] Before the health emergency, do you happen to carry out activities in collaboration with those who live in the neighbourhood?* • *Every day (1 or more times)* • *Weekly* • *Monthly* • *Sporadically* • *Never, this is the first time* This information can be disaggregated according to other variables of interest such as age, gender, etc.
Data input type	Qualitative: the response of the participant on different scales: dichotomic, ordinal of 5 points (see «required data»)
Data collection frequency	Annually or at minimum, before and after NBS implementation.
Level of expertise required	Moderate – Social research experts needed
Synergies with other indicators	Relation to Sociocultural inclusiveness (*Connectedness to nature,* Perceived social support, cohesion, and interaction…), Pro-environmental identity and behaviour, Sense of empowerment, Place identity, *Participatory*

	planning and governance, Trust in decision-making procedure,
Connection with SDGs	SDG 3 Good health and wellbeing, SDG 5 Gender equality, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, SDG 16 Peace, justice and strong institutions, SDG 17 Partnerships for the goals
Opportunities for participatory data collection	The questionnaires are in themselves a tool for the participation of both citizens and other actors or stakeholders.
Additional information	
References	Herranz-Pascual et al. (2020) CLEVER Social Survey Questionnaire (CLEVER-SSQn) In Zorita et al. D4.3 Monitoring strategy in the FR interventions. Deliverable 4.3, CLEVER Cities Project, 6th July 2020. NCS (2017) "Benefits of Volunteering". Corporation for National and Community Service. Retrieved 12 April 2017. PeaceCorps (2012) "Environmental Volunteer Work"*. PeaceCorps. Archived from* the original *on 3 May 2012*. Retrieved 30 April 2012*.* Wilson, John (2000). "Volunteering". Annual Review of Sociology. 26 (26): 215. doi:10.1146/annurev.soc.26.1.215.

20.8 Proportion of target group reached by an NBS project

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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People reached by an NBS project	**Social Justice and Social Cohesion** **Participatory Planning and Governance**
Description and justification	Much of a project’s success depends on reaching the “right” people. In many instances the reach of a project is assessed by the total number of people reached, or the total number of people from vulnerable or under-represented groups who become involved.
Definition	Percentage of people in the target group that have been reached and/or are activated by the NBS project.

Strengths and weaknesses	The strength of the “people reached by NBS project” metric is that it provides a quantitative measure of the project’s engagement of people within the target group, enabling rapid assessment of how successful the project has been in this regard. Conversely, the weakness of the metric is that the target group must be clearly defined in order to quantify the size of the target audience. This could be particularly challenging in NBS projects as the co-creation process is driven equally by project planners and stakeholders, meaning that the target audience can change with time as the NBS is co-defined. Evaluation of the target audience, identification of critical stakeholders and quantification of the total target audience should, therefore, be an on-going process in an NBS project. Note that this metric does not consider how people are reached, or identify limitations to citizen engagement.
Measurement procedure and tool	People reached by an NBS project can be calculated as: $\left(\frac{Number\ of\ citizens\ reached}{Total\ no.citizens\ in\ target\ group}\right) \times 100$
Scale of measurement	District to metropolitan scale
Data source	
Required data	Number of citizens reached or activated in the target group by the NBS project total number of citizens in the target group
Data input type	Quantitative
Data collection frequency	On-going process during the NBS project
Level of expertise required	Moderate
Synergies with other indicators	Synergies with indicator group *Participatory Planning and Governance* indicators
Connection with SDGs	SDG 10 Reduced inequalities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from

	http://nws.eurocities.eu/MediaShell/media/CITYkeys D14Indicatorsforsmartcityprojectsandsmartcities.pdf

20.9 Perceived personal safety

Project Name: Naturvation (Grant Agreement no. 730243)

Author/s and affiliations: Sara Maia[1] and Dora Almassy[1]

[1] *Central European University (CEU), Budapest, Hungary*

Perception of personal safety	**Social Justice and Social Cohesion**
Description and justification	Perception of safety is related to public and community safety and measures citizens' fear of crime and harassment in public green spaces (e.g., parks, urban forests). For certain cases, perception of safety can report proportions of the population or a proportion of a study sample who feel safe "walking alone after dark", or measure the perception of safety or threat in a neighbourhood or in public parks (1).
Definition	Measures citizens fear of crime and harassment in public green spaces
Strengths and weaknesses	
Measurement procedure and tool	Perception of safety can be measured through different methods, including the use of surveys and questionnaires (e.g., evaluating landscape safety through a photograph questionnaire) (1, 2, 4, 6, 8, 10, 11, 14), interviews (5, 8, 13), GIS or remote sensing & satellite imagery (e.g., aerial photography) (1, 3, 5, 7, 9), as well as field-work observation and experiments (e.g., recording participants self-rated feelings while walking in the forest) (1, 4, 5, 11, 13, 14).
Scale of measurement	The proportion of studies that showed positive benefits for an NBS were used as a base for the scoring and distributed between scores ranging from 1 to 5 according to the proportions of positive impacts. Indications of negative impacts were noted here in the score document as a proportion of studies. When data for benefits of an NBS was not present in the literature it was denoted as not applicable (NA).
Data source	
Required data	

Data input type	
Data collection frequency	
Level of expertise required	
Synergies with other indicators	
Connection with SDGs	*SDGs:* 15, 9, 16, 10
Opportunities for participatory data collection	
Additional information	
References	Baran, P. K., Tabrizian, P., Zhai, Y., Smith, J. W. and Floyd, M. F. (2018) 'An exploratory study of perceived safety in a neighborhood park using immersive virtual environments', *Urban Forestry & Urban Greening*, 35, pp. 72–81. doi: 10.1016/j.ufug.2018.08.009. Chiang, Y.-C., Nasar, J. L. and Ko, C.-C. (2014) 'Influence of visibility and situational threats on forest trail evaluations', *Landscape and Urban Planning*, 125, pp. 166–173. doi: 10.1016/j.landurbplan.2014.02.004. Chong, S., Lobb, E., Khan, R., Abu-Rayya, H., Byun, R. and Jalaludin, B. (2013) 'Neighbourhood safety and area deprivation modify the associations between parkland and psychological distress in Sydney, Australia', *BMC Public Health*, 13(1), p. 422. doi: 10.1186/1471-2458-13-422. Cohen, D. A., Han, B., Derose, K. P., Williamson, S., Marsh, T., Raaen, L. and Mckenzie, T. L. (2016) 'The Paradox of Parks in Low-Income Areas: Park Use and Perceived Threats', *Environment and Behavior*, 48(1), pp. 230–245. doi: 10.1177/0013916515614366. Harvey, C., Aultman-Hall, L., Hurley, S. E. and Troy, A. (2015) 'Effects of skeletal streetscape design on perceived safety', *Landscape and Urban Planning*, 142, pp. 18–28. doi: 10.1016/j.landurbplan.2015.05.007. Hong, A., Fox, E. H., Hong, A., Sallis, J. F., King, A. C., Conway, T. L., Saelens, B., Cain, K. L., Fox, E. H. and Frank, L. D. (2018) 'Linking green space to neighborhood social capital in older adults : The role of perceived safety Social Science & Medicine Linking green space to neighborhood social capital in older adults : The role of perceived safety', *Social Science & Medicine*. Elsevier, 207(April), pp. 38–45. doi: 10.1016/j.socscimed.2018.04.051.

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20.10 Perceived safety of neighbourhood

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Adina Dumitru[1], Catalina Young[2], Irina Macsinga[2]

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Perceived safety of neighbourhood		**Social Justice and Social Cohesion**
Description and justification	Neighborhood safety is generally understood as an environmental demand (environmental press) in that perceived or actual low safety of a neighborhood environment could exceed person's physical or psychological capacity to manage the demands of the environment (Jin-Choi & Matz-Costa, 2018). Such adversity is particularly challenging for vulnerable groups like women, children, or elders. As a dimension of social capital, relations with neighbors and social support from interactions with neighbors are strongly related to the subjective sense of community, and mediate the relationship between neighborhood factors and residents' well-being. Research on neighborhood effects has explored relationships between burdensome physical conditions (e.g., living in deteriorating neighborhoods, public drug use, public drinking, loitering, street harassment, poor lighting, homeless sleeping in public, abandoned cars, trash, overgrown trees) and perceptions of psycho-social conditions (e.g., trust, support, sense of well-being) (Kruger, 2008; Loukaitou-Sidaris, 2006). Along these lines, neighborhood safety has been highlighted as a significant indicator for both the social capital of a community, and the health and well-being of its members, thereby a major factor in the implementation, and potential success of any collective initiatives like NBS. Indeed, McCabe (2014) brings forth evidence on how community gardens as community-based multi-prolonged initiatives effectively stabilize distressed neighborhoods, and positively associate with reduced violence, greater perception of residents' safety, lowered stress levels, improved relations with police, and greater empowerment as residents take pride and ownership in the development of their neighborhoods. Furthermore, Bogar and Beyer (2015) conducted a systematic study of existing research on relationships among urban green space, violence, and crime in the United States, and found overwhelmingly	

	positive associations between urban green space and neighborhood safety that withstand methodological idiosyncrasies and a limited understanding of causal pathways. Notably, Sreetheran and van den Bosch (2014) systematically reviewed the combination of characteristics that evoke fear of crime in urban green spaces and delineated their complex interaction by putting forward a social-ecological framework to promote a thorough understanding of the cumulative effect of the complex interaction between environmental factors (such as vegetation character, density, and maintenance), individual aspects (e.g., age, gender, education level, minority status, ethnic background) and social attributes (like social cohesion, trust, frequency of visit) on people's fear towards crime or perceived personal safety in urban green spaces. In accordance with the research investigated by the authors, gender is a significant and strong predictor of fear of crime in urban green spaces in that females have significantly higher fear levels than their male counterparts. Of all social attributes explored, social incivilities (e.g., the presence of youth gangs, beggars, homeless persons) were found to have a significant impact on fear of crime in urban green spaces. As the most investigated environmental attribute, vegetation density and maintenance was reported as a major cue evoking fear of crime in urban green spaces (Sreetheran & van den Bosch, 2014).
Definition	Self-reported perceptions of neighborhood/community crime and safety.
Strengths and weaknesses	+reliable indicator of challenges to neighborhood/community resources for a shared sense of trust, and for an individual sense of well-being +perception of safety with respect to green spaces (parks, trees etc.) can inform NBS on best approaches so as to meet community's capacity to manage the demands of environment +consistently adds to the information on a community's shared notion of trust and solidarity -measurement scales usually limit the investigation to neighborhood crime, conflict, and violence, whereas physical conditions related to housing (e.g., garbage, insects, and inadequate heat) and neighborhood (e.g., noise, crime, abandoned buildings, dark streets and sidewalks, and low accessibility to shops) hazards play an important role into a shared sense of community safety as well

Measurement procedure (P) and tool (T)	☒ *Quantitative P*: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: 8 items *Conflict and Violence Scale* from "Social Cohesion and Inclusion" module of the *Integrated Questionnaire for the Measurement of Social Capital* (SC-IQ) (Grootaert et al., 2004) adapted to purposed of NBS research o T: 7-items from *Criminal Victimization and Perceptions of Community Safety Survey* (Smith et al., 1999) adapted to the purposes of NBS research ☒ *Qualitative P*: o T: case study methodology – structured interviews, case study analysis o T: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation ☒ Public participation geographic information system (PPGIS) methods/approaches

Scale of measurement	▪ SC-IQ (Grootaert et al., 2004) – 8 items representing *Conflict and Violence Scale* from "Social Cohesion and Inclusion" module (neighbourhood level) **1.** In your opinion, is your neighborhood generally peaceful or marked by violence? 1 Very peaceful 2 Moderately peaceful 3 Neither peaceful nor violent 4 Moderately violent 5 Very violent **2**. Compared to ... years ago*, has the level of violence in your neighborhood increased, decreased, or stayed the same? [* ENUMERATOR: TIME PERIOD CAN BE CLARIFIED BY SITUATING IT BEFORE/AFTER ...e.g., the park was built] 1 Increased a lot 2 Increased a little 3 Stayed about the same 4 Decreased a little 5 Decreased a lot **3.** In general, how safe from crime and violence do you feel when you are alone at home? 1 Very safe 2 Moderately safe 3 Neither safe nor unsafe 4 Moderately unsafe 5 Very unsafe **4.** How safe do you feel when walking down your street alone after dark? 1 Very safe 2 Moderately safe 3 Neither safe nor unsafe 4 Moderately unsafe 5 Very unsafe **5.** In the past 12 months, have you or anyone in your household been the victim of a violent crime, such as assault or mugging? 1 Yes 2 No → go to question 7. **6.** How many times? **7.** In the past 12 months, has your house been burglarized or vandalized? 1 Yes 2 No **8.** How many times? ▪ Criminal Victimization and Perceptions of Community Safety Survey (Smith et al., 1999) – 7 items (neighbourhood and city level), to be adapted so as to best fit in with objectives of final survey **1.** How fearful are you about crime in your neighborhood? 1.Very fearful 2. Somewhat fearful 3. Not very fearful – Skip to 3 4 .Not at all fearful – Skip to 3 5. Don't know – Skip to 3 **2.** Over the last 12 months, have your fears increased, decreased, or stayed the same? 1. Increased 2. Decreased 3. Stayed the same 4. Don't know **3.** How fearful are you about crime in your city? 1 Very fearful 2. Somewhat fearful 3. Not very fearful – Skip to 5 4 .Not at all fearful – Skip to 5 5. Don't know –

	Skip to 5 **4.** Over the last 12 months, have your fears increased, decreased, or stayed the same? 1. Increased 2. Decreased 3. Stayed the same 4. Don't know **5.** The following questions are more neighborhood specific. Do any of the following conditions or activities exist in your neighborhood? (Read each category then enter the appropriate code for each category – 1, yes; 2, no; 3, don't know) ...Abandoned cars and/or buildings ...Rundown/neglected buildings ...Poor lighting ...Overgrown shrubs/trees ...Trash ...Empty lots ...Illegal public drinking/public drug use ...Public drug sales ...Vandalism and Graffiti ...Prostitution ...Panhandling/begging ...Loitering/"hanging out" ...Truancy/youth skipping school ...Transients/homeless sleeping on benches, streets *NOTE: Do any of the categories in 5 contain an entry of 1 (yes)?* *Yes - continue with questions 6 and 7* *No* **6.** Do any of the conditions you just mentioned make you feel less safe in your neighborhood? 1.Yes 2. No 3. I don't know **7.** Which of the conditions just mentioned affects your feeling of safety the most? ...Abandoned cars and/or buildings ...Rundown/neglected buildings ...Poor lighting ...Overgrown shrubs/trees ...Trash ...Empty lots ...Illegal public drinking/public drug use ...Public drug sales ...Vandalism and Graffiti ...Prostitution ...Panhandling/begging ...Loitering/"hanging out" ...Truancy/youth skipping school ...Transients/homeless sleeping on benches, streets ...Don't know

Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges
Data input type	Quantitative (quantitative and qualitative, if case study methodology and/or participatory data collection are opted for)
Data collection frequency	Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection through case study methodology and PPGIS requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC5.2 Actual/real safety SC6 Place attachment (sense of place): Place identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC12 Social desirability HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure HW13 Levels of aggressiveness and violence HW15 Exploration behaviour in children
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 6. Ensure availability and sustainable management of water and sanitation for all Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection, GIS with top-down goals of understanding neighborhood dynamics, location-based PPGIS) may be applied to collect community-relevant information about factors that play a role in members' perception of safety;

	data can further inform NBS implementation and expansion.
Additional information	
References	Bogar, S., & Beyer, K.M. (2015). Green Space, Violence, and Crime A Systematic Review. *Trauma, Violence, & Abuse,* 17, 160–171. doi: 10.1177/1524838015576412 Grootaert, C., Narayan, D., Jones, V.N., & Woolcock, M. (2004). *Measuring Social Capital: An Integrated Questionnaire*. World Bank Working Paper 18. Washington D.C.: World Bank. Retrieved from http://documents.worldbank.org/curated/en/515261468740392133/Measuring-social-capital-an-integrated-questionnaire Jin Choi, Y. & Matz-Costa, C. (2018). Perceived Neighborhood Safety, Social Cohesion, and Psychological Health of Older Adults. *Gerontologist*, 58(1), 196-206. doi: 10.1093/geront/gnw187 Kruger, D.J. (2008). Verifying the operational definition of neighborhood for the psychosocial impact of structural deterioration. *Journal of Community Psychology*, 36(1), 53-60. doi: 10.1002/jcop.20216 Kyttä, M., Kuoppa, J., Hirvonen, J., Ahmadi, E., & Tzoulas, T. (2014). Perceived safety of the retrofit neighborhood: A location-based approach. *Urban Design International*, 19(4), 311-328. doi: 10.1057/udi.2013.31 Loukaitou-Sidaris, A. (2006). Is it Safe to Walk? Neighborhood Safety and Security Considerations and Their Effects on Walking. *Journal of Planning Literature*, 20(3), 219-232. doi: 10.1177/0885412205282770 McCabe, A. (2014). Community Gardens to Fight Urban Youth Crime and Stabilize Neighborhoods. *International Journal of Child Health and Human Development*, 7(3), 223–236. Raymond, C.M., Gottwald, S., Kuoppa, J., & Kyttä, M. (2016). Integrating multiple elements of environmental justice into urban blue space planning using public participation geographic information systems. *Landscape and Urban Planning*, 153, 198-208. doi: 10.1016/j.landurbplan.2016.05.005 Sieber, R. (2006). Public Participation Geographic Information Systems: A Literature Review and Framework. *Annals of the Association of American Geographers*, 96(3), 491–507. doi: 10.1111/j.1467-8306.2006.00702.x Smith, S.K., Steadman, G.W., Minton, T.D., & Townsend, M. (1999). *Criminal victimization and perceptions of community safety in 12 cities, 1998*. Washington, DC: Bureau of Justice Statistics and Office of Community Oriented Policing Services, U.S. Department of Justice. Retrieved from

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20.11 Number of violent incidents, nuisances and crimes per 100 000 population

Project Name: UNaLab (Grant Agreement no. 730052)

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Safety, including indicators of crime	**Social Justice and Social Cohesion**
Description and justification	The number of violent incidents, reportable nuisances and other crimes is a primary indicator of feelings of personal safety (ISO, 2018). For simplicity, the crime rate of a given metropolitan area can be assessed before and after NBS implementation to determine the impact of NBS actions on local crime. Individual surveys are necessary to directly assess citizens' feelings of personal safety, but the crime rate can provide an easily quantifiable metric of actual crime in a given area.
Definition	Number of violent incidents, nuisances and crimes per 100 000 population
Strengths and weaknesses	+ Simple and easy to use indicator - All the crimes might not be reported
Measurement procedure and tool	The crime rate is defined as the number of violent incidents, annoyances and crimes per 100 000 population. It is calculated as: $\frac{Total\ number\ of\ crimes\ reported}{(City's\ total\ population/100\ 000)}$

	The result is expressed as the number of crimes per 100 000 population.
Scale of measurement	District to metropolitan scale
Data source	
Required data	Number of crimes reported and city's population
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation
Level of expertise required	Moderate
Synergies with other indicators	No synergies identified
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 15 Life on land, and SDG 16 Peace, justice and strong institutions
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. Retrieved from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf International Organization for Standardization (ISO). (2018). Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018). Retrieved from https://www.iso.org/standard/68498.html

20.12 Realised safety

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Adina Dumitru[1], Catalina Young[2], Irina Macsinga[2]

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[2] *West University of Timisoara, Romania*

Realised safety	Social Justice and Social Cohesion
Description and justification	Neighborhood safety is generally understood as an environmental demand (environmental press) in that perceived or actual low safety of a neighborhood environment could exceed person's physical or psychological capacity to manage the demands of the environment (Jin-Choi & Matz-Costa, 2018). Such adversity is particularly challenging for vulnerable groups like women, children, or elders. As a dimension of social capital, relations with neighbors and social support from interactions with neighbors are strongly related to the subjective sense of community, and mediate the relationship between neighborhood factors and residents' well-being. Research on neighborhood effects has explored relationships between burdensome physical conditions (e.g., living in deteriorating neighborhoods, public drug use, public drinking, loitering, street harassment, poor lighting, homeless sleeping in public, abandoned cars, trash, overgrown trees) and perceptions of psycho-social conditions (e.g., trust, support, sense of well-being) (Kruger, 2008; Loukaitou-Sidaris, 2006). Along these lines, neighborhood safety has been highlighted as a significant indicator for both the social capital of a community, and the health and well-being of its members, thereby a major factor in the implementation, and potential success of any collective initiatives like NBS. For instance, Bogar and Beyer (2015) conducted a systematic study of existing research on relationships among urban green space, violence, and crime in the United States, and found overwhelmingly positive associations between urban green space and neighborhood safety that withstand methodological idiosyncrasies and a limited understanding of causal pathways. Similarly, McCabe (2014) brings forth evidence on how community gardens as community-based multi-prolonged initiatives effectively stabilize distressed neighborhoods, and positively associate with reduced violence, greater perception of residents' safety, lowered stress levels, improved relations with police, and greater empowerment as residents take pride and ownership in the development of their neighborhoods. Indeed, McCabe (2014) brings forth evidence on how community gardens as

	community-based multi-prolonged initiatives effectively stabilize distressed neighborhoods, and positively associate with reduced violence, greater perception of residents' safety, lowered stress levels, improved relations with police, and greater empowerment as residents take pride and ownership in the development of their neighborhoods. Furthermore, Bogar and Beyer (2015) conducted a systematic study of existing research on relationships among urban green space, violence, and crime in the United States, and found overwhelmingly positive associations between urban green space and neighborhood safety that withstand methodological idiosyncrasies and a limited understanding of causal pathways.
Definition	Actual presence of environmental (e.g., unattended dogs) and/or human (e.g., reckless drivers) factors that have an impact on a neighborhood/community's objective parameters of safety (e.g., crime types, frequency of crimes committed, number of hospitalizations related to neighborhood safety hazards, etc.)
Strengths and weaknesses	+objective indicator of challenges to neighborhood/community resources for a shared sense of trust, and for an individual sense of well-being +safety hazards related to green spaces (parks, trees, etc.) can inform NBS on best approaches so as to meet community's capacity to manage the demands of environment +consistently adds to the information on a community's shared notion of trust and solidarity -measurements of actual safety usually limit the investigation to neighborhood crime, conflict, and violence, yet physical conditions related to housing (e.g., garbage, insects, and inadequate heat) and neighborhood (e.g., noise, crime, abandoned buildings, dark streets and sidewalks, heavy traffic, and low accessibility to shops) hazards are relevant to actual/real safety as well
Measurement procedure (P) and tool (T)	☒ *Quantitative*: objective measures (e.g., reported crimes in a neighbourhood per capita, crime density, number of crimes per building, or number of emergency calls) ☒ Public participation geographic information system (PPGIS) methods/approaches
Scale of measurement	-
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges
Data input type	Quantitative (quantitative and qualitative, if participatory data collection is opted for)

Data collection frequency	Before NBS implementation and/or aligned to timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection through case study methodology and PPGIS requires high expertise in psycho-social research o Basic training needed if participatory data collection is opted for
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC3 Linking social capital SC4.2 Solidarity between neighbours SC4.3 Tolerance and respect SC5.1 Perceived safety SC6 Place attachment (sense of place): Place identity SC9 Empowerment: Perceived control and influence over NBS decision-making SC12 Social desirability HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure HW13 Levels of aggressiveness and violence HW15 Exploration behaviour in children
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 6. Ensure availability and sustainable management of water and sanitation for all Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Opportunities for participatory data collection	Participatory methods (e.g., collaborative participatory data collection, GIS with top-down goals of understanding neighborhood dynamics, location-based PPGIS) may be applied to collect community-relevant information about crimes and safety hazards; data can further inform NBS implementation and expansion.
Additional information	

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20.13 Area easily accessible for people with disabilities

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Area easily accessible to persons with physical disabilities	**Social Justice and Social Cohesion**
Description and justification	An NBS can open up opportunities to increase social justice, providing people the possibility to meet and interact with other groups and interests. Design Scenarios which will create multi-target infrastructures, combining risk reduction with the provision of public spaces, could improve sociability of places (Byrd et al., 2017). To this aim, the extensions of new areas accessible to people with disabilities can provide a measure of the benefit induced by the project in terms of social justice.
Definition	The Indicator can be defined as the size of the part of the study area made accessible to people with disabilities. This Indicator can be calculated both in the Baseline Scenario and in the Design Scenarios (e.g., NBS Scenario or Hybrid Scenario).
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of social justice.
Measurement procedure and tool	The Indicator is equal to the size of the parts of the study area that are accessible to people with disabilities since they are devoid of architectural barriers. Given the vector data of the project, common GIS software tools allow calculating these areas.
Scale of measurement	km^2
Data source	Project team
Required data	Project layout map
Data input type	Maps
Data collection frequency	
Level of expertise required	Medium

Synergies with other indicators	
Connection with SDGs	10
Opportunities for participatory data collection	
Additional information	
References	Byrd C., Andersson E., Kronenberg J., Hansen R., Buijs A. (2017). Understanding and Promoting the Values of Urban Green Infrastructure: a learning module. GREEN SURGE project Deliverable 4.5, University of Copenhagen, Copenhagen, Denmark

20.14 Change in properties incomes

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Change in properties incomes	**Social Justice and Social Cohesion** **New Economic Opportunities and Green Jobs**
Description and justification	The implementation of NBS can increase the value of land and real estate by increasing the overall quality of the surrounding environment. The rate of increase in properties incomes can be used as an Indicator of the performance of the Design Scenario in terms of social justice.
Definition	The indicator can be defined as the increase, in terms of percentage, of the profit or income received by virtue of owning property after the implementation of the Design Scenario. This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario or Hybrid Scenario) computing the percentage difference by properties income in the Design Scenarios themselves and the one in the Baseline Scenario.

Strengths and weaknesses	It could be difficult to get the data necessary to calculate the Indicator.
Measurement procedure and tool	The measurement procedure entails an ex-post indicator evaluation. Given the data provided by national and/or private real estate monitoring agencies, the Indicator can be calculated as following: $$\frac{I_{DS} - I_{BS}}{I_{DS}} \cdot 100$$ where I_{DS} is the value of rent received from the ownership of land and/or real estate after the new infrastructure (both NBS, Hybrid solutions and Grey infrastructures) provided in the Design Scenario is implemented; I_{BS} is the value of rent received from the ownership of land and/or real estate in the Baseline Scenario.
Scale of measurement	%
Data source	National and/or private real estate monitoring agencies
Required data	Values of rent received from the ownership of land and/or real estate
Data input type	Quantitative
Data collection frequency	Six months
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	10
Opportunities for participatory data collection	
Additional information	
References	

HEALTH AND WELLBEING

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21 Recommended Indicators of Health and Wellbeing

21.1 Level of outdoor physical activity

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Level of outdoor physical activity	**Health and Wellbeing**
Description and justification	The outdoor environment may influence how physically active an individual is by offering suitable spaces for certain types of activities. It may also attract people outdoors because of the experiences it offers. Such outings ordinarily entail some form of physical activity, usually walking (Hartig, Mitchell, de Vries, & Frumkin, 2014). Numerous studies in various countries have shown that access to, and use of, urban green space contributes to increased physical activity, higher rates of recreational walking and reduced sedentary time (Almanza, Jerrett, Dunton, Seto, Pentz, 2012; Schipperijn, Bentsen, Troelsen, Toftager, & Stigsdotter, 2013; Lachowycz and Jones, 2014; Sugiyama et al., 2014; Braubach et al., 2017; Sallis et al., 2016). This has been proven valid for all age categories, including children, working age adults and senior citizens. For example, a comprehensive study conducted by Schipperijn

	et al. (2013) has demonstrated positive associations between urban green space and both physical activity and positive affect. Greater surrounding greenness has been linked to improved physical and mental health in all socioeconomic strata and in both sexes in Spain (Triguero-Mas et al., 2015). As documented under indicator HW 10 (Prevalence, incidence, morbidity of chronic stress), two complementary theoretical perspectives explain the psychological pathways of beneficial effects of nature on health, wellbeing, and mental states, namely Attention Restoration Theory (ART - Kaplan, 1995) and Stress Recovery Theory (SRT - Ulrich et al., 1991). Mental restoration and relaxation from leisure activities (e.g., walks in parks vs. walks in urban settings, gardening) pursued in the nature and green space have been studied as strong evidence of mental health benefits consequent to nature experience (Aspinall, Mavros, Coyne, & Roe, 2013; Bratman et al., 2015; Braubach et al., 2017; Hartig et al., 2014; van den Berg & Custers, 2011).
Definition	Schipperijn et al. (2013) defined: *Outdoor Physical activity as self-reported participation in organized or unorganized sport or exercise, outdoors, at least once a week. *Physical activity in urban green space (UGS) as the self-reported participation in sport or exercise taking place in the nearest UGS at least once a week. ***UGS can be replaced by NBS, as defined by current project, to apply the same definition to further measurements
Strengths and weaknesses	+ reliable indicator of physical and mental health, well-being, and life expectancy (Braubach et al., 2017; Frumkin et al., 2017; Klein et al, 2016) + solid empirical evidence as to relationship between physical and mental health, and wellbeing, and physical activity in nature and urban green space (parks, playgrounds, and residential greenery) + robust empirical evidence for the role of physical activity in cardiovascular disease and obesity

Measurement procedure and tool	☒ *Quantitative P*: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
	    o T: *International Physical Activity Questionnaire* (IPAQ) (International Physical Activity Questionnaires, n.d.). IPAQ (both long - 27 items, and short form - 7 items) assesses physical activity undertaken across a comprehensive set of domains including:
	        • leisure time physical activity

	• domestic and gardening (yard) activities • work-related physical activity • transport-related physical activity
Scale of measurement	▪ International Physical Activity Questionnaire (IPAQ – short/7 items) (International Physical Activity Questionnaires, n.d.) *See website for the International Physical Activity Questionnaire (IPAQ) for information about the use of the questionnaire and links to the questionnaire itself, in multiple languages: https://sites.google.com/site/theipaq/questionnaire_links* We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport. Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time. **1.** During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling? _____ days per week No vigorous physical activities Skip to question 3 **2.** How much time did you usually spend doing vigorous physical activities on one of those days? _____ hours per day _____ minutes per day Don't know/Not sure Think about all the moderate activities that you did in the last 7 days. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time. **3.** During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking. _____ days per week No moderate physical activities Skip to question 5

	4. How much time did you usually spend doing moderate physical activities on one of those days? _____ hours per day _____ minutes per day Don't know/Not sure Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure. **5.** During the last 7 days, on how many days did you walk for at least 10 minutes at a time? _____ days per week No walking Skip to question 7 **6.** How much time did you usually spend walking on one of those days? _____ hours per day _____ minutes per day Don't know/Not sure The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television. **7.** During the last 7 days, how much time did you spend sitting on a week day? _____ hours per day _____ minutes per day Don't know/Not sure
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for physical exercise, etc.
Data input type	Quantitative
Data collection frequency	After NBS implementation and aligned with timing relevant to HW12 and synergies with other indicators
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	SC7 Geographical access to NBS SC8 Perceived access to NBS HW3 General Wellbeing and Happiness HW4 Life expectancy and healthy life years expectancy HW6 Prevalence, incidence, morbidity, and mortality of cardiovascular diseases HW8 Incidence of obesity/obesity rates (adults and children) HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW13 Improvement of behavioural development and symptoms of attention-deficit/hyperactivity disorder (ADHD) HW14 Exploratory behaviour in children
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages

	Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
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21.2 Level of chronic stress (Perceived stress)

Project Name: proGIreg (Grant Agreement no. 776528)

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Perceived stress	**Health and Wellbeing**
Description and justification	This is an indicator of the level of psychological stress experienced by the participants based on a validated questionnaire. Stress reduction is one of the well-established mechanisms underlying the health benefits of the green spaces. However, evidence from natural experiments is lacking.
Definition	Perceived stress on a scale from 0 (low stress) to 4 (high stress)
Strengths and weaknesses	A strength of this indicator is that it is obtained by using a validated and widely used questionnaire to assess psychological stress. A limitation is that the indicator is self-reported, and participants may misreport their actual perceived stress.
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes the Perceived Stress Scale questionnaire, which includes 4 items on the amount of time in the last month that the participant felt a certain way. The answers are on a scale from 0 (never) to 4 (very often). This survey is repeated before and after the implementations of NBS in order to observe a potential change in mental health status.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on mental health.
Connection with SDGs	Good health and wellbeing: if the implementation of NBS is associated with decreased stress, NBS contribute to improved health and wellbeing.

Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Cohen, Kamarck & Mermelstein. 1983. A global measure of perceived stress. Journal of Health and Social Behavior; 24, 4.

21.3 General wellbeing and happiness

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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General wellbeing and happiness	Health and Wellbeing
Description and justification	Cross-disciplinary literature operates with a variety of concepts to delineate general wellbeing (WB) and happiness, such as (subjective) wellbeing (SWB), happiness, life satisfaction (LS), experienced utility, and quality of life (Larson, Jennings, & Coutier, 2016; MacKerron & Mourato, 2013). Cervinka, Röderer, and Hefler (2012) categorize WB as an umbrella-term that includes experiences of positive emotional states and processes ranging from short-term to long-term, from current positive feelings (positive affect) to habitual dispositions (personality-factors), and that encompasses pleasurable affect as well as general life satisfaction. A growing body of empirical evidence documents the otherwise intuitive notion that people who are more connected with nature and engage in nature's beauty (i.e., experience positive emotional responses when witnessing nature's beauty) report more subjective well-being (Frumkin, Bratman, Breslow, Cochran, Kahn Jr., Lawler, Levin, Tandon, Varanasi, Wolf, & Wood, 2017; ; Howell, Dopko, Passmore, & Buro, 2011; Howell & Passmore, 2013; Larson et al., 2016; Pritchard, Richardson, Sheffield, & McEwan, 2019; Zhang, Howell, & Iyer, 2014). MacKerron and Maurato (2013) document theoretical and empirical evidence for at least three reasons for thinking that experiences of natural environments will be positively related to health, wellbeing and happiness: 1. the existence of direct pathways by which such experiences affect the nervous system, bringing about stress reduction and restoration of attention;

	2. natural environments may be lower in environmental ‘bads’ that have significant negative impacts on physical and mental wellbeing, which in turn could affect happiness; 3. natural environments might increase happiness by facilitating and encouraging – for practical, cultural and/or psychological reasons – behaviours that are physically and mentally beneficial, including physical exercise, recreation and social interaction. Research on complex/multi-dimensional relationship between nature connectedness/nature affiliation (i.e., affective, cognitive and experiential factors related to our belonging to the natural world) and wellbeing indicate that exposure to elements of the natural world affects our well-being by boosting our positive affect, by eliciting feelings of ecstasy, respect, and wonder, by fostering feelings of comfort and friendliness, by heightening our intrinsic aspirations and generosity, and by increasing our vitality (Capaldi, Dopko, & Zelenski, 2014; Howell & Passmore, 2013).
Definition	MacKerron and Maurato (2013) distinguish three categories of SWB: *evaluative* SWB, in which people are asked for global assessments of their lives – for example, their ‘satisfaction with life as a whole’; *eudemonic* SWB, based on reports concerning ‘flourishing’, purpose and meaning in life, and the realization of one’s potential; and hedonic or *experienced* SWB, based on reports of mood, affect or emotion, and representing the Utilitarian view of wellbeing as pleasure and pain. The authors note that answers across the three categories of SWB or happiness tend to be positively correlated – and also related to other account of wellbeing – but they may respond differentially to different external factors, such as income (MacKerron & Maurato, 2013). **Life satisfaction** (Diener, Emmons, Larsen, & Griffin, 1985) is a cognitive, judgmental process based on a comparison of one’s current state of affair with a standard that each individual sets for him or herself (i.e., not externally imposed). Diener et al. (1985) developed the Satisfaction with Life Scale (SWLS) around the idea that one musk ask subjects for an overall judgment of their life in order to measure the concept. Life satisfaction belongs to the category of evaluative subjective WB, as organized by current literature (Dolan & Metcalfe, 2012; MacKerron & Maurato, 2013).
Strengths and weaknesses	+ reliable indicator of a global assessment of an individual’s satisfaction with own life + empirical evidence as to relationship between subjective wellbeing and connectedness to nature

	- multidimensional and complex construct whose relationship with exposure to nature is mediated/moderated by numerous of variables, like engagement with natural beauty (Zhang et al., 2014), meaning in life (Howell, Passmore, & Buro, 2013), mindfulness (Howell et al., 2011), presence of natural elements (Ryan, Weinstein, Bernstein, Brown, Mistretta, & Gagné, 2010)
Measurement procedure and tool	☒ *Quantitative P*: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: *Satisfaction with Life Scale* (Diener et al., 1985), a 7-point scale comprising 5 items that measure individual's general satisfaction with own life as a cognitive-judgmental process (i.e., based on a comparison with a standard that individual had set for him/herself)
Scale of measurement	▪ Satisfaction with Life Scale (SWLS – Diener et al., 1985) *Instructions: Below are five statements with which you may agree or disagree. Using the 1-7 scale below, indicate your agreement with each item by placing the appropriate number on the line preceding that item. Please be open and honest in your responding. The 7-point scale is: 1-strongly disagree, 2-disagree, 3-slightly disagree, 4-neither agree nor disagree, 5-slightly agree, 6-agree, 7-strongly agree* 1. In most ways my life is close to my ideal. 2. The conditions of my life are excellent. 3. I am satisfied with my life. 4. So far I have gotten the important things I want in life. 5. If I could live my life over, I would change almost nothing.
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for social interaction and for physical exercise, etc. ✓ Essential: Data on SC6 (Place Attachment-Sense of Place: Place Identity) ✓ Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator SC6 (Place Attachment)
Data input type	Quantitative
Data collection frequency	After NBS implementation or aligned with timing of targeted (especially long-term) objectives

Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	SC6 Place attachment (Sense of Place): Place Identity SC11.1 Positive environmental attitudes motivated by contact with NBS SC11.2 Environmental Identity HW4 Life expectancy and healthy life years expectancy HW5 Prevalence and incidence of auto-immune diseases HW6 Prevalence, incidence, morbidity, and mortality of cardiovascular diseases HW7 Prevalence, incidence, morbidity, and mortality of respiratory diseases HW8 Incidence of obesity/obesity rates (adults and children) HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure HW13 Levels of aggressiveness and violence HW14 Improvement of behavioural development and symptoms of attention-deficit/hyperactivity disorder (ADHD) HW15 Exploratory behaviour in children
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
References	Capaldi, C. A., Dopko, R. L., & Zelenski, J. M. (2014). The relationship between nature connectedness and happiness: a meta-analysis. *Frontiers in psychology*, *5*, 976. doi:10.3389/fpsyg.2014.00976 Cervinka, R., Röderer, K., & Hefler, E. (2012). Are nature lovers happy? On various indicators of well-being and connectedness with nature. *Journal of Health Psychology*, *17*(3), 379–388. https://doi.org/10.1177/1359105311416873 Diener, E., Emmons, R. A., Larsen, R. J., & Griffin, S. (1985). The Satisfaction With Life Scale. *Journal of Personality Assessment, 49*(1), 71-75. http://dx.doi.org/10.1207/s15327752jpa4901_13 Dolan, P., & Metcalfe, R. (2012). The relationship between innovation and subjective wellbeing. Research Policy, 41(8), 1489-1498. Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn, P. H., Jr, Lawler, J. J., … Wood, S. A. (2017). Nature Contact

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21.4 Self-reported mental health and wellbeing

Project Name: proGIreg (Grant Agreement no. 776528)

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Self-reported mental health and wellbeing	Health and Wellbeing
Description and justification	This indicator of mental health status is based on a validated and widely used questionnaire. An accumulating body of evidence has demonstrated a positive association between green space exposure and self-perceived general mental health and wellbeing. However, evidence from natural experiments is lacking, while such studies could strengthen the evidence for causality of the association.
Definition	Self-reported mental health and wellbeing status
Strengths and weaknesses	A strength of this indicator is that it is obtained by applying a validated and widely used questionnaire to assess mental health status. This questionnaire has been translated into many languages and re-validated. A limitation is that the indicator is self-reported, although validation studies have demonstrated that the questionnaire has acceptable predictive value .
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes a section of the SF-36 health survey questionnaire on mental health, in which several items ask about the amount of time during the past 4 weeks a participant experienced a certain feeling. The answers are given on a scale from 1 (all of the time) to 6 (none of the time). This survey is repeated before and after the implementations of NBS in order to observe a potential change in mental health status.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on mental health.

Connection with SDGs	Good health and wellbeing: if the implementation of NBS provide mental health benefits, NBS contribute to improved health and wellbeing.
Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Brazier et al. (1992). Validating the SF-36 health survey questionnaire: a new outcome measure for primary care. BMJ; 305,160.

21.5 Cardiovascular diseases (prevalence, incidence, morbidity and mortality)

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Prevalence, incidence, morbidity and mortality of cardiovascular diseases (CVD)	Health and Wellbeing
Description and justification	Accumulating evidence supports the notion that ecological features such as the diurnal cycles of light and day, sunlight exposure, seasons, and geographic characteristics of the natural environment such as altitude, latitude, and green spaces are important determinants of cardiovascular health and CVD risk (Bhatnagar, 2017). Some of the beneficial cardiovascular effects of greenery might relate to a decrease in the levels of local air pollution, increased proximity to walking spaces, or lower levels of mental stress (Bhatnagar, 2017). Recent studies and systematic reviews of empirical evidence have found support for the association between access and use of green spaces, and the prevalence and mortality of cardiovascular disease and risk, as well as for improved rates of recovery from cardiovascular disease (Gascon, Triguero-Mas, Martínez, Dadvand, Rojas-Rueda, Plaséncia, & Nieuwenhuijsen, 2016; Grazuleviciene, Vencloviene, Kubilius, Grizas, Dedele, Grazulevicius,Ceponiene, Tamuleviciute-Prasciene, Nieuwenhuijsen, Jones, & Gidlow, 2015a; Kuo, 2015; Pereira, Foster, Martin, Christian, Boruff, Knuiman, & Giles-Corti, 2012; Tamosiunas, Grazuleviciene, Luksiene, Dedele, Reklaitiene, Baceviciene, Vencloviene, Bernotiene, Radisauskas, Malinauskiene, Milinaviciene, Bobak, Peasey,

	& Nieuwenhuijsen, 2014; Villeneuve, Jerrett, Su, Burnett, Chen, Wheeler, & Goldberg, 2012). Tamosiunas et al. (2014) brought forth evidence for the fact that distance from and use of urban green spaces are associated to lower risk of cardiovascular disease and improved chances of recovery from coronary artery disease in a study conducted on a sample of more than 5000 people which indicated that park users living at a distance of less than 350 meters away from a park had a significantly lower risk of fatal and non-fatal CVD. Living in a city presents numerous health hazards that contribute to CVD by constituting major obstacles to physical activity (i.e., lack of exercise, sedentary lifestyle), like heavy environmental pollution, high traffic, no sidewalks, fewer "green spaces," or open land for public use (Laslett, Alagona, Clark, Drozda, Saldivar, Wilson, Poe, & Hart, 2012). Walking in a green environment for 30 minutes on seven consecutive days, as compared to walking on a busy city street, has been found to improve recovery from coronary artery disease (Grazuleviciene et al., 2015a). For pregnant women, increase in distance to green spaces was associated to an increase in blood pressure, risk of preterm birth, and decrease of gestational age (Grazuleviciene, Danileviciute, Dedele, Vencloviene, Andrusaityte, Uždanaviciute, & Nieuwenhuijsen, 2015b). A recent study on a sample of almost 250.000 American senior adults, aged 65 and older, found that higher neighbourhood greenness was associated with reduced heart disease risk independent of socio-demographic status and neighbourhood income, although the relationship was weaker when adding in cardio-metabolic risk factors (Wang, Lombard, Rundek, Chuanhui Dong, Marinovic Gutierrez, Byrne, Toro, Nardi, Kardys, Li Yi, Szapocznik, & Brown, 2019). Pereira et al. (2012) found that those living in neighbourhoods that had a high variability in greenness had a lower risk of stroke than those in either high overall greenness or low overall greenness. Gascon et al. (2016) conducted a systematic review of research concerning the relationship between residential green spaces and mortality in adults (stroke SMR, circulatory causes SMR, lung cancer, respiratory disease, diabetes, heart disease), and concluded on support for the hypothesis that living in areas with higher amounts of green spaces reduces mortality, mainly CVD.
Definition	**CVD** generally refers to conditions that involve narrowed or blocked blood vessels that can lead to a heart attack, chest pain (angina) or stroke (Heart Disease, n.d.). They include:

	high blood pressure, hypertension, arrhythmias (abnormal heart rhythms), heart failure, heart valve disease, cardiomyopathy (heart muscle disease), vascular disease (blood vessel disease). **Prevalence** is a measure of the burden of disease in a population in a given location and at a particular time, as represented in a count of the number of people affected (Ward, 2013). Prevalence is a function of both the incidence and duration of disease. In turn, duration is affected by the availability and effectiveness of curative treatments and by survival times of afflicted individuals (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). **Incidence** represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010). **Morbidity** refers to the state of being diseased and the severity and impact of disease. Like prevalence, measures of morbidity represent the burden that a disease places on a population. In contrast to prevalence, morbidity estimates use more complex approaches that are potentially more informative than a simple count of cases (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). **Mortality** measures deaths caused by a specific disease, deaths resulting from treatment for a specific disease, or deaths in which a specific disease is a contributing factor, but not the primary cause. Mortality is the number of deaths due to a disease during a specific time divided by the number of persons in that population at the beginning of the time period. Hence, mortality is a rate in the sense that it represents how quickly deaths occur relative to population size and the passage of time. It can be interpreted as reflecting the risk of death from a particular cause faced by persons within the population being studied (National Institutes of Health. Autoimmune diseases

	coordinating committee—Autoimmune diseases research plan, n.d.).
Strengths and weaknesses	+ many recent studies indicating that even in modern urban environments of sprawling metropolises and congested conurbations, residential proximity to vegetation is associated with lower levels of stress, diabetes mellitus, stroke, and CVD (Dadvand, Bartoll, Basagaña, Dalmau-Bueno, Martinez, Ambros, Cirach, Triguero-Mas, Gascon, Borrell, & Nieuwenhuijsen, 2016; James, Banay, Hart, & Laden, 2015) - limited empirical evidence as to the contribution of mechanisms involved in the beneficial cardiovascular effects of greenery (i.e., decrease in the levels of local air pollution, increased proximity to walking spaces, lower levels of mental stress) (Bhatnagar, 2017)
Measurement procedure and tool	☒ *Quantitative*: epidemiological data (Health Data Administration/Cities) Incidence of CVD relevant for measurement, along prevalence, as it indicates the number of new cases of disease within a certain period (for example, since the implementation of the NBS), and can be expressed as a risk or an incidence rate. Recommended variables for CVD: o prevalence/incidence/morbidity/mortality of CVDs (coronary artery disease/coronary heart disease/narrowing of the arteries; heart attack; abnormal heart rhythms, or arrhythmias; heart failure; heart valve disease; congenital heart disease; heart muscle disease/cardiomyopathy; pericardial disease; aorta disease and Marfan syndrome; vascular disease/blood vessel disease) o blood pressure/hypertension HBP o stroke/cerebrovascular accident CVA o CRP (C-Reactive protein) levels (blood test)
Scale of measurement	-
Data source	
Required data	✓ Essential: NBS characteristics for each city/site
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation (longitudinal)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	P3 Perceived Quality of Green Spaces Sc5.1 Perceived Safety

	Sc5.2 Actual Safety SC7 Geographical Access to NBS SC8 Perceived Access to NBS HW3 General Wellbeing and Happiness HW4 Life expectancy and healthy life years expectancy HW8 Incidence of obesity/obesity rates (adults and children) HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
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21.6 Quality of Life

Project Name: Nature4Cities (Grant Agreement no. 730468)

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Quality of Life - QOL	**Health and Wellbeing**
Description and justification	The Quality of Life indicator indicates the global level of perceived quality of Life. It is capable to describe initial planning problems like perceived health in urban areas). Environmental quality of life is a multidimensional concept and considers the benefits of environment on physical, psychological and social dimensions (WHO, 1998), as well as multiple aspects of interactions between individuals and their environment (thermal comfort, noise, air quality, ambience, etc.). The Environmental Quality of Life (EQoL) scale developed in Nature4Cities is dedicated to the assessment of NBS benefits on quality of life. Understanding NBS evaluation and NBS perceived benefits would be a major step in promoting existing NBS, as well as a key to success for new NBS projects (Nature4Cities D4.3).
Definition	WHO defines Quality of Life as an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person's physical health, psychological state, personal beliefs, social relationships and their relationship to salient features of their environment (WHO, 1995). In Nature4Cities the Environmental Quality of Life Scale (EQoL) have been developed as an operational tool dedicated to the assessment of perceived benefits in terms of quality of life linked to Nature Based Solutions.
Strengths and weaknesses	This indicator is developed and applied within WHOQOL-BREF. When health providers implement new policies it is important that the effect of policy changes on the quality of life of people in contact with health services is evaluated. The WHOQOL instruments allow such monitoring of policy changes (Nature4Cities D2.1).

	In Nature4Cities the possibility of linking the EQoL scale scores to a variety of other physical, perceived or psychological indicators was demonstrated. In this sense, the EQoL scale can be used as a diagnostic tool in order to understand how people in a given area perceive and assess the benefits of NBS around where they live, with the possibility of targeting a particular type of inhabitant (for example, elderly people or patients
Measurement procedure and tool	In Nature4Cities the EQoL scale was developed with the idea of six separate modules, each one dedicated to a particular type of NBS: public gardens and parks, natural spaces, urban farms or collective gardens, green roofs and walls, blue spaces and biodiversity. This tool is meant to assess individual and collective perceptions and the impact of NBS on the different sub-dimensions of quality of life (i.e., physical, psychological and social quality of life). In its final form, the EQoL scale can be used in a variety of ways: As a diagnostic tool: - To assess the overall satisfaction of individuals regarding their environment or existing NBS in their environment; - To assess users' satisfaction if a given NBS is targeted. As an assessment tool: - To measure the efficiency of an NBS after its implementation by comparison with environmental quality of life before the NBS implementation; Finally, the EQoL scale can give specific hints if specific public and more vulnerable are targeted (for example, elderly people or patients).
Scale of measurement	☒ City ☒ Neighbourhood ☒ Object
Data source	• the response of the participant
Required data	• the participant response / the response is rated on a 5-point scale from « 1 = very poor » to « 5 = very good »
Data input type	Quantitative: The response of the participant on a lickert scale (a score from 1 to 5)
Data collection frequency	• One to several times in planning process. Before and after the NBS implementation.
Level of expertise required	Medium calculation difficulty and required data

Synergies with other indicators	
Connection with SDGs	SDG 3 Good Life and Well-being, SDG 11 Sustainable Cities and Communities
Opportunities for participatory data collection	This indicator is directly linked to the participants.
Additional information	The EQoL scale presented in Nature4Cities can deliver global environmental quality of life scores for each of the modules within the scale, which are related to the most common and well-known NBS forms. In this case, it is possible to consider implementing the EQoL scale for studies about the impact of physical, perceived or psychological predictors on environmental quality of life related to NBS. So far, the EQoL scale has been developed in eight different languages (English, French, Spanish, Dutch, German, Portuguese, Hungarian and Turkish), but base materials already exist for translation into other languages.
References	The World Health Organization Quality of Life assessment (WHOQOL): position paper from the World Health Organization. (1995). Soc Sci Med, 41(10), 1403-1409 The World Health Organization Quality of Life (WHOQOL)-BREF © World Health Organization 1996, http://www.who.int/mental_health/media/en/76.pdf The World Health Organization Quality of Life (WHOQOL)-BREF © World Health Organization 2004, http://www.who.int/substance_abuse/research_tools/en/english_whoqol.pdf / http://www.who.int/substance_abuse/research_tools/whoqolbref/en/ Nature4Cities, D2.1 - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS. https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions Nature4Cities, D4.3 - Development of an alternative value scale for NBS implementation in cities. https://www.nature4cities.eu/post/eqol-scale-operational-tool-to-assess-nbs-benefits-on-quality-of-life

22 Additional Indicators of Health and Well-being

22.1 Self-reported physical activity

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Carmen de Keijzer[1], Payam Dadvand[1]

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Self-reported physical activity	Health and Wellbeing
Description and justification	An indicator of overall physical activity a participant does per week, based on the most-used validated short physical activity questionnaire. Several studies on the association between green space exposure and physical activity have shown that an increase in green space was associated with more physical activity. However, these results were not always consistent.
Definition	Self-reported physical activity in metabolic equivalent of task (*MET*) minutes per week
Strengths and weaknesses	A strength of this indicator is that it is obtained by using a validated and widely used questionnaire to assess the overall physical activity level. This questionnaire has been translated into many languages and has been re-validated many times. A limitation is that the indicator is self-reported, although validation studies have demonstrated that the questionnaire is reliable. Another limitation is that it measures overall physical activity, thus not specifically focusing on physical activity done in green spaces.
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes the short-from International Physical Activity Questionnaire (IPAQ). In the IPAQ, the participants are asked how many days and how much time per day they spent on vigorous physical activity, moderate physical activity, walking, and sitting in the last 7 days. With these data, the overall physical activity in MET minutes per week can be calculated. This survey is repeated before and after the implementations of NBS in order to observe a potential change in physical activity.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables

Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is linked to physical activity.
Connection with SDGs	Good health and wellbeing: if the implementation of NBS is associated with an increase in physical activity, NBS contribute to improved health and wellbeing.
Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Lee, Macfarlane, Lam & Stewart. 2011. Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. International Journal of Behavioral Nutrition and Physical activity. 8,115.

22.2 Observed physical activity level within NBS

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Carmen de Keijzer[1], Payam Dadvand[1]

[1] *Fundacion Privada Instituto de Salud Global Barcelona, Barcelona, Spain*

Observed physical activity level within NBS	**Health and Wellbeing**
Description and justification	An indicator of the total physical activity that takes place in a NBS, obtained by direct observation of activity in the NBS. This is an important indicator of the potential benefits obtained from a NBS, as implementing a new NBS or improving an existing NBS is hypothesized to increase the use and activity that takes place in the NBS.
Definition	Observed weekly physical activity in the NBS (% over three levels of physical activity [sedentary, walking, or vigorous])
Strengths and weaknesses	A strength is that the indicator is objective and provides an estimate of the physical activity that take place specifically in the NBS. Moreover, it disentangles different types of activity/use of these spaces (e.g., walking, jogging/running, cycling, etc.) that occur in NBS. This observation tool has been widely used to assess physical activity in parks, playgrounds, and other relevant environments. A potential weakness is that the

	observations take place in one week, and by chance, this week may not be representative of the physical activity that generally takes place in the NBS.
Measurement procedure and tool	System of Observing Play and Recreation in Communities (SOPARC) uses direct observation to estimate the number of visitors and provides an assessment of the visitors' physical activity levels. Trained observers go to the NBS site to observe and count the number of users, and type of activity that they are doing at the site (e.g., sedentary, walking, or very active). These observations are systematic and periodic; measurements are taken in specific periods of time (morning, lunchtime, afternoon, and evening) and specific days (within one week; two weekdays and two weekend-days). This procedure is repeated twice; once before the NBS is implemented and once after the NBS is implemented.
Scale of measurement	NBS level
Data source	
Required data	SOPARC observation and summary forms
Data input type	Continuous variables
Data collection frequency	Twice (once before and once after the implementation of the NBS), except if the site is not accessible before the implementation of the NBS (in that case, just once, only after the implementation)
Level of expertise required	Low
Synergies with other indicators	This indicator is linked to physical activity indicators.
Connection with SDGs	Good health and wellbeing: if the implementation of NBS is associated with an increase in physical activity, NBS contribute to improved health and wellbeing.
Opportunities for participatory data collection	The tool could be implemented by ordinary citizens after a short formal training.
Additional information	
References	McKenzie, Cohen, Sehgal, Williamson, Golinelli, (2006). System for Observing Play and Recreation in Communities (SOPARC): Reliability and Feasibility Measures. J. Phys. Act. Health 3 Suppl 1, S208-S222.

22.3 Encouraging a healthy lifestyle

Project Name: UNaLab (Grant Agreement no. 730052)

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Encouraging a healthy lifestyle	Health and Wellbeing
Description and justification	A core co-benefit of NBS is the encouragement of healthy lifestyles for urban residents. Many different measures can be employed to encouraging a healthy lifestyle, such as: - Increasing bicycling opportunities in the neighbourhood - network of bicycle paths covering an area between residences and businesses/services - Increasing walking opportunities in the neighbourhood - network of pedestrian walkways covering an area between residences and businesses/services - Increasing the number, diversity or accessibility public sports facilities - Increasing the extent or accessibility of community gardening facilities - Designating public areas as non-smoking zones
Definition	Extent to which the NBS project and associated activities serve to promote a healthy lifestyle among local residents (qualitative, unitless)
Strengths and weaknesses	+ The indicator gives useful data for assessing impacts of the NBS on healthy lifestyle - Data collection and processing might be challenging
Measurement procedure and tool	The overall process of NBS co-creation, co-implementation and co-management with stakeholders provides ample opportunity to specifically target NBS interventions that provide opportunities for local citizens to adopt healthier lifestyles. The extent to which this is considered during NBS planning and implementation is assessed qualitatively using a five-point Likert scale from not at all (1, no encouragement of healthy lifestyles) to excellent (extensive online and offline encouragement): **Not at all – 1 — 2 — 3 — 4 — 5 — Excellent** 1. Not at all: no measures were taken to encourage a healthy lifestyle.

	2. Poor: there was little encouragement of a healthy lifestyle. 3. Somewhat: there was some encouragement of a healthy lifestyle with the implementation of some measures. 4. Good: a sufficient encouragement of a healthy lifestyle was translated into several offline (biking facilities, public sports facilities) and online (i.e., reminder app) initiatives. 5. Excellent: a healthy lifestyle was extensively encouraged offline (biking facilities, public sports facilities, pedestrian networks) and online (i.e., exercise apps).
Scale of measurement	District to metropolitan scale
Data source	
Required data	NBS project documentation, urban land use data
Data input type	Quantitative
Data collection frequency	Before and after implementation of the NBS project
Level of expertise required	Moderate
Synergies with other indicators	Synergies with indicators *Distribution of public green space*, *Accessibility of urban green spaces*, *Proportion of road network dedicated to pedestrians and/or bicyclists*, and *Availability and equitable distribution of blue-green space*
Connection with SDGs	SDG 3 Good health and well-being, and SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., & Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys D1.4. http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

22.4 Incidence of obesity

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Incidence of obesity among adults and children	Health and Wellbeing
Description and justification	With an abundance of convenient, palatable, energy dense foods and increasingly fewer demands for physical activity in usual lifestyles, the contemporary environment enables the energy balance to be tipped in favour of weight gain (obesogenic environment) (Bhrem & D'Alession, 2014). In adults, obesity is associated with increasing risk of cardiovascular disease, type 2 diabetes, and all-cause mortality. Most of the associated mortality and morbidity is mediated through major chronic diseases related to obesity, such as cardiovascular disease, diabetes, and cancer (Bhrem & D'Alession, 2014). Overweight children face a greater risk of a host of problems, including type 2 diabetes, high blood pressure, high blood lipids, asthma, sleep apnea, chronic hypoxemia (too little oxygen in the blood), early maturation, and orthopaedic problems (Samuels, 2004). They also suffer psychosocial problems, including low self-esteem, poor body image, and symptoms of depression (Samuels, 2004). Studies conducted so far have focused on the relationship between access to green space and obesity or obesity-related health conditions, as well as to what extent this relationship is influenced by levels of physical activity, socio-economic status and age. A systematic review of evidence found that the majority of research undertaken have found a positive association between green space and obesity-related health indicators, but that the relationship varied across age, socioeconomic status and the type of greenspace measure, and findings are inconsistent and mixed across studies (Lachowicz & Jones, 2011). Beyond objective opportunities to access green space for physical activity and the availability and affordability of healthy food, actual use of green spaces might be a much better predictor of obesity outcomes (Lachowicz & Jones, 2011). Yoon and Kwon (2014) performed multilevel analysis to investigate community environmental effects on obesity and obesity risks. Relying on data collected with Community Health Surveys over a period of 2 years, the authors reported that objectively measured physical environmental variables did not significantly influence

	obesity, but *subjective perception of the community environment* (e.g., perceived accessibility to exercise facilities, satisfaction with safety, satisfaction with natural environment, satisfaction with living environment, satisfaction with public transportation) significantly influenced obesity. While obesity rates were higher among residents living in communities with high satisfaction with the natural environment, rates were lower among those living in communities reporting high satisfaction with use of public transportation. This means that providing access to green spaces might not be sufficient in reducing obesity, if green spaces and facilities for active mobility, exercise and leisure are not perceived as high quality and satisfactory. Calls for future research in studies focus on understanding intermediary mechanisms (e.g., psychosocial factors), as well as the amount and quality of green space necessary for significant reductions in obesity across all age groups (Lachowicz & Jones, 2011; Lachowicz & Jones, 2014).
Definition	ADULTS Obesity is defined as a measure of Body Mass Index (BMI) - a ratio of weight to height that is calculated by the following formula: BMI = weight (kg) ÷ height $(m)^2$ For adults, BMIs in the range of 18.5 to 24.9 are considered to be healthy – and associated with the lowest risk of mortality and morbidity. Overweight is defined as a BMI of 25.0 to 29.9; obesity is defined as a BMI of at least 30, with 3 sub-categories (Class I, Class II, and Class III) that are associated with increasing risk of cardiovascular disease, type 2 diabetes, and all-cause mortality (Bhrem and D'Alession, 2014). CHILDREN There is no consensus on a cut-off point for excess fatness of overweight or obesity in children and adolescents. European researchers classified overweight as at or above 85 percentile and obesity as at or above 95 percentile of BMI (Sahoo, Sahoo, Choudhury, Sofi, Kumar,& Bhadoria, 2015). **Incidence** represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a

	risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010).
Strengths and weaknesses	+ some evidence as to an association between exposure to nature (e.g., physical exercise, healthy food intake) and obesity-related health indicators - inconsistent and mixed results across studies, pointing at other variables that may be more relevant as predictors for obesity-related health indicators (e.g., actual use of green spaces, Lachowicz & Jones, 2011)
Measurement procedure and tool	☒ *Quantitative*: epidemiological data (Health Data Administration/Cities) Recommended measurements for obesity: o Measurements of BMI - adults* o Waist circumference - children o Measurement of subjective perception of the community environment (e.g., perceived accessibility to exercise facilities. satisfaction with safety, satisfaction with natural environment, satisfaction with living environment, satisfaction with public transportation) was proven to be of significance and it is recommended that is taken into account (see He Yoon and Kwon, 2014). Body mass index (BMI) is the most commonly used simple measure of adiposity, but it has limitations: it measures presumed excess weight given height, rather than actual body fat, and does not give any indication as to the distribution of fat in the body, and in adults, central adiposity is more closely associated with health risks than general adiposity. A wide range of alternative simple tools to measure adiposity or obesity is available, such as waist circumference, neck circumference, skinfold thickness, waist-to-hip ratio, waist-to-height ratio, body adiposity index, Rohrer's ponderal index, Benn's index and fat mass index (Simmonds, Burch, Llewellyn, Griffiths, Yang, Owen, Duffy, & Woolacott, 2015; Simmonds, Llewellyn, Owen, & Woolacott, 2015). While BMI seems appropriate for differentiating adults, it may not be as useful in children because of their changing body shape as they progress through normal growth. In addition, BMI fails to distinguish between fat and fat-free mass (muscle and bone) and may exaggerate obesity in large muscular children. Furthermore, maturation pattern differs between genders and different ethnic groups. While health consequences of obesity are related to excess fatness, the ideal method of classification should be based on direct measurement of fatness. Although methods such as densitometry can be used in research practice, they are

	not feasible for clinical settings. For large population-based studies and clinical situations, bioelectrical impedance analysis (BIA) is widely used. Waist circumference seems to be more accurate for children because it targets central obesity, which is a risk factor for type II diabetes and coronary heart disease (Sahoo et al., 2015).
Scale of measurement	-
Data source	
Required data	✓ Essential: NBS characteristics for each city/site
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation (longitudinal)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	P3 Perceived Quality of Green Spaces Sc5.1 Perceived Safety Sc5.2 Actual Safety SC7 Geographical Access to NBS SC8 Perceived Access to NBS HW1 Sustainable nutrition/adoption HW3 General Wellbeing and Happiness HW4 Life expectancy and healthy life years expectancy HW6 Prevalence, incidence, morbidity, and mortality of cardiovascular disease (CVD) HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
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22.5 Heat-related discomfort: Universal Thermal Climate Index (UTCI)

Project Name: UNaLab (Grant Agreement no. 730052)

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Universal Thermal Climate Index (UTCI)	Climate Resilience Natural and Climate Hazards Health and Wellbeing
Description and justification	UTCI index represents air temperature of the reference condition with the same physiological response as the actual condition. The UTCI provides a one-dimensional value that reflects the human physiological reaction to the multi-dimensional outdoor thermal environment (Bröde et al., 2012). It can predict both whole body thermal effects (hypothermia and hyperthermia; heat and cold discomfort), and local effects (facial, hands and feet cooling and frostbite). Applications of the UTCI include weather forecasts, bioclimatological assessments, bioclimatic mapping, urban design, engineering of outdoor spaces, outdoor recreation, epidemiology and climate impact research.
Definition	The UTCI is the air temperature that would produce under reference conditions the same thermal strain as the actual thermal environment. In other words, the UTCI is the reference environmental temperature causing strain.
Strengths and weaknesses	+ Mathematical expression of a person's thermal comfort in the outdoors + The output is expressed in easily understandable temperature units, e.g., °C.
Measurement procedure and tool	The human body core temperature must be maintained within a narrow range around 37°C to ensure proper function of the body's inner organs and the brain, thus optimising human comfort, performance and health. In contrast, the temperature of the skin and extremities can vary widely, depending upon environmental conditions. This variation in the temperature of extremities is one of the mechanisms to equilibrate heat production and heat loss. The heat exchange between the human body and environment can be described in the form of the energy balance equation:

$$M + W + C + K + E + Q + Res \pm S = 0$$

where

M=heat produced by metabolism;
W=heat generated by muscular activity;
C=sensible heat flux (heat transferred by convection);
K=heat transferred through conduction contact with solid bodies);
E=latent heat flux (evaporative heat flux);
Q=radiative heat transfer;
Res=heat transfer through respiration; and,
S=heat content of the body.

The UTCI is derived from this mathematical model of thermoregulation with an integrated adaptive clothing model that also accounts for predicted votes of the dynamic thermal sensation based on core and skin temperature (Fiala et al., 1999, 2001, 2003; Havenith et al., 2011). The deviation of UTCI temperature from measured air temperature depends on measured values of air temperature (T_a) and mean radiant temperature (T_{mrt}), wind speed at a height of 10 m (v_a) and humidity expressed as water vapour pressure (p_a) or relative humidity (rH):

$$UTCI(T_a, T_{mrt}, v_a, p_a) = Ta + Offset(T_a, T_{mrt}, v_a, p_a)$$

The model reference condition is walking at 4 km/h (135 W/m^2) with $T_{mrt}=T_a$, v_a=0.5 m/s, rH=50% (T_a >29°C) and p_a=20 hPa (T_a >29°C) (Bröde et al., 2012). The UTCI dynamic model response can be determined using the online calculator available from http://utci.org. The relationship between UTCI temperature (expressed in °C) and physiological stress is shown in the table below (adapted from Błażejczyk et al., 2010).

UTCI (°C) range	Stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal stress
0 to +9	Slight cold stress
-13 to 0	Moderate cold stress
-27 to -13	Strong cold stress
-40 to -27	Very strong cold stress
Below -40	Extreme cold stress

Scale of measurement	Plot – street – neighbourhood – district
Data source	
Required data	Air temperature, T_a (°C) Mean radiant temperature, T_{mrt} (degrees Kelvin) Water vapour pressure (hPa) Relative humidity (%) Wind speed at a height of 10 m (m/s)
Data input type	Quantitative
Data collection frequency	Frequency as desired. UTCI can be calculated frequently with measurement intervals determined by (automated) weather data acquisition.
Level of expertise required	Low to Moderate
Synergies with other indicators	Direct relation to *Heatwave incidence* and *Number of combined tropical nights and hot days* indicators. Similar to *Physiological equivalent temperature (PET)*
Connection with SDGs	SDG 3 Good health and well-being, SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through direct participation in weather data collection
Additional information	
References	Błażejczyk, K., Broede, P., Fiala, D., Havenith, G., Holmér, I., Jendritzky, G., Kampmann, B. & Kunert, A. (2010). Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. Miscellanea Geographica, 14, 91-102. Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. & Havenith, G. (2012). International Journal of Biometeorology, 56, 481-494. Fiala, D., Havenith, G., Bröde, P., Kampmann, B & Jendritzky, G. (2011). UTCI-Fiala multi-node model of human temperature regulation and thermal comfort. International Journal of Biometeorology, 56, 429-441. Fiala D, Lomas KJ, Stohrer M (1999) A computer model of human thermoregulation for a wide range of environmental conditions: the passive system. Journal of Applied Physiology, 87, 1957–1972. Fiala D, Lomas KJ, Stohrer M (2001) Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. International Journal of Biometeorology, 45, 143–159.

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22.6 Hospital admissions due to high temperature during extreme heat events

Project Name: UNaLab (Grant Agreement no. 730052)

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Hospital admissions due to high temperature during extreme heat events	Health and Wellbeing
Description and justification	Heat waves are the most significant weather-related cause of human mortality worldwide (Agarwal, Dwivedi & Ghanshyam, 2018).
Definition	The number of hospital admissions per 100 000 inhabitants due to high temperature during extreme heat events from baseline values
Strengths and weaknesses	+ Easy to measure - Difficulties in ruling out other causes for hospital admissions
Measurement procedure and tool	This metric can easily be evaluated using public health data regarding daily emergency room admissions. These data can be used either to evaluate total emergency room admissions, or to assess hospital admissions for specific disease categories such as heat stroke, dehydration and cardiac arrest (e.g., Davis & Novicoff, 2018). Further disaggregation of data may include separation by population demographic (e.g., Gronlund, Zanobetti, Schwartz, Wellenius & O'Neill, 2014).
Scale of measurement	District to metropolitan scale
Data source	

Required data	Public health data regarding either total emergency room admissions or hospital admissions for specific disease categories. Population data.
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the indicator group *Temperature* indicators
Connection with SDGs	SDG 3 Good health and well-being, and SDG 13 Climate action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Agarwal, A.K., Dwivedi, S. & Ghanshyam, A. (2018). Summer heat: Making a consistent health impact. Indian Journal of Occupational and Environmental Medicine, 22(1), 57-58. Davis, R.E., & Novicoff, W.M. (2018). The impact of heat waves on emergency department admissions in Charlottesville, Virginia, U.S.A. International Journal of Environmental Research and Public Health, 15(7) 1436. Gronlund, C.J., Zanobetti, A., Schwartz, J.D., Wellenius, G.A., & O'Neill, M.S. (2014). Heat, heat waves, and hospital admissions among the elderly in the United States, 1992-2006. Environmental Health Perspectives, 122(11), 1187-1192.

22.7 Heat-related mortality

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Heat-related mortality	**Health and Wellbeing**
Description and justification	A built-up environment has significant influence on urban air temperature, which has been found to be considerably warmer than its surrounding rural or peri-urban areas. This phenomenon is called the urban heat island (UHI) effect,

where urban structures absorb solar heat (radiation) during the daytime and release it back to the environment at nighttime (Oke, 1981 as cited in Lehmann, 2014, p. 5). Introducing greenery in cities is seen as the most cost effective strategy for mitigating the urban heat island effect, because greenery helps to cool the environment through the process of evapotranspiration where large amounts of solar radiation can be converted into latent heat (Lehmann, 2014).

Bowler, Buyung-Ali, Knight and Pullin (2010) reviewed the cooling effect of urban greening and found moderate to strong evidence for reduced temperature. The meta-analysis demonstrated that, on average, a park is 0.94 °C cooler as compared to surrounding built environments. Increased heat is a strong predictor of a range of diseases (including several which have to date not been addressed in studies on natural environments and health, such as infant mortality and renal disorders) and mortality (Basagaña, Sartini, Barrera-Gómez, Dadvand, Cunillera, Ostro, Sunyer, & Mercedes Medina-Ramón, 2011; Benmarhnia, Deguen, Kaufman, & Smargiassi, 2015). It also has an impact on mental health (Berry, Bowen, & Kjellstrom, 2010).

The relation between heat and lung cancer mortality is not sufficiently investigated (van den Bosch and Ode Sang, 2017). An increase in mortality with heat has been reported for some specific causes, namely cardiovascular disease, respiratory disease, mental, and nervous systems disorders, diabetes, and kidney and urinary system diseases (Basagaña et al., 2011).

In the heat-related mortality literature, it is typical to distinguish two types of heat exposures: first, increases in ambient temperatures which can be defined as periods of high temperatures over single days, associated with mortality, and second, consecutive days of high heat also known as heat wave days, where population mortality is greater than on non-heat wave days (Benmarhnia et al., 2015). Basagaña et al. (2011) used a long mortality series (24 years) in a large geographic area of Spain to assess the effect of extremely hot days on mortality using a fine classification of the cause of death, including external causes and causes of infant mortality. The study included all persons who died in Catalonia during the warm season (defined as May 15–October 15, which included the half-months with an average maximum temperature greater than 20°C) of the 24-year period from 1983 to 2006.

	Exposures to temperature and to humidity (records) were assigned to each deceased person based on the values registered in the nearest weather station within the climatic zone of the town of death. Epstein and Moran (2006) advanced arguments for use of DI - the Discomfort Index – for the measurement of heat stress.
Definition	**Heat-related Deaths Indicator** shows the annual rate for deaths classified by medical professionals as "heat-related" in a given country, based on death certificate records. Every death is recorded on a death certificate, where a medical professional identifies the main cause of death (also known as the underlying cause), along with other conditions that contributed to the death. These causes are classified using a set of standard codes. Dividing the annual number of deaths by the country's population in that year, then multiplying by one million, will result in the death rates (per million people) that this indicator shows (Climate Change Indicators: Heat-Related Deaths, n.d.). **Mortality** measures deaths caused by a specific disease, deaths resulting from treatment for a specific disease, or deaths in which a specific disease is a contributing factor, but not the primary cause. Mortality is the number of deaths due to a disease during a specific time divided by the number of persons in that population at the beginning of the time period. Hence, mortality is a rate in the sense that it represents how quickly deaths occur relative to population size and the passage of time. It can be interpreted as reflecting the risk of death from a particular cause faced by persons within the population being studied (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).
Strengths and weaknesses	+ robust evidence as to UHI being a strong predictor of death rates, especially for certain health conditions, like cardiovascular disease, respiratory disease, renal disorders, etc. - limited empirical evidence on heat's role in lung cancer complications, etc.
Measurement procedure and tool	☒ *Quantitative*: epidemiological data (Health Data Administration/Cities) Recommended variables: o Discomfort Index, DI (i.e., Temperature–humidity index, THI) - combination of temperature and humidity that is a measure of the degree of discomfort experienced by an individual in warm weather (Temperature–

	humidity index - Meteorological Measurement, n.d.) o Heat-related Deaths Indicator
Scale of measurement	-
Data source	
Required data	✓ Essential: NBS characteristics for each city/site
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation (longitudinal)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	HW3 General Wellbeing and Happiness HW4 Life expectancy and healthy life years expectancy HW6 Prevalence, incidence, morbidity, and mortality of cardiovascular disease (CVD) HW7 Prevalence, incidence, morbidity, and mortality of respiratory disease (RD) HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure HW13 Levels of aggressiveness and violence
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
References	Basagaña, X., Sartini, C., Barrera-Gómez, J., Dadvand, P., Cunillera, J., Ostro, B., Sunyer, J., & Medina-Ramòn, M. (2011). Heat waves and cause-specific mortality at all ages. *Epidemiology,* 22, 765–772. doi: 10.1097/EDE.0b013e31823031c5 Benmarhnia, T., Deguen, S., Kaufman, J.S., & Smargiassi, A. (2018). Vulnerability to Heat-related Mortality: A Systematic Review , Meta-analysis , and Meta-regression Analysis. Epidemiology (Cambridge, Mass.), 26. doi: 10.1097/EDE.0000000000000375 Berry, H., Bowen, K., & Kjellstrom, T. (2010). Climate change and mental health: A causal pathways framework. *International Journal of Public Health*, 55, 123-32. doi: 10.1007/s00038-009-0112-0 Bowler, D., Buyung-Ali, L., Knight, T.M., & Pullin, A. (2010). Urban greening to cool towns and cities: A systematic review of the

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22.8 Exposure to noise pollution

Project Name: Nature4Cities (Grant agreement: No. 730468), UNaLab (Grant Agreement no. 730052) and URBAN GreenUP (Grant Agreement no. 730426)

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Exposure to noise pollution	**Health and well-being**
Description and justification	Prolonged exposure to noise, such as the environmental noise pollution caused by road, rail and airport traffic, industry, construction, and other outdoor activities, can lead to significant physical and mental health effects (ISO, 2018). Environmental noise pollution is any disturbing noise that interferes with or harms humans or wildlife. The L_{DEN} indicator has been defined several years ago by a European expert group, in order to compare different noise situations all over European cities (noise maps of people exposed to sound pollution) through the use of a single, common and harmonized indicator. Despite the assumptions and limitations of such energetic descriptors, the L_{DEN} indicator is now stabilized and generalized. The L_{DEN} is a daily equivalent sound pressure level (T=00h-24h), with a 0dB(A) penalty increase for the Day period (T=6h-18h), a 5dB(A) penalty increase for the Evening period (T=18h-22h) and a 10dB(A) penalty increase for the Night period (T=22h-6h).
Definition	The L_{DEN} is an acoustic indicator for sound environment. L_{DEN} is expressed in dB(A) because it is based on a combination of equivalent sound pressure levels Leq,T (energetic summation through logarithmic law), calculated with the A ponderation on 3 periods (day, evening, night), depending on the sound source emission (i.e., road traffic conditions).

	The indicator is the proportion (%) of population exposed to noise levels of L_{den} > 55 dB(A), before and after NBS implementation.
Strengths and weaknesses	+ Relatively easy to measure - Accurate data require extensive and precise measurements
Measurement procedure and tool	<u>L_{DEN} - Day-evening-night noise level (Nature4Cities):</u> Measured L_{DEN} (in situ measurements) $L_{den} = 10\log_{10}\frac{1}{24}\left(12\times10^{\frac{L_{day}}{10}} + 4\times10^{\frac{L_{evening}+5}{10}} + 8\times10^{\frac{L_{night}+10}{10}}\right)$ In which L_{day}, L_{night} and $L_{evening}$ are the A-weighted long-term averages Simulated L_{DEN} (numerical predictions): NMPB2008 or CNOSSOS-EU (see reference pdf document from UN/Ifsttar/LAE/BG) Measurement unit: Decibels with A ponderation: “dB(A)” Tools: - Measured L_{DEN} (in situ measurements): integrating sonometer, either professional, low-cost or even smartphone http://noise-planet.org/noisecapture.html - Simulated L_{DEN} (numerical predictions): noise prediction software, e.g., open-source tool “NoiseModelling” http://noise-planet.org/noisemodelling.html <u>Exposure to noise pollution (UNaLab):</u> Environmental noise pollution is commonly measured in level of A-weighted decibels (dB(A)), which accounts for the hearing threshold of a human ear being less sensitive to very high and very low frequencies, which means that noise reduction can be calculated as: $\left(\frac{dB(A)\ level\ after\ NBS\ implementation}{dB(A)\ level\ before\ NBS\ implementation}\right)\times 100 = \%\ change\ in\ noise\ level$ An alternative calculation involves an estimation of the share of the population of a defined urban area that is affected by noise >55 dB during the night: $\left(\frac{No.\ inhabitatants\ exposed\ to\ noise > 55\ dB(A)}{Total\ number\ of\ inhabitants}\right)\times 100 = \%\ population\ affected\ by\ noise$ Regardless of the calculation used, the noise level should be measured (or modelled) at the object receiving the noise. In urban areas, “night” hours are defined differently depending on jurisdiction but typically involve a specific

	time range, e.g., 22:00-07:00, rather than the meteorological definition of night as the period between dusk and dawn. <u>Noise reduction rates applied to UGI within a defined road (URBAN GreenUP):</u> It is accounted for two factors that influence noise reduction services: vegetation (NBS) characteristics and distance to the noise source. The analysis is focused on road traffic noise, as this is a constant source and most disturbing to people. The measurements before and after the intervention have to be made on similar dates, same day of the week and hour. Simulations with and without NBS will be assessed to define the impact of the NBS. A strategic noise map is the presentation of data on one of the following aspects: - A noise situation in terms of the noise indicators L_{DEN} and L_{NIGHT}; - The exceeding of a limit value; - The estimated number of dwellings that are exposed to specific values of a noise indicator; - The estimated number of people exposed to noise. Values of L_{DEN} and L_{NIGHT} can be determined either by computation or by measurement (at the assessment positions) and that for prediction, only computation is applicable.
Scale of measurement	Object, neighbourhood and city scale
Data source	
Required data	- Measured L_{DEN} (in situ measurements): acoustic acquisition (in dB(A)) on hourly periods (with typically 1 sec sampling rate), gathered on 3 periods (Day, Evening, Night) and next aggregated on 24h (see definition above). - Simulated L_{DEN} (numerical predictions): acoustic simulation (in dB(A)) on hourly periods (depending on input data, e.g., road traffic characterization, built-up implementation through GIS, etc.), gathered on 3 periods (Day, Evening, Night) and next aggregated on 24h (see definition above). - Georeferenced data for built-up area: data from OPEN STREET MAP (OSM) - Road traffic counts: data from district, city or regional agencies - Number of inhabitants exposed to noise, and total number of inhabitants
Data input type	- Measured L_{DEN} (in situ measurements): quantitative (L_{DEN} acquisition in dB(A) using sonometer)

	- Simulated L_{DEN} (numerical predictions): quantitative (georeferenced data, traffic counts, etc.) + qualitative (e.g., typology of NBS in urban medium)
Data collection frequency	At least before and after the project's implementation, to characterize the vegetation or occasional measurement (and long-period monitoring) of biomass size or continuous measurement of climatic data
Level of expertise required	Relatively easy to understand. Low to moderate
Synergies with other indicators	Related to *Area devoted to roads* indicator
Connection with SDGs	SDG 3 Good health and Well-being, SDG 9 Industry, innovation and Infrastructure, SDG 11 Sustainable cities and communities, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
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Nature4Cities, D2.2 - Expert-modelling toolbox

Nature4Cities, D2.3 – NBS database completed with urban performance data https://www.nature4cities.eu/post/applicability-urban-challenges-and-indicators-real-case-studies

Nature4Cities, D2.4 - Development of a simplified urban performance assessment (SUA) tool

URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl

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URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl

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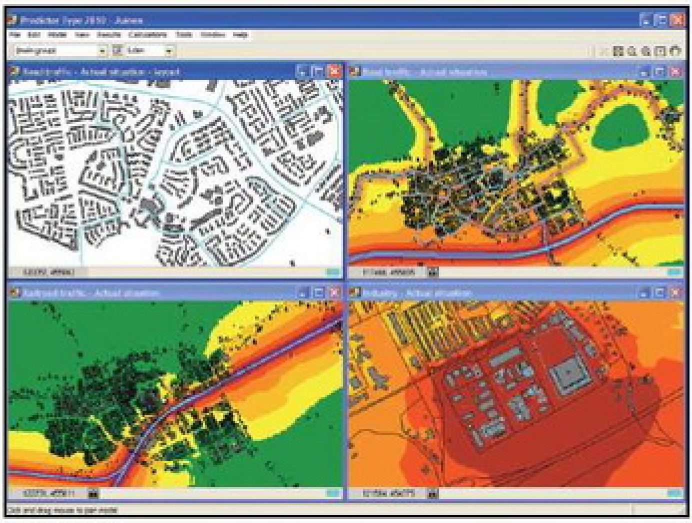

Figure: Example of data visualization.

22.9 Perceived chronic loneliness

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Chronic loneliness	**Health and Wellbeing**
Description and justification	Loneliness is a growing problem in industrialized countries, where around one in three people is affected, and one in 12 severely (Cacioppo & Cacioppo, 2018). It has become a public health problem, since in addition to the serious consequences for the psychological well-being of individuals who suffer it, longitudinal studies show that loneliness implies an increased risk of morbidity and premature mortality, when compared with individuals who are more socially integrated or do not feel isolated (Cacioppo & Cacioppo, 2018; Shankar et al., 2017). Specifically, loneliness increases the risk of premature death by 26% (Cacioppo & Cacioppo, 2018), and the strength of social

	isolation as a predictor of mortality is similar to other well-documented risk factors, such as obesity or smoking (Pantell et al., 2013). The so-called "common sense treatments" (i.e., social skills training) have not been effective in tackling loneliness, while behavioural interventions and community programs show greater evidence of positive impact (Cacioppo & Cacioppo , 2018). Many recent interventions aim to improve well-being through connection and contact with green spaces, since the majority of studies published in this regard show a positive relationship between some aspect of green space, and health and wellbeing (Wendelboe-Nelson et al., 2019). Even the combination of virtual social interaction with the relaxation effect of experiencing nature through virtual reality has been shown to contribute to reductions in feelings of loneliness, as well as in the risks in associated illnesses (White et al., 2018). Green spaces increase social cohesion through fostering positive social interactions and social engagement (Jennings & Bamkole, 2019). Natural features also enhance feelings of place attachment and identity, promoting a sense of community that contributes to a decrease in feelings of loneliness (Prezza et al., 2001). A lower presence of green spaces in people's living environment was found to be related to greater feelings of loneliness and perceived shortage of social support (Maas et al., 2009). The association between green spaces, perceived social support and loneliness was found to be the strongest in highly urbanized areas.
Definition	Loneliness, or social isolation, can be defined as disengagement from social ties, institutional connections, or community participation (Seeman, 1996).
Strengths and weaknesses	+ The indicator allows evaluating one of the most pressing problems for health and well-being in modern societies + Especially important indicator to assess levels of physical and mental health in the elderly - The relationship between the indicator, exposure to green spaces and levels of health and wellbeing are mediated by other variables such as social contact in those places.
Measurement procedure and tool	☒ Quantitative P: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: Three-Item Loneliness Scale (Hughes et al., 2004). It includes three items with a three-point Likert response scale (Hardly ever; Some of the time; Often). The Three-Item Loneliness Scale greatly expands the possibilities for loneliness research in the older population.
Scale of measurement	▪ Three-Item Loneliness Scale (Hughes et al., 2004)

	The next questions are about how you feel about different aspects of your life. For each one, tell me how often you feel that way. 1. First, how often do you feel that you lack companionship? 2. How often do you feel left out? 3. How often do you feel isolated from others?
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for social interaction and for physical exercise, etc. ✓ Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator SC6 (Place Attachment)
Data input type	Quantitative
Data collection frequency	After NBS implementation or aligned with timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	SC1 Bonding social capital SC2 Bridging social capital SC4.1 Trust in community SC4.2 Solidarity between neighbors SC4.3 Tolerance and respect SC5.1 Perceived safety SC6 Place attachment (Sense of Place): Place Identity HW3 General wellbeing and happiness HW4 Life expectancy and healthy life years expectancy HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety ENV23 Green-space accessibility
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	No opportunities identified
Additional information	
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22.10 Somatisation

Project Name: proGIreg (Grant Agreement no. 776528)

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Somatisation	**Health and Wellbeing**
Description and justification	Somatisation is the manifestation of psychological distress by the presentation of physical symptoms. As previous studies have observed associations between green space

	exposure and mental health, green space exposure could be hypothesized to be associated with somatisation.
Definition	Somatisation scale
Strengths and weaknesses	The strength of this indicator is that evidence on an association between green space exposure and somatisation is scarce. In addition, the questionnaire used to assess somatisation symptoms has been validated and is available in several languages. However, a limitation is that somatisation symptoms are difficult to link to mental or physical health problems.
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes a section of the well-established Four-Dimensional Symptom Questionnaire (4DSQ) on somatisation. The answers are given on a scale from 0 to 3 and the summary score can be categorized as low, moderately high, or very high somatisation symptoms. This survey is repeated before and after the implementations of NBS in order to observe a potential change in somatisation symptoms.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on mental health.
Connection with SDGs	Good health and wellbeing: if the implementation of NBS are associated with decreased somatisation symptoms, NBS contribute to improved health and wellbeing.
Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Terluin et al. 2006. The Four-Dimensional Symptom Questionnaire (4DSQ): a validation study of a multidimensional self-report questionnaire to assess distress, depression, anxiety and somatisation. BMC Psychiatry; 6, 34.

22.11 Mindfulness

Project Name: proGIreg (Grant Agreement no. 776528)

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Mindfulness	**Health and Wellbeing** **Knowledge and Social Capacity Building**
Description and justification	Mindfulness is a well-recognized indicator that correlates with several cognitive and affective outcomes (e.g., attention, awareness, happiness, distress). The empirical investigation showed that mindfulness is strongly related to connectedness to nature and pro-environmental behaviour.
Definition	Ability of being conscious or aware of something within the environment
Strengths and weaknesses	Strengths: Reliable measurement tool; easy to assess. Weaknesses: Potential biases in self-reported data
Measurement procedure and tool	This indicator is obtained using a validated scale named "Cognitive and Affective Mindfulness Scale-Revised" (CAMS-R – Feldman et al., 2007). Participants are required to complete the CAMS-R before and after the NBS implementation. The scale includes 12 items with a 4-point Likert scale, from "Rarely/Not at all" to "Almost always".
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions (baseline) and once after (follow-up)
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness and to the indicators on mental health and well-being
Connection with SDGs	• Good health and wellbeing • Reduced inequalities • Sustainable cities and communities

	• Peace, justice and strong institutions
Opportunities for participatory data collection	The questionnaires can be both self-reported and administrable in an interview method.
Additional information	
References	Feldman, Hayes, Kumar, Greeson, Laurenceau (2007). Mindfulness and emotion regulation: The development and initial validation of the Cognitive and Affective Mindfulness Scale-Revised (CAMS-R). Journal of psycho-pathology and Behavioral Assessment, 29, 177.

22.12 Visual access to green space

Project Name: proGIreg (Grant Agreement no. 776528)

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Visual access to green space	**Green Space Management** **Health and Wellbeing**
Description and justification	Visual access to green space is an indicator of exposure to green spaces. Previous experimental studies have shown short-term looking at green spaces could have mental health benefits such as reducing stress, restoring attention, and improving mood. An emerging body of evidence is also suggestive of the health benefits of the long-term visual exposure to green spaces.
Definition	Self-reported amount of green space in the view from windows at home and the frequency of looking at the view.
Strengths and weaknesses	A strength of this indicator is that few epidemiological studies have considered visual access to green space in the long-term association between green spaces and health. A limitation is that the indicator is self-reported.
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes a section with the following questions: "*At home, how much green space (trees, grasses, flowers, etc.) can you see through the following window(s)?*" with possible answers on a scale from 0 (no green space/no window) to 4 (all of the view completely filled green space) "*How often (during the day) do you look out through the following window(s)?*" with possible answers on a scale from 0 (no window/never) to 3 (often)

	This survey is repeated before and after the implementations of NBS in order to observe a potential change in visual exposure to green and blue spaces.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators of exposure to green space
Connection with SDGs	Good health and wellbeing: accumulating evidence demonstrates that increased green space exposure has been associated with better health and wellbeing. An increased visual exposure to green spaces is likely to contribute to improved health and wellbeing. Sustainable cities and communities: The implementation of nature-based solutions may contribute to increased visual exposure to nature and to sustainable cities and communities.
Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Van den Bosch et al (2015) Autonomic Nervous System Responses to Viewing Green and Built Settings: Differentiating Between Sympathetic and Parasympathetic Activity. Int J Environ Res Public Health; 12(12): 15860–15874 Berto (2014) The role of nature in coping with psycho-physiological stress: a literature review on restorativeness. Behav Sci (Basel). 2014 Oct 21;4(4):394-409 Bratman et al (2012) The impacts of nature experience on human cognitive function and mental health. Annals of the New York Academy of Sciences; 1249(1): 118-136 Abkar et al (2010) Influences of viewing nature through windows. Australian Journal of Basic and Applied Sciences; 4(10): 5346-5351

22.13 Perceived restorativeness of public green space / NBS

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Perceived Restorativeness	Health and Wellbeing
Description and justification	In recent decades a growing body of environmental psychology research has demonstrated the psychological benefits of interacting with natural environments, especially green spaces (Joye & Dewitte, 2018). There is strong evidence that experiencing nature through leisure activities pursued in green spaces (i.e., walking in parks, gardening) has benefits in mental health, creativity and mental relaxation (Aspinall et al., 2013; Bratman et al., 2015; Braubach et al., 2017; Hartig et al., 2014; Van der Berg & Custers, 2011; Williams et al., 2018). Natural physical settings play an important role in coping with stress, as there are robust links between exposure to natural environments and recovery from physiological stress and mental fatigue (Berto, 2014). Two complementary theoretical perspectives explain the psychological pathways of beneficial effects of nature on health, wellbeing, and mental states, namely Attention Restoration Theory (ART - Kaplan, 1995) and Stress Recovery Theory (SRT - Ulrich et al., 1991). Regarding ART, the theory suggests that concentration capacity is a limited resource and susceptible to fatigue by overuse, but that it can be restored by exposure to natural environments (Ohly et al., 2016; Zhang et al., 2017). These environments are a healthy resource, which allows and promotes the restoration of individuals within it from their state of directed attention fatigue (Zhang et al., 2017). Although this theory has been widely cited, there is uncertainty regarding which attentional aspects are affected by exposure to natural environments (Ohly et al., 2016). It is hypothesized that the restorative effect of these environments derives from its soft fascinating characteristics; these can set an individual in an effortless mode of attention, thereby giving directed attention to a relative opportunity to rest and replenish itself (Joye & Dewitte, 2018). Softly fascinating stimuli not only requires little effort, but also leaves mental space for reflection (Basu et al., 2019). In turn, exposure to nature can boost an individual’s sense of connectedness (i.e., emotional or cognitive bonds to the natural world), as there is a bidirectional relationship between connectedness and restoration (Wyles et al., 2019). Both the connection with nature and nature

	restorativeness are an alternative source of motivation, to reinforce the relationship between environmental knowledge, environmental attitudes and engagement in pro-environmental behaviour (Berto & Barbiero, 2017; Whitburn et al., 2019). Much of recent research in the restorative process of natural environments has focused on knowing how cities can incorporate elements that facilitate attentional restoration, since this process can be affected both positively and negatively by different urban factors (Zhang et al., 2017). Cities can be potentially restorative, improving urban designs to offer psychological benefits to citizens (San Juan et al., 2017), since urban nature environment fosters mental health as a natural therapy intervention to improve pro-environmental behaviour for urban communities (Othman et al., 2020). Specifically, the restorative potential of an urban area can be reinforced by the design and proper selection of landscape types and elements (Deng et al., 2020). These authors stress that the elements that promote the optimal restorative environment are water features and the appearance of natural forest. In fact, urban gardens are an essential source for the psychological restoration, as well as urban biodiversity or ecosystem services (Young et al., 2020). Biodiversity, or ecological quality of environments (number of species, integrity of ecological processes) has numerous benefits to human health and well-being (Meyer-Grandbastien et al., 2020; Wood et al., 2018). In addition, there are other factors that contribute to increasing the restorative power offered by urban environments, such as the presence of sounds characteristic of nature as opposed to noise sounds related to traffic (Zhang et al., 2017), or the amount vegetation and perceived safety (Tabrizian et al., 2018). In conclusion, exposure to natural scenes mediates the negative effects of stress reducing the negative mood state, and above all enhancing positive emotions and wellbeing (Berto, 2014), that´s why city planners and designers should seriously attend to restorativeness effects in urban areas.
Definition	Restoration can be seen as a sequential, interactive process that begins with physiological relaxation and results in affective and attention restoration and broader life reflection (Pasanen et al., 2018).
Strengths and weaknesses	+ The indicator allows to know the restorative potential of a nature-based solution - Understanding the relationship of the indicator with well-being involves knowing the intermediate attentional mechanism
Measurement procedure and tool	☒ Quantitative P: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

	o T: *Perceived Restorativeness Scale* (the short, PRS - 11) (Pasini et al., 2014), a shorter, parallel version of the Perceived Restorativeness Scale (PRS – 26) (Hartig et al., 1997), developed to address original psychometric limitations; PRS is based on the Attention Restoration Theory (ART; Kaplan, 1995) and its short version measures an individual's perception of 4 restorative factors assumed to be present to a greater or lesser extent in the environment, namely physical and/or psychological "being-away" from demands on directed attention, "fascination" a type of attention assumed to be effortless and without capacity limitations, the "coherence" and "scope" perceived in an environment. Participant's judgments are made on a 0 to 10-point scale, where 0 = not at all, 6 = rather much, and 10 = completely.
Scale of measurement	▪ Perceived Restorativeness Scale (the short, PRS - 11) (Pasini et al., 2014) *We are interested in how you experience this environment. To help us understand your experience, we have provided the following statements for you to respond to. Please read carefully, then ask yourself: "how much does this statement apply to my experience there?". To indicate your answer, circle only one numbers on the rating scale beside the statement. A sample of the rating scale is given below and at the top of each subsequent page. So, for example, if you think that the statement does not at all apply to your experience of the environment, then you would circle "0" (not at all), if you think it applies rather much, then you would circle "6" (rather much), but if you think that it applies very much, you would circle 10 (very much).* 1. Places like that are fascinating (Fascination) 2. In places like this my attention is drawn to many interesting things (Fascination) 3. In places like this it is hard to be bored (Fascination 4. Places like that are a refuge from nuisances (Being Away) 5. To get away from things that usually demand my attention I like to go to places like this (Being Away) 6. To stop thinking about the things that I must get done I like to go to places like this (Being Away 7. There is a clear order in the physical arrangement of places like this (Coherence) 8. In places like this it is easy to see how things are organized (Coherence) 9. In places like this everything seems to have its proper place (Coherence)

	10. That place is large enough to allow exploration in many directions (Scope) 11. In places like that there are few boundaries to limit my possibility for moving about (Scope)
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature ✓ Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator SC6 (Place Attachment)
Data input type	Quantitative
Data collection frequency	After NBS implementation or aligned with timing of targeted (especially long-term) objectives
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	SC5.1 Perceived safety SC6 Place attachment (Sense of Place): Place Identity SC 11.1 Positive environmental attitudes motivated by contact with NBS SC11.2 Environmental identity SC ?? Pro-environmental behaviour HW3 General wellbeing and happiness HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW 12 Enhanced Physical Activity HW 14 Improvement of behavioral development and symptoms of attention-deficit/hyperactivity disorder (ADHD) ENV23 Green-space accessibility
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Aspinall, P., Mavros, P., Coyne, R., & Roe, J. (2013). The urban brain: Analyzing outdoor physical activity with mobile EEG. *British Journal of Sports Medicine,* 49(4), 272-276. Basu, A., Duvall, J., & Kaplan, R. (2019). Attention restoration theory: Exploring the role of soft fascination and mental bandwidth. *Environment and Behavior*, *51*(9-10), 1055-1081.

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22.14 Perceived social support

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Giuseppina Spano[1], Yole de Bellis[1], Giovanni Sanesi[1],

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Perceived social support	**Place Regeneration** **Health and Wellbeing**
Description and justification	Empirical evidences showed that supportive social groups and effective and helpful social networks are associated with a good mental and physical health. This indicator is measured in the neighbourhood context since a perception of high social support fosters social inclusion and justice.
Definition	Perception of various ways in which individuals aid others.
Strengths and weaknesses	Strengths: Reliable measurement tool; easy to assess. Weaknesses: Potential biases in self-reported data.
Measurement procedure and tool	This indicator is obtained using a 8-point scale on general social support and a 6-point scale on social support in the neighborhood. Participants are required to complete the scales before and after the NBS implementation.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions (baseline) and once after (follow-up).
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness and to indicators on mental health.
Connection with SDGs	• Good health and wellbeing • Reduced inequalities • Sustainable cities and communities • Peace, justice and strong institutions
Opportunities for participatory data collection	The questionnaires can be both self-reported and administrable in an interview method.
Additional information	

References	Pearson, J. E. (1986). The definition and measurement of social support. Journal of Counseling & Development.

22.15 Connectedness to nature

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: : Giuseppina Spano[1], Yole de Bellis[1], Giovanni Sanesi[1],

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Connectedness to nature	**Health and Wellbeing**
Description and justification	This indicator is a measure of individuals' trait levels of feeling emotionally connected to the natural world. Previous studies confirmed that connectedness to nature predicts the self-reported well-being and life satisfaction.
Definition	Sense of connectedness and oneness to nature.
Strengths and weaknesses	Strengths: The questionnaire is widely used in social sciences. It also provides a reliable tool to assess the relationship between human being and the natural environment. Weaknesses: Potential biases in self-reported data.
Measurement procedure and tool	This indicator is obtained using a validated scale named "Connectedness to Nature Scale" (CNS - Mayer, 2004). Participants are required to complete the CNS before and after the NBS implementation. The scale includes 14 items with a 5-point Likert scale, from "Strongly disagree" to "Strongly agree".
Scale of measurement	General population in residential neighbourhoods.
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions (baseline) and once after (follow-up).
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on socio-cultural inclusiveness.
Connection with SDGs	• Good health and wellbeing • Sustainable cities and communities

	• Peace, justice and strong institutions
Opportunities for participatory data collection	The questionnaires can be both self-reported and administrable in an interview method.
Additional information	
References	Mayer, F. (2004). The connectedness to nature scale: A measure of individuals' feeling in community with nature. Journal of environmental psychology, 24, 503-515

22.16 Prevalence of attention deficit/ hyperactivity disorder (ADHD)

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Behavioural development and symptoms of attention deficit/ hyperactivity disorder (ADHD)	**Health and Wellbeing**
Description and justification	Attention Deficit/Hyperactivity Disorder (ADHD) is the most commonly diagnosed behavioural disorder in children (Taylor and Kuo, 2011). A series of studies have documented reductions of symptoms of ADHD in children when they perform activities in green outdoor environments, independent of age, gender, income groups, community types or geographic regions (Kuo & Taylor, 2004). A walk of barely 20 minutes in a park holds more significant effects than a downtown or neighbourhood walk (Taylor & Kuo, 2011). Furthermore, children with ADHD who play regularly in green play settings were found to have milder symptoms than children who play in built outdoor and indoor settings (Taylor & Kuo, 2011). Authors report that only relatively open green spaces have this effect (Taylor & Kuo, 2011). A large study of children between the ages of 7 and 10 in Barcelona found empirical support for the beneficial impact of contact with green spaces and blue spaces (beaches) on indicators of behavioural development and symptoms of attention deficit/hyperactivity disorder (ADHD) in schoolchildren. More playtime spent in green spaces and higher frequency of beach visits/attendance was found to be associated to better behavioural development, emotional adjustment, and better peer relationships,

	whereas less surrounding greenness was associated to higher ADHD scores (Amoly, Dadvand, Forns, López-Vicente, Basagaña, Julvez, Alvarez-Pedrerol, Nieuwenhuijsen, & Sunyer, 2014). Finally, a longitudinal study conducted in New Zealand, using data from a sample of almost 50.000 children born in 1998 assessed associations between ADHD prevalence and proximity to green spaces across the lifespan, as well as rural living, while controlling for other variables relevant in the onset of ADHD (Donovan, Michael, Gatziolis, Mannetje, & Douwes, 2019). The study found that children who had always lived in a rural area and those that were exposed to greenness after 2 years of age were less likely to develop ADHD. Also, prenatal and proximity to greenness in the first two years of life had no association to prevalence of ADHD (Donovan et al., 2019).
Definition	*ADHD* is a disorder that makes it difficult for a person to pay attention and control impulsive behaviors. He or she may also be restless and almost constantly active. ADHD is not just a childhood disorder. Although the symptoms of ADHD begin in childhood, ADHD can continue through adolescence and adulthood. Even though hyperactivity tends to improve as a child becomes a teen, problems with inattention, disorganization, and poor impulse control often continue through the teen years and into adulthood (Attention-Deficit/Hyperactivity Disorder (ADHD): The Basics, n.d.). *Diagnostic tools:* Diagnostic and Statistical Manual of Mental Disorders (DMS-V), International Classification of Diseases (ICD, 10th revision)
Strengths and weaknesses	+ previous empirical evidence as to relationship between improved symptomatology of ADHD and exposure to nature and urban green space - research focused only on hyperactive/ADHD children; no data on hyperactive adults and exposure to greenness
Measurement procedure and tool	☒ *Quantitative P*: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: *Strengths and Difficulties Questionnaires* (SDQ, Goodman, 1997) is a behavioral screening questionnaire used to generate separate scores for conduct problems, emotional symptoms, and hyperactivity (Goodman, 1997). The SDQ asks about 25 attributes, 10 of which would generally be thought of as strengths, 14 of which would generally be thought of as difficulties, and one of which—" gets on better with adults than with

	other children"—is neutral. The 25 SDQ items are divided between 5 scales of 5 items each, namely Hyperactivity Scale, Emotional Symptoms Scale, Conduct Problems Scale, Peer Problems Scale, Prosocial Scale (See Goodman, 1997, p. 582 – items scoring).
Scale of measurement	▪ Strengths and Difficulties Questionnaires (SDQ, Goodman, 1997) *For each item (/.../), please mark the box for Not True, Somewhat True or Certainly True. It would help us if you answered all items as best you can even if you are not absolutely certain or the item seems daft! Please give your answers on the basis of the child's behaviour over the last six months or this school year.* Considerate of other people's feelings / Restless, overactive. cannot stay still for long / Often complains of headaches, stomach-aches or sickness / Shares readily with other children (treats, toys, pencils, etc.) / Often has temper tantrums or hot tempers / Rather solitary, tends to play alone / Generally obedient, usually does what adults request / Many worries, often seems worried / Helpful if someone is hurt, upset or feeling ill / Constantly fidgeting or squirming / Has at least one good friend / Often fights with other children or bullies them / Often unhappy, down-hearted or tearful / Generally liked by other children / Easily distracted, concentration wanders / Nervous or clingy in new situations, easily loses confidence / Kind to younger children / Often lies or cheats / Picked on or bullied by other children / Often volunteers to help others (parents, teachers, other children) / Thinks things out before acting / Steals from home, school or elsewhere / Gets on better with adults than with other children / Many fears, easily scared / Sees tasks through to the end. good attention span
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for play and physical exercise, etc.
Data input type	Quantitative
Data collection frequency	After NBS implementation and aligned with timing of HW14 study (i.e., relevant to study design, observation of children's play, etc.)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise

Synergies with other indicators	HW1 Sustainable nutrition/adoption HW3 General Wellbeing and Happiness HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure HW13 Levels of aggressiveness and violence HW15 Exploratory behaviour in children
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
References	Amoly, E., Dadvand, P., Forns, J., López-Vicente, M., Basagaña, X., Julvez, J., … Sunyer, J. (2014). Green and blue spaces and behavioral development in Barcelona schoolchildren: the BREATHE project. *Environmental health perspectives*, *122*(12), 1351–1358. doi:10.1289/ehp.1408215 Attention-Deficit/Hyperactivity Disorder (ADHD): The Basics (n.d.). Retrieved from https://www.nimh.nih.gov/health/publications/attention-deficit-hyperactivity-disorder-adhd-the-basics/index.shtml Donovan, G., Michael, Y., Gatziolis, D., Mannetje, A., & Douwes, J. (2019). Association between exposure to the natural environment, rurality, and attention-deficit hyperactivity disorder in children in New Zealand: a linkage study. *Lancet Planet Health*, 3, e226–234. Goodman, R. (1997). The Strengths and Difficulties Questionnaire: A research note. *Journal of Child Psychology and Psychiatry*, 38, 58 1-586. Kuo, F. E., & Taylor, A. F. (2004). A potential natural treatment for attention-deficit/hyperactivity disorder: evidence from a national study. *American journal of public health*, *94*(9), 1580–1586. doi:10.2105/ajph.94.9.1580 Taylor, A., & Kuo, M. (2011). Could Exposure to Everyday Green Spaces Help Treat ADHD? Evidence from Children's Play Settings. *Applied Psychology: Health and Well-Being,* 3, 281 - 303. doi: 10.1111/j.1758-0854.2011.01052.x

22.17 Exploratory behaviour in children

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Exploratory behaviour in children	Health and Wellbeing
Description and justification	Regular contact with nature has many benefits for healthy child development. These range from the development of motor, cognitive, social and emotional skills; the regulation of attention and behavior; health-related benefits such as the development of a healthy immune system and a healthy vision, among others; and the development of knowledge, interest, appreciation and attachment to nature. Play is a fundamental activity in children´s healthy development as well as mental and emotional health (Gill, 2014). Free play has significant positive effects on cognitive and social- emotional development, independence and creativity (Allee-Herndon, Taylor, & Roberts, 2019). A classical study has studied a diversity of urban environments and the role of different types of landscapes on play (Moore, 1986 as cited in Chawla, 2015, p. 436). The study found that natural elements emerged as children's most frequent favourite places. Both the parks and rough ground functioned as places where children could be alone or with friends and gain environmental knowledge and awareness. Moore proposed that the number and type of skill-related behaviours supported by a given setting could be considered a reasonable measure of its childhood environmental quality (Chawla, 2015). As naturalized playgrounds have become more popular, the following elements have been described as essential to their design (White & Stoecklin, 1998): ✓ Water ✓ Indigenous vegetation, including trees, bushes, flowers and long grasses that children can explore and interact with ✓ Animals, creatures in ponds, butterflies, bugs ✓ Sand, and best if it can be mixed with water ✓ Diversity of colour, textures and materials ✓ Ways to experience the changing seasons, wind, light, sounds and weather ✓ Natural places to sit in, on, under, lean against, climb and provide shelter and shade ✓ Different levels and nooks and crannies, places that offer socialization, privacy and views

	✓ Structures, equipment and materials that can be changed, actually, or in their imaginations, including plentiful loose parts Many recent studies have shown that natural areas provide for more imaginative, constructive, sensory, and socially cooperative play than asphalt, flat expanses of lawn, or built play equipment (Fjørtoft, 2004; Fjørtoft & Sagaie, 2000; Samborski, 2010; Stanley, 2011; Cloward Drown & Christensen, 2014). Wells and Evans (2003) concluded that the benefits to children were greater when they experienced a greater amount of exposure to nature. In playground observations, Luchs and Fikus (2013) documented that children engaged in longer play episodes and a greater variety of different types of play in a natural versus traditional play area.
Definition	"Playscape" - play activities defined and classified into three categories (Frost, 1992 as cited in Fjørtoft and Sagaie, 2000, p. 86): (1) ***Functional*** play comprised gross-motor activities and basic skills and were implemented in games like play tag, chase and catch, leapfrog, hide and seek, catch a tree, making angels in the snow, and other games involving basic movements. (2) ***Construction*** play was the type of play that was afforded by landscape structures and loose parts, e.g., building shelters, dens and other constructions like a pirate ship, building with cones and sticks and other moveable things. In the winter season, snow was an excellent building material. (3) ***Symbolic*** play included socio-dramatic play and was recorded as role play and fantasy play such as play house, pirates, play farm with cones and sticks, etc.
Strengths and weaknesses	+ previous empirical evidence as to relationship between outdoor activity/exposure to nature and improved manifestations associated to exploratory behaviour in children (e.g., creativity, etc.) - complex methodologies demanding qualified researchers for both collecting qualitative data, and for its analysis
Measurement procedure and tool	☒ *Quantitative P*: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) ☒ *Qualitative P*: o T: case study methodology –case study analysis, ethnographic case study (e.g., Stanley, 2011), drawings collection and analysis, surveys, brainstorming sessions, "Walkabout" audio-recorded interviews, Informal audio-recorded observations and

	photographs (e.g., Luchs & Fikus, 2013; Samborski, 2010)
Scale of measurement	
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for play and physical exercise, etc.
Data input type	Qualitative (and quantitative)
Data collection frequency	After NBS implementation and aligned with timing of HW15 study (i.e., relevant to study design, observation of children's play, etc.)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise ☒ Qualitative data collection (case study and narrative study methodology, for example) requires high expertise in psycho-social research
Synergies with other indicators	HW1 Sustainable nutrition/adoption HW3 General Wellbeing and Happiness HW8 Incidence of obesity / obesity rates (adults and children) HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure HW13 Levels of aggressiveness and violence HW14 Improvement of behavioural development and symptoms of attention-deficit/hyperactivity disorder (ADHD)
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
References	Allee-Herndon, K., & Taylor, D., & Roberts, S. (2019). Putting Play in Its Place: Presenting a Continuum to Decrease Mental Heath Referrals and Increase Purposeful Play in Classrooms. *International Journal of Play*. doi: 10.1080/21594937.2019.1643993 Chawla, L. (2015). Benefits of Nature Contact for Children. *Journal of Planning Literature*, 30. doi: 10.1177/0885412215595441 Cloward Drown, K., & Christensen, K. (2014). Dramatic Play Affordances of Natural and Manufactured Outdoor Settings for Preschool-Aged Children. *Children, Youth and Environments*, 24. doi: 10.7721/chilyoutenvi.24.2.0053

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22.18 Self-reported anxiety

Project Name: proGIreg (Grant Agreement no. 776528)

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Self-reported anxiety	Health and Wellbeing
Description and justification	An indicator of the level of anxiety experienced by participants based on a validated questionnaire. An accumulating body of evidence has demonstrated a protective association between green space exposure and mood disorders including anxiety disorders. However, evidence from natural experiments is lacking.
Definition	Self-reported anxiety score on a scale from 0 to 3 and by category (mild, moderate, or severe anxiety)

Strengths and weaknesses	A strength of this indicator is that it is obtained by using a validated and widely used questionnaire to assess anxiety. A limitation is that the indicator is self-reported, and participants may misreport their actual anxiety symptoms.
Measurement procedure and tool	The indicator is obtained using a survey which is taken by a sample of the general population. The survey includes the GAD-7 questionnaire with has 7 items on anxiety by asking how often in the last 2 weeks the participants had any anxiety problems. The answers are on a scale from 0 (not at all) to 3 (nearly every day). This survey is repeated before and after the implementations of NBS in order to observe a potential change in anxiety symptoms.
Scale of measurement	General population in residential neighbourhoods
Data source	
Required data	Questionnaire data
Data input type	Continuous variables
Data collection frequency	Twice; once before the implementation of the nature-based solutions and once after.
Level of expertise required	Low
Synergies with other indicators	This indicator is related to other indicators on mental health.
Connection with SDGs	Good health and wellbeing: if the implementation of NBS is associated with decreased anxiety symptoms, NBS contribute to improved health and wellbeing.
Opportunities for participatory data collection	The questionnaires are self-reported and as such are reported by the citizens themselves.
Additional information	
References	Spitzer et al. 2006. A brief measure for assessing generalized anxiety disorder: The GAD-7. JAMA Internal Medicine; 166, 10.

22.19 Prevalence, incidence, morbidity and mortality of respiratory diseases

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Adina Dumitru[1], Catalina Young[2], Irina Macsinga[2]

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Prevalence, incidence, morbidity and mortality of respiratory diseases (RD)	Health and Wellbeing
Description and justification	Breathing unhealthy air is a cause or contributor to most respiratory conditions. The most common sources of unhealthy air are tobacco smoke, indoor air pollution from burning solid fuels, unhealthy air in the workplace, air pollution from traffic and industrial sources, air containing microbes, and air with toxic particles or fumes (Forum of International Respiratory Societies: Respiratory diseases in the world Realities of Today – Opportunities for Tomorrow, 2013). Increased concentrations of greenhouse gases, especially carbon dioxide, in the earth's atmosphere have already substantially warmed the planet, causing more severe and prolonged heat waves, temperature variability, increased length and severity of the pollen season, air pollution, forest fires, droughts, and heavy precipitation events and floods, all of which put respiratory health at risk. The main diseases of concern are asthma, rhino-sinusitis, chronic obstructive pulmonary disease (COPD) and respiratory tract infections, but the extent to which these are spread will vary according to the proportion of susceptible individuals in a given population. Individuals with pre-existing cardiopulmonary diseases are at higher risk of suffering from climate changes (D'Amato, Cecchi, D'Amato, & Annesi-Maesano, 2014). Furthermore, many respiratory illnesses are related to immunologic dysfunction and this has been associated to unbalanced respiratory and gut microbiomes, due to a lack of appropriate exposure to biodiverse environments both at a time when a healthy immune system is formed as well as in adulthood (Haahtela et al., 2013; Hanski et al., 2012; Kuo, 2015). A study on children and adults in Finish and Russian Karelia found that allergic symptoms and diseases were systematically more common in Finnish children and adults than in their Russian counterparts (Haahtela, Laatikainen, Alenius, Auvinen, Fyhrquist, Hanski, von Hertzen, Jousilahti, Kosunen, Markelova, Mäkelä, Pantelejev, Uhanov, Zilber, & Vartiainen, 2015). Sensitization to birch pollen was significantly larger in Finnish children, and while adults born in the 4o's in the

	two regions had similarly low rates of respiratory illnesses, those born in the 70's differed significantly, supporting the notion that the epidemic of allergy and asthma is a result of reduced exposure to natural environments with rich microbiota, a changed diet and a sedentary lifestyle (Haahtela et al., 2015). Villeneuve et al. (2012) advanced research findings that suggest that areas that have more green space have a slightly lower mortality rate (stronger association for respiratory disease mortality), yet authors emphasize the need for more research aimed at identifying whether there is a selection bias related to people who have been exercising in their youth move to areas with green space as well as the specific characteristics of green space that have the strongest influence on mortality, and at evaluating the potential confounding role of other lifestyle-related mortality risk factors. The ways in which green space affects respiratory symptoms are yet to be fully understood, and seem to depend on the characteristics of the bio-geographical region (Markevych et al., 2017; Tischer et al., 2017), which indicates that other factors (e.g., dryness, heat, etc.) need to be taken into account. Results of designs aimed at exploring the link between respiratory disease and greenspace are inconsistent across studies, which makes it difficult to draw useful conclusions with regards to the amount, type and structure of green space that would be conducive to respiratory health. A systematic review of the greenspaces' effect on allergies and atopic sensitization, using studies that covered 11 cohorts, showed that findings are not consistent across studies, with four cohorts registering protective effects from greenspace, two cohorts showing an increase in sensitization related to greenspace, and five cohorts displaying no significant effect of greenspace on atopic sensitization (Lambert, Bowatte, Tham, Lodge, Prendergast, Heinrich, Abramson, Dharmage, & Erbas, 2018). Lambert et al. (2018) suggest that this is due to variations in exposure measurements, study populations and location, the specific allergens tested, and inclusion of confounders. Authors also conclude that not only the contributions of greenspace to specific allergens need to be understood, but also how the amount, type of greenspace and specific allergens contribute to prevalence, incidence and risk of particular respiratory disease should be considered in future studies (Lambert et al., 2018).
Definition	**RD** is a type of disease that affects the lungs and other parts of the respiratory system. Respiratory diseases

include asthma, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, pneumonia, and lung cancer (National Cancer Institute - Dictionary of Cancer Terms, n.d.).

Prevalence is a measure of the burden of disease in a population in a given location and at a particular time, as represented in a count of the number of people affected (Ward, 2013). Prevalence is a function of both the incidence and duration of disease. In turn, duration is affected by the availability and effectiveness of curative treatments and by survival times of afflicted individuals (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Incidence represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010).

Morbidity refers to the state of being diseased and the severity and impact of disease. Like prevalence, measures of morbidity represent the burden that a disease places on a population. In contrast to prevalence, morbidity estimates use more complex approaches that are potentially more informative than a simple count of cases (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Mortality measures deaths caused by a specific disease, deaths resulting from treatment for a specific disease, or deaths in which a specific disease is a contributing factor, but not the primary cause. Mortality is the number of deaths due to a disease during a specific time divided by the number of persons in that population at the beginning of the time period. Hence, mortality is a rate in the sense that it represents how quickly deaths occur relative to population size and the passage of time. It can be interpreted as reflecting the risk of death from a particular cause faced by persons within the population being studied (National Institutes of Health. Autoimmune diseases

	coordinating committee—Autoimmune diseases research plan, n.d.).
Strengths and weaknesses	+ some research that supports the notion of a solid association between greenspace and exposure to nature, and respiratory disease prevalence and mortality (e.g., Villeneuve et al., 2012) - inconsistencies across studies make it difficult to draw useful conclusions with regards to the amount, type and structure of green space that would be conducive to respiratory health; e.g., ecological cross-sectional study found no evidence at the scale of the American city for the general claim that access to green space yields health benefits; not only that there was no association between greenness and mortality from heart disease, diabetes, lung cancer, or automobile accidents, but mortality from all causes was significantly higher in greener cities (Richardson, Mitchell, Hartig, de Vries, Astell-Burt, & Frumkin, 2012)
Measurement procedure and tool	☒ *Quantitative*: epidemiological data (Health Data Administration/Cities) Incidence of RD relevant for measurement, along prevalence, as it indicates the number of new cases of disease within a certain period (for example, since the implementation of the NBS), and can be expressed as a risk or an incidence rate. Pre-existing cardio-pulmonary diseases relevant to investigate, as they were found to heighten the risk of suffering from climate changes (D'Amato et al., 2014). Recommended variables for RD: o prevalence/incidence/morbidity/mortality of RD (asthma; acute bronchitis/cough; emphysema; lung cancer; pulmonary hypertension; autoimmune diseases that damage the lungs, such as scleroderma and rheumatoid arthritis)
Scale of measurement	-
Data source	
Required data	✓ Essential: NBS characteristics for each city/site
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation (longitudinal)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	P3 Perceived Quality of Green Spaces Sc5.1 Perceived Safety Sc5.2 Actual Safety SC7 Geographical Access to NBS

	SC8 Perceived Access to NBS HW3 General Wellbeing and Happiness HW4 Life expectancy and healthy life years expectancy HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
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22.20 Morbidity, Mortality and Years of Life Lost due to poor air quality

Project Name: UNaLab (Grant Agreement no. 730052)

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Morbidity, Mortality and Years of Life Lost due to poor air quality	Air Quality Health and Wellbeing
Description and justification	Air pollution has been related to numerous adverse health effects, typically expressed in several morbidity and mortality endpoints (see Costa et al., 2014). In particular, an increasing amount of epidemiological and clinical studies observes that exposure to air pollution is associated with increased risk of heart disease, myocardial infarction and stroke as well as lung cancer (e.g., Costa et al., 2014). While the impact of these health effects may appear low at the individual level, the overall public-health burden is sizable as the entire population is exposed (Pascal et al., 2011).
Definition	Reduction in years of life (y) due to premature mortality in comparison with standard life expectancy (Morbidity): Long-term (annual) incidence of chronic bronchitis due to poor air quality calculated using atmospheric NO_2 and PM_{10} data (Mortality): Long-term (annual) incidence of mortality due to poor air quality calculated using atmospheric $PM_{2.5}$, PM_{10}, O_3 and NO_2 data
Strengths and weaknesses	+ The indicator is easy to define - The method needs a lot of input data
Measurement procedure and tool	The general approach in health impact assessment is to use exposure-response functions, linking the concentration of pollutants to which the population is exposed to the number of health events occurring in that population (Costa et al., 2014; Silveira et al., 2016). Therefore, the following aspects are usually considered: i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age groups, and iv) exposure time. The health response is usually calculated by:

$\Delta R = IR \times CRF \times \Delta C \times Pop$

Where,

- ΔR is the response as a result of the number of the unfavourable implications (cases, days or episodes) over all health indicators;
- IR is the baseline morbidity/mortality annual rate (%); this information is available in the national statistical institute of each country;
- CRF is the correlation coefficient between the pollutant concentration variation and the probability of experiencing a specific health indicator (%; i.e., Relative Risk (RR) associated with a concentration change of 1 μg m^{-3});
- ΔC indicates the change in the pollutant concentration (μg m^{-3}) after adoption of the adaptation/mitigation measure;
- Pop is the population units per age group exposed to pollution.

Morbidity (chronic bronchitis) due to poor air quality is calculated using NO_2 and PM_{10} to determine CRF and ΔC in the preceding equation.

Mortality, assessed as total mortality, is calculated using PM_{10}, $PM_{2.5}$, O_3 and NO_2 to determine CRF and ΔC in the preceding equation.

Both morbidity and mortality are based on long-term (annual) effects (Table). Where air quality data are derived from WRF-Chem results can be calculated on a daily/weekly/monthly/annual basis at the grid, neighbourhood or city scale.

Table. Air pollutant health indicators (WHO, 2013)

Pollutant	Health outcome	Age group
PM_{10}	Chronic bronchitis (incidence)	>18 y
	Chronic bronchitis (prevalence)	6-18 y
	Total mortality	<1 y
		>30 y

$PM_{2.5}$	Total mortality	>30 y
NO_2	Total mortality	>30 y
	Prevalence of bronchitic symptoms in asthmatic children	5–14 y
O_3 (April-September)	Total mortality (respiratory diseases)	>30 y

Years of life lost (YLL) is an often-used health indicator, and refers to the total number of years of reduced life due to premature mortality. Using the mortality indicator, the YLL can be calculated as the number of deaths multiplied by a standard life expectancy at the age at which death occurs (see Gardner & Sanborn, 1990).

Scale of measurement	Street to metropolitan scale
Data source	
Required data	i) involved pollutants and their air concentration levels, ii) health indicators analysed in terms of morbidity and mortality, iii) affected age groups, and iv) exposure time
Data input type	Quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Moderate
Synergies with other indicators	Other indicators in the *Air quality* indicator group
Connection with SDGs	SDG 3 Good health and well-being, SDG 15 Life on land
Opportunities for participatory data collection	No opportunities identified
Additional information	
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22.21 Prevalence and incidence of autoimmune diseases

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Prevalence and incidence of autoimmune diseases	Health and Wellbeing
Description and justification	Numerous authors stress the relevance of immune-regulatory mechanisms in the manifestation of the generally expected beneficial effects of exposure to nature (Hanski et al, 2012; Kuo, 2015; Rook, 2013; von Hertzen et al., 2015). Rook (2013) argue that multiple physiological consequences of exposure to the natural environment (e.g., sunlight, physical exercise) supplement the immune-regulatory effects of microbial biodiversity (i.e., low CRP levels, low inflammation, low cytokine response to stress) and the psychological rewards of interaction with nature (e.g., relaxation, restoration, exercise, social capital). These notions have been brought forth by *the hygiene hypothesis (i.e., Old Friends mechanism, biodiversity hypothesis)* that explains the increasing prevalence of chronic inflammatory diseases (autoimmunity, allergy and inflammatory bowel diseases) in urban communities in high-income countries by a predisposition to poor regulation of inflammation gradually developed through

	reduced exposure to immunoregulation-inducing macro- and microorganisms, and microbiota that accompanied mammalian evolution (Haahtela et al., 2013; Rook, Lowry, & Raison, 2013; von Hertzen et al., 2015). Rook (2013) suggests that the rapid occurrence of psychological effects could explain the fact that most studies have been oriented towards the psychological explanations, while there is still limited empirical evidence as to the contribution of immunoreglatory processes in the positive experience of exposure to nature (i.e., immunoregulatory mechanisms require prolonged exposure, especially during childhood when much of immune system training occurs). There is evidence to suggest however that exposure to biodiverse urban green space (with a variety of microorganisms) is likely to be important in both reducing systemic inflammation and boost immune defence (Lee et al., 2012; Park et al., 2010). For examples, studies on immersion into forest environments have shown positive effects on natural killer cells, as well as intracellular anti-cancer proteins in lymphocytes (Li, 2010). Some support has been gathered for the hypothesis that such effects might be due to the effect of essential oils from trees as well as the stress reduction effects of green environments (Li, 2010) and that the effects lasted for up to 7 days after trips (Li et al., 2011). Above all, there is a stringent need for empirical evidence of the relationship between biodiversity and immunoregulation, as well as improved control of AIDs' evolution.
Definition	**AID** is a condition which is triggered by the immune system initiating an attack on self-molecules due to the deterioration of immunologic tolerance to auto-reactive immune cells. The initiation of attacks against the body's self-molecules in AIDs, in most cases is unknown, but a number of studies suggest that they are strongly associated with factors such as genetics, infections and /or environment (Page, du Toit, & Page, 2011). For most AIDs, cure is unusual, and survival is generally measured in years or decades. Hence, the chronicity of autoimmune disease leads to a high prevalence despite a relatively low annual incidence (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). Most prevalence surveys are limited by their reliance on self-reporting of disease status rather than a physician-confirmed diagnosis. Self-reporting of AIDs can result in misclassification and underreporting (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

	Prevalence is a measure of the burden of disease in a population in a given location and at a particular time, as represented in a count of the number of people affected (Ward, 2013). Prevalence is a function of both the incidence and duration of disease. In turn, duration is affected by the availability and effectiveness of curative treatments and by survival times of afflicted individuals (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). **Incidence** represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010).
Strengths and weaknesses	+ empirical support to the notion that exposure to biodiverse urban green space is important in both reducing systemic inflammation and boost immune defence (Lee et al., 2012; Jin Park, 2010) - limited empirical evidence as to the contribution of immunoreglatory processes in the positive experience of exposure to nature (Rook, 2013; von Hertzen et al., 2015)
Measurement procedure and tool	☒ *Quantitative*: epidemiological data (Health Data Administration/Cities) Incidence of AID relevant for a measurement, along prevalence, as it indicates the number of new cases of disease within a certain period (for example, since the implementation of the NBS), and can be expressed as a risk or an incidence rate. Recommended variables for inflammatory processes and immunoregulation: o prevalence/incidence of inflammatory disorders o prevalence/incidence of cardiovascular disease o prevalence/incidence of asthma o prevalence/incidence of depression o stress resilience o CRP (C-Reactive protein) levels (blood test) o atopic sensitization (i.e., allergic disposition) (see Hanski et al., 2012)

Scale of measurement	-
Data source	
Required data	✓ Essential: NBS characteristics for each city/site
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation (longitudinal)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	HW3 General Wellbeing and Happiness HW4 Life expectancy and healthy life years expectancy HW6 Prevalence, incidence, morbidity, mortality of cardiovascular diseases (CVDs) HW7 Prevalence, incidence, morbidity, mortality of respiratory diseases (RIDs) HW8 Incidence of obesity/obesity rates (adults and children) HW10 Prevalence, incidence, morbidity of chronic stress HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
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22.22 Prevalence, incidence and morbidity of chronic stress

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Prevalence, incidence and morbidity of chronic stress	Health and Wellbeing
Description and justification	Numerous authors emphasize that modern urban wellbeing challenged by chronic stress and insufficient physical activity can be healthily nurtured by natural environment exposure which promotes mental and physical health and reduces morbidity and mortality in urban residents by providing psychological relaxation and stress alleviation, enhancing immune function, stimulating social cohesion, supporting physical activity, and reducing exposure to air pollutants, noise and excessive heat (Braubach, Egorov, Mudu, Wolf, Ward Thompson, & Martuzii, 2017; Hartig, Mitchell, de Vries, & Frumkin, 2014). The psychological pathways to the beneficial effects of exposure to/engagement with nature have been founded on two complementary theoretical frameworks. Attention Restoration Theory (ART) emphasizes the role of nature in relieving mental fatigue and proposes that nature allows restoration from directed attention fatigue and enable more effective cognitive performance (Kaplan, 1995). Stress Recovery Theory (SRT) emphasizes the role of nature in relieving physiological stress and posits that natural environments influence affective states by promoting recovery from stress, and diminishing arousal and negative thoughts through psycho-physiological pathways (Ulrich, Simons, Losito, Fiorito, Miles, & Zelson, 1991). Psychological Stress is thought to be a significant factor in the onset, course and exacerbation of various diseases, like depression, cardiovascular diseases, immune-related disorders, and it has been related to higher overall mortality (Cohen, Janicki-Deverts, & Miller, 2007; Hammen, 2005; Klein, Brähler, Dreier, Reinecke, Müller, Schmutzer, Wölfling, & Beutel, 2016). The psychological approach to stress brings forth the role of subjective perception of stressful situations in coping and resilience, and focuses on the person's appraisal of the significance of the stressor (primary appraisal) and the individual coping abilities (secondary appraisal) within a person environment transaction (Klein et al., 2016).

	Given the complex psychophysiological pathways of stress, measurement is usually approached holistically through collection of both subjective psychological (i.e., subjective rating scales, self-report measures) and objective physiological data (most frequently, salivary analysis due to the validity, reliability and ease of collection of salivary data) (Beil & Hanes, 2013). For instance, van den Berg and Custers (2011) measured salivary cortisol levels and self-reported mood to demonstrate that gardening alleviated acute stress faster than reading. Beil and Hanes (2013), Roe, Thompson, Aspinall, Brewer, Duff, Miller, Mitchell, and Clow (2013), and Ward Thompson, Roe, Aspinall, Mitchell, Clow, and Miller (2012) used diurnal cortisol to demonstrate that exposure to green space reduced chronic stress in adults living in deprived urban neighborhoods. Hair cortisol was used as a biomarker of chronic stress in research documenting similar relationships between green space and stress reduction (Gidlow, Randall, Gillman, Smith, & Jones, 2016; Wippert, Honold, Wang, & Kirschbaum, 2014).
Definition	*Stress* is the process by which an individual responds psychologically, physiologically, and often with behaviors, to a situation that challenges or threatens well-being (Baum, Fleming, & Singer, 1985 as cited in Ulrich et al., 1991, p. 202). The psychological component includes cognitive appraisal of the situation, emotions such as fear, anger, and sadness, and coping responses (Ulrich et al., 1991). *Psychological stress* occurs when an individual perceives that environmental demands tax or exceed his or her adaptive capacity (Cohen, Kessler, & Gordon, 1995 as cited in Cohen et al., 2007).
Strengths and weaknesses	+ reliable indicator of physical and mental health, well-being, and satisfaction with own life (Braubach et al., 2017; Frumkin et al., 2017; Klein et al, 2016) + solid empirical evidence as to relationship between levels of stress/perception of stress and exposure to nature and urban green space (parks, playgrounds, and residential greenery) - complex psychophysiological pathways of stress – construct cannot be measured via a single marker, and both psychometric and physiological data need to be collected
Measurement procedure and tool	☒ *Quantitative P*: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration) o T: *Perceived Stress Scale* (Cohen, Kamarck, & Mermelstein, 1983), a self-report measure intended to capture the degree to which persons perceive situations in their life as

	excessively stressful relative to their ability to cope. To date, there are three standard versions of the PSS: the original 14-item form (PSS-14), the PSS-10, and a four-item form (PSS-4) Cohen et al., 1983). Cohen and Williamson (1988) suggested that the PSS-10 is the best form of the PSS and recommended the PSS-10 be used in future research (as cited in Taylor, 2015, p. 90). ☒ *Quantitative P*: biochemical assessments of diurnal cortisol secretion (hair, blood, salivary cortisol) o T: e.g., saliva sampling devices; morning blood samples; cortisol levels extracted from a 3cm sample of scalp hair can reflect the past 3 months of cortisol secretion, offering a stable and feasible measure of long term stress exposure, where higher HCC reflects higher chronic stress levels (Gidlow et al., 2016)
Scale of measurement	▪ Perceived Stress Scale (Cohen et al., 1983) *The questions in this scale ask you about your feelings and thoughts during the last month. In each case, you will be asked to indicate how often you felt or thought a certain way. Although some of the questions are similar, there are differences between them and you should treat each one as a separate question. The best approach is to answer each question fairly quickly. That is, don't try to count up the number of times you felt a particular way, but rather indicate the alternative that seems like a reasonable estimate.* *For each question choose from the following alternatives:* *0. never* *1. almost never* *2. sometimes* *3. fairly often* *4. very often* In the last month, how often... 1 ...have you been upset because of something that happened unexpectedly? 2 ...have you felt that you were unable to control the important things in your life? 3 ...have you felt nervous and "stressed"? 4 ...have you felt confident about your ability to handle your personal problems? (R) 5 ...have you felt that things were going your way? (R) 6 ...have you found that you could not cope with all the things that you had to do? 7 ...have you been able to control irritations in your life? (R)

	8 ...you felt that you were on top of things? (R) 9 ...you been angered because of things that were outside your control? 10 ...have you felt difficulties were piling up so high that you could not overcome them?
Data source	
Required data	✓ Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for social interaction and for physical exercise, etc. ✓ Essential: Data on SC6 (Place Attachment-Sense of Place: Place Identity); HW3 (GWB and Happiness); HW11 (MH WB: Depression and Anxiety) ✓ Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator SC6 (Place Attachment)
Data input type	Quantitative
Data collection frequency	After NBS implementation and aligned with timing relevant to biochemical assessments (e.g., 2-3 months after implementation for hair cortisol levels)
Level of expertise required	☒ Methodology and data analysis requires high expertise in psycho-social research ☒ Quantitative data collection requires no expertise
Synergies with other indicators	SC6 Place attachment (Sense of Place): Place Identity SC7 Geographical access to NBS SC8 Perceived access to NBS SC11.1 Positive environmental attitudes motivated by contact with NBS SC11.2 Environmental Identity HW3 General Wellbeing and Happiness HW4 Life expectancy and healthy life years expectancy HW5 Prevalence and incidence of auto-immune diseases HW6 Prevalence, incidence, morbidity, and mortality of cardiovascular diseases HW7 Prevalence, incidence, morbidity, and mortality of respiratory diseases HW8 Incidence of obesity/obesity rates (adults and children) HW11 Mental Health Wellbeing: Depression and Anxiety HW12 Restoration-Recreation: Enhanced physical activity and meaningful leisure HW13 Levels of aggressiveness and violence HW14 Improvement of behavioural development and symptoms of attention-deficit/hyperactivity disorder (ADHD) HW15 Exploratory behaviour in children
Connection with SDGs	Goal 3. Ensure healthy lives and promote well-being for all at all ages

	Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Opportunities for participatory data collection	-
Additional information	
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NEW ECONOMIC OPPORTUNITIES AND GREEN JOBS

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23 Recommended Indicators of New Economic Opportunities and Green Jobs

23.1 Valuation of NBS

23.1.1 Value of NBS calculated using GI-Val

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Recommended citation: The Mersey Forest, Natural Economy Northwest, CABE, Natural England, Yorkshire Forward, The Northern Way, Design for London, Defra, Tees Valley Unlimited, Pleasington Consulting Ltd, and Genecon LLP (2010). GI-Val: the green infrastructure valuation toolkit. Version 1.6 (updated in 2018). https://bit.ly/givaluationtoolkit

Valuation of NBS	**New Economic Opportunities and Green Jobs**
Description and justification	GI-Val is The Mersey Forest's green infrastructure valuation toolkit. The current prototype is free and open source, and can be downloaded under a Creative Commons License from: https://www.merseyforest.org.uk/services/gi-val/.

	The toolkit takes the form of a spreadsheet calculator and a user manual. There has been a great deal of research on the valuation of the benefits provided by the natural environment using a wide range of techniques. Many of these are academic and not accessible to project managers who need to be able to rely on sound data from easily accessible sources to provide a robust valuation that they can employ as justification to funders and/or developers. To enable such a valuation to be carried out, The Mersey Forest has developed GI-Val. The GI-Val toolkit calculates monetary values for the social, economic and environmental benefits provided by green infrastructure. The following fully-operational tools are currently available in the GI-Val toolkit and can, in combination, yield an overall value for implemented NBS: • Tool 1.4. Reduced peak summer temperature • Tool 1.6. Reduction in carbon emissions from buildings – cooling • Tool 2.1. Energy and CO_2 emissions savings from reduced volume of water entering combined sewers • Tool 2.2. Savings in wastewater treatment costs to domestic and commercial water customers • Tool 4.2. Reduced mortality rates from increased walking and cycling • Tool 4.6. Avoided costs for air pollution control measures • Tool 5.1. Residential land and property uplift • Tool 8.1. Volume and value of tourism related expenditure • Tool 9.1. Recreational value • Tool 10.1. Willingness to pay for protection or enhancement of biodiversity • Tool 11.1. Employment-based GVA generated by land management An independent assessment of GI Val by the Ecosystems Knowledge Network is available from this link, along with links to other tools: https://ecosystemsknowledge.net/green-infrastructure-valuation-toolkit-gi-val
Definition	The GI-Val toolkit provides a simle framework to identify and broadly assess the benefits of proposed NBS investments and existing green assets, including direct contributions to the local economy and wider non-market returns for society and the environment.

Strengths and weaknesses	- Tool developed using English data. - The toolkit remains a prototype and this means there are some green infrastructure benefits for which it cannot calculate a direct financial value. While there is a rich body of evidence that illustrates and demonstrates the different types of benefits deriving from quality green infrastructure, robust valuation techniques do not yet exist for all benefits. Therefore some valuations come with detailed caveats as they are based on limited evidence at this stage. - The toolkit's calculation is designed to be useful for initial, indicative project appraisal, providing a range of figures indicating the potential impact of a green infrastructure intervention or the value of an existing green infrastructure asset. The toolkit does not assess the quality of the design or detailed management requirements of green infrastructure. It does not replace a full cost benefit analysis, but it provides a basic valuation at a much lower cost. - Valuations such those made with a toolkit or cost benefit analysis also need to be seen as part of a much bigger picture. The valuation should not replace community engagement and local dialogue about what is valued about a place. Calculating economic value of green assets will always be a controversial technique and financial value should only be seen as one factor in decision-making. - The reported GVA values include transfers from one organisation to another, which means that although GVA increases for the beneficiaries, it may not increase for the study area as a whole.
Measurement procedure and tool	The toolkit provides a set of calculator tools, to help assess an existing green asset or proposed green investment. They are organised under eleven key benefits of green infrastructure: The toolkit looks at how the range of green infrastructure benefits derived from an asset or investment can be shown: • in monetary terms – applying economic valuation techniques where possible • quantitatively – for example with reference to jobs, hectares of land, visitors • qualitatively – referencing case studies or important research where there appears to be a link between green infrastructure and economic, social or environmental benefit but where the scientific basis for quantification and/or monetisation is not yet sufficiently robust.

	The toolkit uses standard valuation techniques to assess the potential benefits provided by green infrastructure within a defined project area. These benefits are assessed in terms of the functions that the green infrastructure may perform, support or encourage, depending upon the type of project. Once data are entered into the toolkit, financial values are generated for many NBS benefits. The toolkit identifies the marginal benefit and the additional value of the green infrastructure/NBS. Coded algorithms ensure that there is no 'double counting' of component values.
Scale of measurement	Plot to city scale
Data source	
Required data	General information about baseline conditions and NBs interventions for the area under examination
Data input type	Numeric data
Data collection frequency	Individual assessments
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	Developing the toolkit's next iteration will require wide and sustained collaboration. To facilitate this process, interested parties are invited to pass the toolkit to others who might be able to incorporate it into their work and to provide feedback on their experience in using the toolkit, good and bad! Sources of improved evidence Suggestions for improving the tools Ideas for new tools The consortium who led the development of this toolkit has handed over the responsibilities for co-ordinating future work to the Green Infrastructure Value Network (GIVaN). Further information on the network can be found at: www.bit.ly/givaluationtoolkit
Additional information	
References	URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl http://www.merseyforest.org.uk/services/gi-val/

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23.1.2 Economic Value of Urban Nature Index

Project Name: Naturvation (Grant Agreement no. 730243)
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Economic value of urban nature	**New Economic Opportunities and Green Jobs**
Description and justification	A score on economic value of nature that reflects its value to the urban residents, relative to other types of urban nature types. It therefore provides a relative value of one type of urban nature relative to another, within an urban setting. This means that while the economic value of nature, in monetary terms, may differ between cities, or also within cities, the relative values can be used to compared values between different NBS even though economic levels different between cities
Definition	Relative value of one type of urban nature relative to another, within an urban setting.
Strengths and weaknesses	
Measurement procedure and tool	Economic values are based on a database of monetary values of urban nature from a wide range of academic research studies (36 published peer-reviewed studies in total, for references see (1)). This database consists of previously performed valuation studies of urban nature in

	a variety of contexts and cities, from 1976 until 2016. Statistical analysis were performed to result in the average monetary values attributed to an urban nature type. The values were based on economic values to citizens (their willingness to pay for a benefit) and the increase of property values from NBS (Hedonic pricing).
Scale of measurement	The obtained average monetary value per NBS were grouped into scores on the scale 1-5. A score between 1-5 was developed based on the obtained average monetary values per urban nature type. **Score 1** corresponds to monetary value of urban nature up to €2.000 ha^{-1} $year^{-1}$, **Score 2** €2.000 - €3.000 ha^{-1} $year^{-1}$, **Score 3** €3.000 - €4.000 ha^{-1} $year^{-1}$, **Score 4** €4.000 - €5.000 ha^{-1} $year^{-1}$ and **Score 5** from €5.000 ha^{-1} $year^{-1}$.
Data source	
Required data	
Data input type	
Data collection frequency	
Level of expertise required	
Synergies with other indicators	
Connection with SDGs	
Opportunities for participatory data collection	
Additional information	
References	Bockarjova, M.; Botzen, W.J.W.; Koetse, Mark J. (2018) Economic Valuation of Green and Blue Nature in Cities : A Meta-Analysis. U.S.E. Working Paper series, vol.18, issue 08. Utrecht University School of Economics. https://dspace.library.uu.nl/handle/1874/374925

23.2 Mean land and/or property value in proximity to green space

Project Name: UNaLab (Grant Agreement no. 730052)

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Land and property value	**New Economic Opportunities and Green Jobs**
Description and justification	The change in attractiveness of an area due to the presence of public green space or other NBS can be determined by an individual's willingness to pay for, and thus the sale price or value of, land or property located in proximity to the NBS (Gore et al., 2013). Similar effects are likely to occur when implementation of NBS encourages development of new housing areas. A survey of real estate developers and consultants from across Europe revealed that 95% of respondents believe that open space readily adds value to commercial. On average, property developers would be willing to pay ≥3% more for the opportunity to be near public open space, with some putting the premium as high as 15-20% (Gensler, the Urban Land Institute [ULI], & the Urban Investment Network [UIN], 2011; Roebeling et al., 2017).
Definition	Mean or median value of land and property according to linear distance from NBS distance. For consistency with "Green space accessibility" indicator, land and property within 300 m linear distance from NBS of at least 0.5 ha in size can be considered 'in proximity' to the NBS. In the case of large-scale NBS, the maximum adopted distance can be up to 1000 m.
Strengths and weaknesses	+ The indicator is easy to define - A great deal of input data needs to be collected and processed
Measurement procedure and tool	Hedonic analysis can be used to understand the effect of NBS on property value. This method enables analysis of property sale data, yielding the difference in sale prices as a function of various attributes that are thought to affect the price. As a result, hedonic analysis can identify the price premium associated with the presence of and access to NBS (Crompton, 2005; Troy & Grove, 2008).

	Change in mean and median land and property prices following implementation of NBS can also be assessed (Forest Research, 2005). The change in mean or median land and property prices can be measured as a percentage or monetary value; however, information may need to be gathered over a period of years to gain a full understanding of the change in value. Data required include real estate values in the area defined as "surrounding the NBS". These data can be extracted annually from municipalities, cadastre and real estate agencies before and after the NBS implementation (see, e.g., Bockarjova et al., 2020) or be simulated based only on pre-existing data and information (see, e.g., Roebeling et al., 2017; Mendonça et al., 2020). Understanding and identifying the buffer zone surrounding NBS and assessing the change in property value in parallel is a critical component. Proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or properties within a 300 m distance from NBS (Tamosiunas et al., 2014; WHO, 2016), particularly those of small or medium size. The type, quality and size of a given NBS, including the different recreational opportunities and aesthetic values, associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local land and property values. In the case of large-scale NBS, the value of land or properties within a 1000 m linear distance of the large NBS may be influenced by their proximity to the NBS.
Scale of measurement	Local, neighbourhood or district scale
Data source	
Required data	Property sale data from municipalities, cadastre and real estate agencies as well as area and categorisation of green spaces
Data input type	Qualitative and quantitative
Data collection frequency	Before and after NBS implementation
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the *Green space accessibility* indicator, and the other indicators in the *New Economic Opportunities and Green Jobs* indicator group
Connection with SDGs	SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure
Opportunities for participatory data collection	No opportunities identified

Additional information	
References	Bockarjova, M., Botzen, W.J.W. & Koetse, M.J., 2020. Economic valuation of green and blue nature in cities: a meta-analysis. Ecological Economics, 169: 106480. Crompton, J.L. (2005). The impact of parks on property values: empirical evidence from the past two decades in the United States. Managing Leisure, 10(4), 203-218. Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., & Phang, Z. (2013). Green Infrastructure's contribution to economic growth: A review. A Final Report for Department for Defra and Natural England. July 2013. London: eftec. Retrieved from http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19056 Forest Research. (2005). Regeneration of previously developed land: Bold Colliery Community Woodland: district valuer's report on property values. Cockermouth, Cumbria: North West England Conservancy. Retrieved from https://www.forestresearch.gov.uk/tools-and-resources/urban-regeneration-and-greenspace-partnership/greenspace-in-practice/planning-integrated-landscapes/brownfield-regeneration/ Gensler, the Urban Land Institute (ULI), & the Urban Investment Network (UIN). (2011). Open Space: An asset without a champion? San Francisco, CA: Gensler. Retrieved from https://www.gensler.com/uploads/document/220/file/Open_Space_03_08_2011.pdf Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. Urban Forestry & Urban Greening, 14(1), 56-64. Mendonça, R., Roebeling, P., Martins, F., Fidélis, T., Teotónio, C., Rocha, J., and Alves, H., 2020. Assessing economic instruments to steer urban residential sprawl, using a hedonic pricing simulation modelling approach. Land Use Policy, 92, 104458. Roebeling, P., Saraiva, M., Palla, A., Gnecco, I., Teotónio, C., Fidélis, T., … Rocha, J. (2017). Assessing the socio-economic impacts of green/blue space, urban residential and road infrastructure projects in the Confluence (Lyon): a hedonic pricing simulation approach. Journal of Environmental Planning and Management, 60(3), 482-499. Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. Environmental Health, 13(1), 20.

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23.2.1 Change in mean house prices/ rental markets

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Changes in mean house prices/rental markets	New Economic Opportunities and Green Jobs
Description and justification	Rental and market prices for homes and retail/commercial spaces can be seen as a good barometer of economic prosperity. A wealth of data exists illustrating the association between high quality green space and NBS and increased real estate values. Research suggests that prices can increase by up to 20% of home or retail spaces overlook or are located near to high quality green and open spaces. It has also been reported that an improved physical environment in terms of aesthetic quality is used by businesses when deciding to locate to an area. Thus, with interventions in NBS there is a potential for improved economic development activities to be situated in each of the demo sites. Such data would also allow the municipality to think more strategically about how they align their economic development targets with their understanding of how, where and NBS could be implemented in the future.
Definition	In progress This KPI will assess the Rental and market prices for homes and retail/commercial spaces through questionnaires and municipality data collection and the influence of the GI or NBS on it.
Strengths and weaknesses	
Measurement procedure and tool	The change in house/rental prices in NBS intervention areas will be measured primarily using secondary analysis of property market data (assessments n Zoopla or similar). A full database of property market value will be collected

	prior to the interventions, and then monitored for a period of 2 years afterward, then analysed to determine if significant change in property values near the interventions has occurred. This will focus on changes in average rental or sale prices for apartments and houses within a 100-metre radius of the NBS interventions, a standard measure of used in such studies. This data will also be complemented by GI-Val calculations. An important consideration in monitoring this KPI over the life of this project will be wider economic changes in the City of Liverpool, the UK (e.g., Brexit), the EU and beyond. For this reason, it will be important to analyse housing prices against relevant benchmarks, to see how values have changed in relative – and not just absolute – terms.
Scale of measurement	City / neighbourhood
Data source	
Required data	City official data, city platforms, questionnaires, small-medium enterprise account (Related to de NBS investment zone)
Data input type	In progress.
Data collection frequency	In progress
Level of expertise required	Technical / Expert
Synergies with other indicators	-
Connection with SDGs	SDG1 / SDG4 / SDG5 / SDG8 / **SDG10** / **SDG11** **/ SDG12**
Opportunities for participatory data collection	--
Additional information	
References	URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl

23.2.2 Average land productivity and profitability

Project Name: NAIAD (Grant Agreement no. 730497)

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Average land productivity and profitability	**New Economic Opportunities and Green Jobs**
Description and justification	Provides an indication of the average economic value of agriculture
Definition	Average economic return of the agricultural activity per ha (EUR/ha)
Strengths and weaknesses	
Measurement procedure and tool	Extrapolation from secondary data sources (literature review and official data)
Scale of measurement	Aquifer scale (Medina del Campo aquifer)
Data source	
Required data	Data on crop area, production, cost, prices, etc.
Data input type	
Data collection frequency	Yearly (if available)
Level of expertise required	Technicians
Synergies with other indicators	
Connection with SDGs	SDG 2, 6, 12

Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.3, DEMO Insurance Value Assessment Report. SC5-09-2016. Operationalising insurance value of ecosystems. Grant Agreement nº 730497

23.2.3 Property betterment and visual amenity enhancement

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Jose Fermoso[1], Silvia Gómez[1], María González[1], Esther San José[1], Raúl Sánchez[1]

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Property betterment and visual amenity enhancement	**New Economic Opportunities and Green Jobs**
Description and justification	Benefits of Consumption versus Benefits to Society. A positive externality on consumption occurs when the consumption of a good or service confers a benefit on third parties who are not involved in the production or consumption of the product.
Definition	This KPI, related to economic aspects measurements, evaluates how NBS interventions can increase consumption benefits, property betterment and visual amenity enhancement resulting from NBS.
Strengths and weaknesses	- Medium or long term assessment.
Measurement procedure and tool	Consumption benefits (Direct property betterment) Direct value on consumption benefits by zone, before and after implementation, during the established period. To be based on analysis of the cadastral value of the properties according to the availability of green areas. It requires a zone analysis, since it depends on the location of the house and its relation with the NBS. ***Consumption benefits= n * Z [(value of improvements vs value of investment) (€/m²)]*** Where n is referring to the number of units with benefit by its direct value (directly related to the each particular NBS) ***Gross value added (GVA)*** Defined as the difference between the value of goods and services produced and the cost of raw materials and other

	non-labour inputs, which are used up in production. The research should conclude what is the total contribution of NBS in % of the total GVA to the region/area economy in EUR per year.
Scale of measurement	City / neighbourhood
Required data	City official data, city platforms, questionnaires, small-medium enterprise account (Related to de NBS investment zone)
Data input type	• (nº improvements) (€/m²) • (nº improvements or nº users) (€/year)
Data collection frequency	Annually
Level of expertise required	Technical / Basic
Synergies with other indicators	-
Connection with SDGs	SDG1 / SDG4 / SDG5 / SDG8 / **SDG10** / **SDG11** / **SDG12**
Opportunities for participatory data collection	None identified
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl An impact evaluation framework to support planning and evaluation of nature-based solutions rojects; An EKLIPSE Expert Working Group report, 2017 "The Model of the Environmental Sustainability Matrix" (“El Modelo de la matriz de Sostenibilidad Ambiental”); La ordenación

	Urbana y el Desarrollo Sostenible, Angel Ibañez Ceba, Fermín Cerezo Rubio, August 2009 Guidance Document on Monitoring and Evaluation – ERDF and Cohesion Fund, Concepts and Recommendations, Programming Period 2014-2020, European Commission, April 2013. Annex1 “A Positive Externality on Consumption” (Science, Tech, Math, Social Sciences); https://www.thoughtco.com/positive-externality-on-consumption-overview-1147392

23.3 Number of new jobs created

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Jose Fermoso[1], Silvia Gómez[1], María González[1], Esther San José[1], Raúl Sánchez[1]

[1] *CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain*

Direct economic activity: Number of new jobs created	**New Economic Opportunities and Green Jobs**
Description and justification	Green jobs should contribute to environmental benefits. They should be strive for minimisation of resources, create decent employment opportunities and build low-carbon sustainable societies. The International Labour Organization (ILO) has a methodology to estimate green jobs. According to ILO's various country-wide studies, primary green activities (i.e., organic agriculture, sustainable forestry), secondary activities (i.e., renewable energy, clean industry, sustainable construction) and tertiary activities (i.e., recycling, sustainable tourism, and sustainable transport) are defined as green jobs.
Definition	This KPI, related to economic aspects measurements, evaluates how NBS interventions can increase the attraction of businesses, or how to increase the value of the existing ones. This value, evaluated through the measurements of number of jobs created will reflect the economic opportunities and potential of NBS solutions.
Strengths and weaknesses	- Medium or long term assessment. - It needs municipality data from different departments. - This KPI will require citizens’ collaboration, so recovering the data could be difficult.
Measurement procedure and tool	Essentially a 'before-after' indicator which captures the part of the employment increase that is (a) direct consequence of NBS implementation (workers employed to implement the NBS project should not be directly counted). The

	positions needs to be filled (vacant posts are not counted) and increase the total number of jobs in the enterprise. If total employment in the enterprise does not increase, the value is zero – it is regarded as realignment, not increase. Safeguarded, etc., jobs are not included. **Gross:** Not counting the origin of the jobholder as long as it directly contributes to the increase of total jobs in the organisation. The indicator should be used if the employment increase can plausibly be attributed to the support. **Full-time equivalent:** Jobs can be full time, part time or seasonal. Seasonal and part time jobs are to be converted to FTE using ILO/statistical/other standards. **Durability:** Jobs are expected to be permanent, i.e., last for a reasonably long period depending on industrial-technological characteristics; seasonal jobs should be recurring. Figures of enterprises that went bankrupt are registered as a zero employment increase. **Timing:** Data is collected before the project starts and after it finishes; the NBS holders are free to specify the exact timing (depending on the NBS time needed to get the profit). Using average employment, based on 6 months or a year, is preferred to employment figures on certain dates. • Number of jobs created (Direct employment) Direct value on employment by zone, before and after implementation, during the established period. ***Number of jobs created= n * Z [(nº jobs) (€/m²)]*** Where *n* is referring to the direct full time employment in during the time defined (directly related to the each particular NBS); *Z*- affected zone/area in reference to the NBS (should depend on NBS the definition of the area)
Scale of measurement	City / neighbourhood
Data source	
Required data	City official data, city platforms, questionnaires, small-medium enterprise accounts… (Related to de NBS investment zone)
Data input type	• (Nº jobs) (€/m²) • (Nº jobs or nº users) (€/year)
Data collection frequency	
Level of expertise required	Technical / Basic

Synergies with other indicators	-
Connection with SDGs	SDG1 / SDG4 / SDG5 / SDG8 / **SDG10** / **SDG11 / SDG12**
Opportunities for participatory data collection	None identified
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl An impact evaluation framework to support planning and evaluation of nature-based solutions rojects; An EKLIPSE Expert Working Group report, 2017 "The Model of the Environmental Sustainability Matrix" ("El Modelo de la matriz de Sostenibilidad Ambiental"); La ordenación Urbana y el Desarrollo Sostenible, Angel Ibañez Ceba, Fermín Cerezo Rubio, August 2009 The five principles of the urbanization theory of Cerdá, Engineering and Territory Magazine, Spanish edition, 2009 Expert evaluation network delivering policy analysis on the performance of Cohesion policy 2007-2013, 2013, "Job creation as an indicator of outcomes in ERDF programmes", Synthesis report, August 2013, A report to the European Commission Directorate-General for Regional and Urban Policy Forestry Commission, Scotland, The economic an d social contribution of forestry for people in Scotland, David Edwards, Jake Morris, Liz O´Brien, Vadims Sarajevs and Gregory Valatin, September 2008 Guidance Document on Monitoring and Evaluation – ERDF and Cohesion Fund, Concepts and Recommendations, Programming Period 2014-2020, European Commission, April 2013. Annex1

23.4 Retail and commercial activity in proximity to green space

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Direct economic activity: Use of ground floor building space for retail, commercial or public purposes in the area surrounding implemented NBS	**New Economic Opportunities and Green Jobs Place Regeneration**
Description and justification	The atmosphere of a neighbourhood and its overall liveability are influenced by the use of ground floor spaces for commercial and public purposes. The availability of amenities not only enhances the consumer experience, but also contributes to successful retail and commerce by supporting small businesses and retailers (Arlington Economic Development, 2014). Residential and office buildings generally have the most potential for increased use of ground floor space.
Definition	Proportion of ground floor surface of buildings within a specified distance (300 m) from NBS of at least 0.5 ha that is used for commercial or public purposes, expressed as percentage of total ground floor surface
Strengths and weaknesses	+ The indicator is easy to define - A large quantity of input data need to be collected and processed
Measurement procedure and tool	This metric is calculated as: $\left(\frac{Ground\ floor\ space\ for\ commerical\ or\ public\ use\ (m^2)}{Total\ ground\ floor\ space\ (m^2)}\right) \times 100$ This indicator may be limited to a defined urban area within a specific linear distance of 300 m from NBS of at least 0.5 ha in size (e.g., for consistency with *Green space accessibility* indicator), but may be extended to a greater linear distance in the case of large-scale NBS.
Scale of measurement	Neighbourhood or district scale
Data source	

Required data	Data about ground floor space usage can be obtained from administrative documents and/or from interviews with the department for urban planning within the local municipality
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the *Green space accessibility* indicator, and with the *New Economic Opportunities and Green Jobs* indicator group
Connection with SDGs	SDG 8 Decent work and economic growth, SDG 9 Industry, innovation and infrastructure
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Arlington Economic Development. (2014). Ground Floor Retail and Commerce: Policies, Guidelines and Action Plan. Draft – September 2014. Arlington, VA: Arlington Economic Development Department, Real Estate Development Group. Retrieved from https://www.arlingtoneconomicdevelopment.com/index.cfm?LinkServID=6E1B9F23-AA29-D1AC-1DFE1072C67F5C64&showMeta=0 Bosch, P., Jongeneel, S., Rovers, V., Neumann, H.-M., Airaksinen, M., and Huovila, A. (2017). CITYkeys indicators for smart city projects and smart cities. CITYkeys project D1.4. http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

23.5 Number of new businesses created and gross value added to local economy

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

Author/s and affiliations: Jose Fermoso[1], Silvia Gómez[1], María González[1], Esther San José[1], Raúl Sánchez[1]

[1] *CARTIF Foundation. Parque Tecnológico de Boecillo, 205, 47151, Boecillo, Valladolid, Spain*

Direct economic activity: New businesses attracted and additional business rates	**New Economic Opportunities and Green Jobs**
Description and justification	This KPI, related to economic aspects measurements, evaluates how NBS interventions can increase the attraction of businesses, or how to increase the value of the existing ones. This value, evaluated through the measurements of number of new business created and the percentage of the gross value added, will reflect the economic opportunities and potential of NBS solutions.
Definition	The impact assessment of the implementation of NBS in terms of new business creation and improvement on business rates.
Strengths and weaknesses	- Medium or long term assessment - It needs municipality data from different departments. - This KPI will require citizens' collaboration, so recovering the data could be difficult.
Measurement procedure and tool	**Number of business created (direct value buss related NBS by zone)** Direct value on business created by zone NBS affected, before and after implementation, during the established period. Number of business created= n * Z [(nº business) (€/m^2)] Where n is referring to the number of business and Z to its increased value (NBS related by zone), during the established period of implementation (directly related to the each particular NBS) **Gross value added (GVA)** Defined as the difference between the value of goods and services produced and the cost of raw materials and other non-labour inputs, which are used up in production. The research should conclude what is the total contribution of NBS in % of the total GVA to the region/area economy in EUR per year.
Scale of measurement	City / neighbourhood
Required data	City official data, city platforms, questionnaires, small-medium enterprise account (Related to de NBS investment zone)

Data input type	▪ (nº business) (€/m²) ▪ (nº business or nº users) (kg/year) (€/year)
Data collection frequency	Annually
Level of expertise required	Technical / Basic
Synergies with other indicators	-
Connection with SDGs	SDG1 / SDG4 / SDG5 / SDG8 / **SDG10** / **SDG11** / **SDG12**
Opportunities for participatory data collection	None identified
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl An impact evaluation framework to support planning and evaluation of nature-based solutions rojects; An EKLIPSE Expert Working Group report, 2017 "The Model of the Environmental Sustainability Matrix" ("El Modelo de la matriz de Sostenibilidad Ambiental"); La ordenación Urbana y el Desarrollo Sostenible, Angel Ibañez Ceba, Fermín Cerezo Rubio, August 2009 Expert evaluation network delivering policy analysis on the performance of Cohesion policy 2007-2013, 2013, "Job creation as an indicator of outcomes in ERDF programmes", Synthesis report, August 2013, A report to the European Commission Directorate-General for Regional and Urban Policy Forestry Commission, Scotland, The economic an d social contribution of forestry for people in Scotland, David Edwards, Jake Morris, Liz O´Brien, Vadims Sarajevs and Gregory Valatin, September 2008

	Guidance Document on Monitoring and Evaluation – ERDF and Cohesion Fund, Concepts and Recommendations, Programming Period 2014-2020, European Commission, April 2013. Annex1

23.6 Recreational monetary value

Project Name: Nature4Cities (Grant Agreement no. 730468)

Author/s and affiliations: Javier Babí Almenar[1], Claudio Petucco[1], Benedetto Rugani[1]

[1] RDI Unit on Environmental Sustainability Assessment and Circularity / Environmental Research & Innovation (ERIN) department / Luxembourg Institute of Science and Technology (LIST) – 41 Rue du Brill, L-4422 Belvaux, Luxembourg

Recreational monetary value	**New Economic Opportunities and Green Jobs**
Description and justification	This is an estimation of the economic value of recreation inside urban NBS interventions. For many nature-based interventions in urban areas recreation is a main function. Then, when doing monetary quantifications of costs and benefits it is important to include the monetary value of recreation. It can be used as part of cost-benefit analysis that consider positive and negative externalities and not only internalized benefits and costs.
Definition	The indicator recreational monetary value estimates the monetary value of recreation in urban NBS interventions based on key components (trees & shrubs, herbaceous plants, water, and size of the NBS), the density of people around the NBS intervention, and willingness to accept value (distance and euros) of recreation in NBS of an average person.
Strengths and weaknesses	Strength: This indicator will anticipate the monetary value that recreation in a public urban green space could have making use of a simple procedure. Additionally, the value can be calculated per year, taking into account changes in the NBS over time. Weakness: The procedure require to know two values: i) the monetary value of an average person visiting the NBS for recreation per year; and ii) the distance that an average person is willing to walk to visit an NBS based on key attributes. These values can be obtained from similar case studies making use of benefit transfer methods. However, the best option would be to calculate it locally, which it is time consuming. This indicator is specific for urban environments.

Measurement procedure and tool	Calculation method : 1st) The walking distance willing to accept for each key attribute of the NBS needs to be estimated making use of Discrete Choice Modelling. If this cannot be done, data from scientific literature can be used. We recommend the use of Ta et al., (2020), which has established the walking distances based on the presence of developed woodland, forest, water, and size of the NBS (green space). 2nd) The distance-attributes (i.e., forest/woodland, presence of water, size) of the NBS should be quantified. For the quantification of woodland and forest, the following aspects need to be considered (based on FAO, Copernicus Land Cover, and Forestry Commission criteria): - The minimum width of forest/woodland patch is 20 m. - The patch inside the NBS classified as forest or woodland has a minimum area of 10% covered by tree crowns. - If the NBS covers an area inferior of 5 ha at least 0.5 ha should be covered by continuous tree cover to quantify the presence of woodland or forest. - The average height of the trees in the forest/woodland patch should be 5 m. If there are only herbaceous plants and grassland covering at least a 10% of the area of the space and above 0.5 ha a minimum walking distance of 4 min (equivalent to 300 m) is considered. 3rd) A cumulative distance is obtained after the characterisation of the NBS based on distance-attributes. Then, based on that distance and the network of walkable streets, network analysis in a GIS software is run to calculate the service area. 4th) Based on existing population density data (for example from census database) we calculate the amount of people served by the NBS. If there is no access to local data, population density can be obtained from the polygons of the Urban Atlas of Copernicus Land initiative. 5th) The number of people obtained is multiplied by the monetary value of yearly recreation for an average person. This provides you the final value. In case, local information is not available we recommend the work of Bernath and Roschewitz (2008). Please, be aware that the use of value from literature require adjustments that at least consider the purchase parity power of the country and year for which the evaluation is applied. Note: In case you are able to calculate how trees are growing over time inside the NBS intervention, you can

	make the calculation of monetary value dynamic. This means you can see how much NBS recreational value is changing over time up to a maximum or a minimum walking distance (4 minutes is the minimum). This makes sense, since mature parks usually attract more people than new ones were vegetation is still not well developed.
Scale of measurement	☒ City ☒ Neighbourhood
Data source	Population estimates: https://land.copernicus.eu/local/urban-atlas/population-estimates-by-urban-atlas-polygon. - Willingness to accept (walking distance + monetary value per average person): local data or the one recommended in the procedure (Ta et al., 2020; Bernath and Roschewitz, 2008)
Required data	- Local Willingness to Accept values (walking distance and monetary) or values extracted from the literature. - Street Network around the NBS of interest - Population or population density data in a spatial explicit format. - Basic data regarding the attributes of the NBS analysed (should be available in documents such as its plan/design).
Data input type	- Spreadsheet with Willingness to Accept data - Shapefile (lines, and polygons) or similar such as CAD.
Data collection frequency	The data collection for the Willingness to Accept should be collected only one time. The rest of the data should be collected one time too, unless yearly monitoring of the evolution is intended. Then, Data regarding attributes of the NBS should be collected each year as weel as regading population density. For predictions of changes in value over time (no monitoring) values only need to be collected one time.
Level of expertise required	Easy-medium. It requires data and it requires at least basic knowledge of monetary valuation and GIS.
Synergies with other indicators	Accessibility of public green spaces at least 0.5 ha in size (Challenge Green Space Management) Recreational value of Green Spaces (Challenge Place Regeneration)
Connection with SDGs	3. Good health and well-being (if the calculation is used to assess alternatives, to ensure the design and implementation of the NBS attracts the maximum number people possible) 10. Reduced inequalities (if the calculation of the distance is used to ensure the whole city is covered by adequate nature-based recreation) 11. Sustainable Cities and Communities (if the calculation is used to compare alternatives and ensure nature-based recreation is adequate for all inhabitants of an urban area)

Opportunities for participatory data collection	Yes, it would be ideal if the Willingness to Accept for distance and monetary value is calculated specifically for the municipality where the indicator is going to be applied. In that case, voluntaries properly trained such university students can help with the application of the Willingness to Accept surveys.
Additional information	The procedure for calculating this indicator is being developed as part of the PhD Thesis of Javier Babí Almenar (to be submitted at the end of 2020). Reference: Babí Almenar, Javier. *2020 (Anticipated)*. Characterisation, biophysical modelling and monetary valuation of urban nature-based solutions as a support tool for urban planning and landscape design. PhD Thesis. University of Bordeaux and University of Trento.
References	Bernath, K. and Roschewitz, A. (2008) Recreational benefits of urban forests: Explaining visitors' willingness to pay in the context of the theory of planned behavior, *Journal of Environmental Management*, 89(3), 155–166. doi: 10.1590/S0001-37652012000100017. Ta, M., Tardieu, L., & Levrel, H. (2020). Specifying preference heterogeneity regarding natural attributes of urban green spaces to inform renaturation policies. In *CIRED Working Paper* (No. 2020-78).

23.7 Overall economic, social and health wellbeing

Project Name: CONNECTING Nature – Coproduction with nature for city transitioning, innovation and governance (Grant Agreement no. 730222)

Author/s and affiliations: Mary Lee Rhodes[1], Conor Dowling[1]

[1] *Trinity Business School, Trinity College, Dublin, Ireland*

Overall economic, social and health well-being	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator provides information about the change in the general well-being of individuals in the community in proximity to the NBS. General measures of well-being will include economic components (incomes and or consumption) as well as social and health components. As a 'cross-cutting' indicator this will provide strong evidence of the impact of the NBS on key aspects of peoples' lives and will be easily linked to existing data collection activities throughout Europe and the world.
Definition	The change in the aggregate HDI (Human Development index) or Social Deprivation Index (SDI) for people living in the vicinity of the NBS.

	(HDI = GNI/capita; life expectancy at birth, years of education – as defined and reported by the United Nations – see below) OR (SDI has various definitions depending upon the region – see measurement discussion below)
Strengths and weaknesses	+ The indicator is easy to define and understand + The data are available and already collected (but perhaps not easy to disaggregate to the community area impacted – see weaknesses) + The HDI indicator is collected annually for all countries by the UN and so may be comparable across countries and their NBS implementations. SDIs are often calculated for populations in smaller geographic areas (see UK/Irl) and so may be more suited to NBS with smaller geographic footprints - If the NBS has a very small geographic area of impact, it may be necessary to collect large quantities of data about individuals within this area in order to construct the relevant index
Measurement procedure and tool	The approach to measuring HDI is widely available from UN sources, with the original methodology and measurement explanation found in Anand & Sen (1994). Their summary explanation is reproduced here for convenience (http://hdr.undp.org/en/content/human-development-index-hdi): "The HDI was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. The HDI can also be used to question national policy choices, asking how two countries with the same level of GNI per capita can end up with different human development outcomes. These contrasts can stimulate debate about government policy priorities. The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions. The health dimension is assessed by life expectancy at birth, the education dimension is measured by mean of years of schooling for adults aged 25 years and more and expected years of schooling for children of school entering age. The standard of living dimension is measured by gross national income per capita. The HDI uses the logarithm of income, to reflect the diminishing importance of income with increasing GNI. The scores for the three HDI dimension indices are then aggregated into a composite index using geometric mean. Refer to Technical notes for more details.

	Social Deprivation Indices are generally specific to a country and their definition of social deprivation. However, in 2008, the World Health Organisation recommended an international approach to track social (and economic) determinants of health outcomes which laid the ground work for a number of countries' approaches to measuring social deprivation. Phillips et al (2016) provide an overview of how a range of countries calculate social deprivation with all of them incorporating components related to income, employment, housing status and education. Within a given country, using the relevant SDI index for areas affected by the NBS is likely to be a useful tool for comparing the impact over time and across regions. Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report HDI/SDI is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator *Distribution of public green space*, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011). Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or properties within a 300-500 m distance from NBS (Tamosiunas et al., 2014). From a data availability standpoint, however, it is like to be more convenient to define the impact area in relation to existing administrative boundaries for which the HDI/SDI indicator is already reported. Note that administrative areas are often established based on population numbers (e.g., electoral districts, community healthcare zones, etc.). This means that the economic data is available for pre-defined geographic areas that may – or may not – align with the expected impact 'buffer zone' or be comparable to other impact indicators' geographic span of impact. Therefore, it may be necessary to assess the proportion of a given administrative area's population / economy that is affected by the NBS in order to use existing data to represent overall impact. In Connecting Nature, we are trialling an approach that will establish thresholds of geographic coverage to determine what proportion of a given administrative area's measurements to include / what weight to assign. Our initial approach will be to set a maximum threshold of geographic coverage above which the entire administrative area's measurements will be included and a minimum threshold below which the area will not be included in the indicator measurement at all. In between these thresholds, it will be up to the relevant measurement body and NBS promoter to

	assess the relevant proportion of the population in the administrative area to include in the overall measurement. The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.
Scale of measurement	District to global scale
Data source	
Required data	See definition of HDI above – which is generally collected from national census bureaus (by the UN) and reported at global, national and sub-national (states, etc.) level. For 2019, the UN data was gathered from the following sources: • Life expectancy at birth: UNDESA (2019). • Expected years of schooling: UNESCO Institute for Statistics (2019), ICF Macro Demographic and Health Surveys, United Nations Children's Fund (UNICEF) Multiple Indicator Cluster Surveys and OECD (2018). • Mean years of schooling: UNESCO Institute for Statistics (2019), Barro and Lee (2018), ICF Macro Demographic and Health Surveys, UNICEF Multiple Indicator Cluster Surveys and OECD (2018). • GNI per capita: World Bank (2019), IMF (2019) and United Nations Statistics Division (2019). SDI-related data is generally gathered by a range of public data collection agencies and aggregated/reported by a designated agency / institute within the country at local area, regional and national levels. A typical example (from Ireland) may be found at: https://www.compass.ie/pobal-hp-deprivation-index-2016-launched/ which draws on Census data and is compiled using a methodology developed by Trutz Haase and Jonathan Pratschke. This index draws on a range of demographic, social class and labour market data – all of which are available at small area scales from the Central Statistics Office. For details regarding the construction of this index see Haase and Pratschke (2017).
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation – but will be determined by the periodicity of the existing data collection and reporting processes
Level of expertise required	Moderate (assuming the use of existing data can be mapped to the specific area impacted by the NBS)
Synergies with other indicators	Synergies with the indicator group *New Economic Opportunities and Green Jobs* indicators; *Social Justice & Social Cohesion* indicators and *Place Regeneration* Indicators.

Connection with SDGs	SDG 1 No Poverty; SDG 3 Good Health & Well-being; SDG 4 Quality Education; SDG 8 Decent work and Economic Growth; SDG 10 Reduced Inequalities and economic growth.
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Anand, S. and Sen, A.K. (1994) "Human Development Index: Methodology & Measurement". Occasional Papers Series, UN Human Development Report Office, accessed Jun 2020 at https://ora.ox.ac.uk/objects/uuid:98d15918-dca9-4df1-8653-60df6d0289dd/download_file?file_format=application/pdf&safe_filename=HDI_methodology.pdf&type_of_work=Report Haase, T. & Pratschke, J. (2017) "The 2016 Pobal HP Deprivation Index for Small Areas (SA): Introduction and Reference Tables" accessed June 2020 at: http://trutzhaase.eu/deprivation-index/the-2016-pobal-hp-deprivation-index-for-small-areas/ Phillips, Robert L., Winston Liaw, Peter Crampton, Daniel J. Exeter, Andrew Bazemore, Katherine Diaz Vickery, Stephen Petterson, and Mark Carrozza (2016) "How other countries use deprivation indices – and why the United States desperately needs one", Health Affairs, 35(11), pp.1991-1998. DOI 10.1377/hlthaff.2016.0709 *UNDP. 2019. Human Development Report 2019. Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. New York: NY.* http://hdr.undp.org/en/content/human-development-report-2019

24 Additional Indicators of New Economic Opportunities and Green Jobs

24.1 New businesses established in proximity to NBS

Project Name: UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

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Indirect economic activity: Establishment of new businesses in the area surrounding NBS	**New Economic Opportunities and Green Jobs**
Description and justification	Urban regeneration can lead to improvement in the economic, physical, and social conditions of an area that has witnessed negative changes (Tallon, 2013). As such, it can include aspects such as development of business, housing, and a positive change on the community level (Tyler, Warnock, Provins, & Lanz, 2013). Nature-based solutions also provide a ground for 'Green businesses' to flourish (Organisation for Economic Co-operation and Development [OECD], 2013).
Definition	Number of new businesses established in the area surrounding implemented NBS (within 300 m linear distance of NBS of at least 0.5 ha in size)
Strengths and weaknesses	+ The indicator is easy to define - A lot of input data needs to be collected
Measurement procedure and tool	A report by Gore, Ozdemiroglu, Eadson, Gianferrara, and Phang (2013) states that gross domestic product (GDP) and gross value added (GVA) metrics alone cannot accurately estimate the contribution of green infrastructure/NBS to economic growth. Some methods to measure success can include occupation of premises in local areas or taking up of vacated spaces, changes in taxation, increase in start-ups, increase in visitors, new and expanding producer and retail firms, direct employment in development, maintenance and services, indirect employment in supporting firms, attracting and retaining the workforce. The major indicator is the number of established businesses located around the implemented NBS and also the rates paid for occupying that particular space (Gore et al., 2013). However, this will require gathering data over a

	period of years to understand the trend and business activities, both before and after the NBS implementation. Data can be derived annually from municipalities, planning departments and interviews with local businesses. Understanding and identifying the buffer zone surrounding NBS and assessing the number of new businesses in parallel is a critical component. It may be useful to define the proximity of land or property to NBS similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or properties within a 300 m distance from NBS. The type, quality and size of a given NBS, and the different recreational opportunities, attractiveness and aesthetic values associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local business development.
Scale of measurement	District to regional scale
Data source	
Required data	A number of possibilities exist, including GDP, GVA, number of start-ups, etc. (See *Measurement procedure and tool)*
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the indicator group *New Economic Opportunities and Green Jobs* indicators and the indicators *Distribution of public green space* and *Accessibility of urban green spaces*
Connection with SDGs	SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., & Phang, Z. (2013). Green Infrastructure's contribution to economic growth: A review. A Final Report for Department for Defra and Natural England. July 2013. London: eftec. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19056 Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space

	benefits in four cities in France and Portugal. Urban Forestry & Urban Greening, 14(1), 56-64. Organisation for Economic Co-operation and Development (OECD). (2013). Green Growth in Cities. Paris, France: OECD Environment Directorate. Retrieved from https://doi.org/10.1787/9789264195325-en Tallon, A. (2013). Urban Regeneration in the UK. Abingdon, Oxon: Routledge. Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. Environmental Health, 13(1), 20. Tyler, P., Warnock, C., Provins, A., & Lanz, B. (2013). Valuing the benefits of urban regeneration. Urban Studies, 50, 169-190.

24.2 Value of rates paid by businesses in proximity to NBS

Project Name: UNaLab (Grant Agreement no. 730052)

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Indirect economic activity: Value of rates paid by businesses	**New Economic Opportunities and Green Jobs**
Description and justification	The major indicator is the total value of rates paid by businesses within a defined area surrounding implemented NBS for occupying that particular space (Gore et al., 2013).
Definition	Value of rates paid by businesses established in the area surrounding implemented NBS (within 300 m linear distance of NBS of at least 0.5 ha in size)
Strengths and weaknesses	+ The indicator is easy to define - A substantial amount of input data needs to be collected
Measurement procedure and tool	To accurately determine the impact of NBS implementation on the value of rates paid by nearby businesses, it is necessary to gather data over a period of years to understand trends and business activities before and after NBS implementation. Data can be derived annually from municipalities, planning departments and interviews with local businesses.

	Understanding and identifying the buffer zone surrounding NBS and assessing the number of new businesses in parallel is a critical component. It may be useful to define the proximity of land or property to NBS similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or properties within a 300 m distance from NBS. The type and size of a given NBS, and the different recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local business development.
Scale of measurement	District to regional scale
Data source	
Required data	Input data from municipalities, planning departments, and interviews with local businesses as well as area and categorisation of green spaces
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the indicator group *New Economic Opportunities and Green Jobs* indicators and the indicators *Distribution of public green space* and *Accessibility of urban green spaces*
Connection with SDGs	SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., & Phang, Z. (2013). Green Infrastructure's contribution to economic growth: A review. A Final Report for Department for Defra and Natural England. July 2013. London: eftec. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19056 Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. Urban Forestry & Urban Greening, 14(1), 56-64.

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24.3 New customers to businesses in proximity to NBS

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Indirect economic activity: New Customers to existing and new businesses (or 'footfall' if necessary)	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator provides information about the change in the number of customers of: 1) existing businesses in proximity to the NBS and/or 2) new businesses established either directly or indirectly due to the NBS. [See factsheets for Indicators 12.1.3.2 and 12.2.1.2]
Definition	The change in the number of customers reported by businesses in the vicinity of the NBS or new businesses directly related to the NBS. Note that this is different from 'footfall' which only counts the presence of an individual in a given location – but who may or may not be a customer of any given business. Customers must – by definition – purchase something from the relevant business. However, it may be easier to collect information about 'footfall' in a given area and let businesses make their own calculations about the conversion of people in the vicinity to 'customers'.
Strengths and weaknesses	+ The indicator is easy to define and understand + The indicator is meaningful for businesses considering starting up or expanding in a given area. + The indicator may assist local authorities determine / provide evidence for appropriate rate levels to set in the area. - The data is 'owned' by individual businesses and may be difficult to collect

	- The causal relationship between the NBS and the purchasing decision by a customer may be difficult to establish (more so than for a similar / related indicator of ‘footfall’).
Measurement procedure and tool	Measuring new customers directly will require asking businesses to report the number of total customers per period (month / year / quarter). It is likely that they will have this data on their financial systems, but it is not generally something that is reported to public bodies. This is because the number of customers a given business has in a period is often considered to be competitively sensitive information. Nevertheless, if businesses within the ‘buffer zone’ of the NBS are willing or can be convinced to provide this information, it should be collected periodically from those businesses and the change in customers may be calculated / analysed and aggregated over time. It should be noted that a single individual may be counted multiple times if they buy from more than one business within the buffer zone, but this is not a problem as long as the indicator is NOT used for purposes other than reporting number of customers. If it proves impossible to get businesses in the buffer zone to provide this information, then the next best indicator is ‘footfall’. Footfall is a measure of the number of people visiting a store or an area in a given period (usually per day). Footfall is generally reported on an average basis – i.e., “on average 20,000 people per day visit the shopping centre”. Footfall is measured using sensor / laser technology that can analyse when people are coming or going into/out of a shop / area and (more advanced) how long they linger. Footfall data may be converted to number of customers through the use of a ‘conversion rate’. Conversion rate is defined the proportion of shop/area visitors who actually make a purchase. Conversion rates are indicators of average purchase behaviour and generated as an average over a period by individual businesses and can be used to approximate number of customers arising from ‘footfall’. As for new customers, ‘footfall’ is something that may already be collected by the relevant businesses or in the area by an industry or public body. If collected by an industry / public body for a given area (generally done for high end / concentrated retail areas), then the data should be requested per period to establish change in ‘footfall’. If not, then individual businesses will have to be asked to provide the data – along with conversion rates – in order to generate customer numbers. If the data is unavailable from businesses or industry sources, and there is appetite (and resources available), then

	sensors may be deployed around the relevant area to measure footfall directly. This is a high cost option, but may be useful as input data for other indicators as well. Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report new customers is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator *Distribution of public green space*, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011). Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or businesses within a 300-500 m distance from NBS (Tamosiunas et al., 2014). Once the relevant buffer zone is agreed then new customers or 'footfall' should be gathered from the businesses in the designated area. The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.
Scale of measurement	Individual business to street/small area
Data source	
Required data	
Data input type	Quantitative
Data collection frequency	The primary data (footfall or customer purchases) is generally collected by businesses on a daily basis. Collection for the purpose of reporting NBS impact can be undertaken over longer periods and reported as period averages
Level of expertise required	Low (assuming the primary data is collected and reported by the relevant businesses themselves)
Synergies with other indicators	Synergies with *GDP* and *numbers of businesses* indicators. 'Footfall' may also be useful input to several health & well-being indicators.
Connection with SDGs	SDG 8 Decent Work and Economic Growth
Opportunities for participatory data collection	No opportunities identified
Additional information	

References	Butz Jr, H.E. and Goodstein, L.D., 1996. Measuring customer value: gaining the strategic advantage. Organizational dynamics, 24(3), pp.63-77. Jones, M.A., Mothersbaugh, D.L. and Beatty, S.E., 2002. Why customers stay: measuring the underlying dimensions of services switching costs and managing their differential strategic outcomes. Journal of business research, 55(6), pp.441-450.

24.4 Local economy GDP

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Indirect economic activity: Change in local economy GDP in proximity to NBS	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator provides information about the change in total consumption/production for a given area in proximity to the NBS. It is a general indicator of the direction of economic growth (increasing/stable/decreasing) and is easily aggregated and comparable at many levels.
Definition	GDP (Gross Domestic Product) is a measure of the 'output' of a specified economy. Data can be collected at any scale as the indicator is simply the total monetary value of all production/sales in a given location / within a given boundary. Eurostat relates GDP to Gross Value Added (see Indicator 12.1.3.4) and defines GDP as: "an aggregate measure of production, GDP is equal to the sum of the gross value added of all resident institutional units engaged in production, plus any taxes on products and minus any subsidies on products. Gross value added is the difference between output and intermediate consumption." It should be noted that GDP is often confused with GNP (Gross National Product), which is defined as GDP plus "net" income from other countries.
Strengths and weaknesses	+ The indicator is widely reported and generally understood

	+ The indicator is a meaningful and comparable at multiple levels of aggregation - The causal relationship between the NBS and the overall change in GDP may be difficult to establish - The geographic scale at which the data is available may not be adequate for reporting NBS impact
Measurement procedure and tool	GDP (and GNP) are regularly calculated and reported by national statistics offices based on sales data collected from businesses, government expenditure and trade flows. The specific components of GDP are: **GDP** = C (private Consumption) + I (gross private Investment) + G (Government investment) + X (eXports) – M (iMports). *GNP* adjusts measures of GDP based on remittances in/out of the country. For example, if Apple Inc. produces €100 million of computers in Ireland and sends €20 million in profits to shareholders in the US, then €20 million would be subtracted from Ireland's GDP (which includes the original €100 million). In addition, the US figure for GNP would be increased by €20 million. GDP is generally reported as a total in a given period (usually a year) within a specific administrative boundary (e.g., state, region, country). Most statistical offices will be able to provide this data at lower levels of geographic scale, following locally defined administrative boundaries. However, it is more likely that *Income per Household or per Person* (See Indicator 12.2.17) will be reported at smaller geographical scales. It is also the case, that in some jurisdictions – and for some purposes – GNI (Gross National Income) is used instead of GDP/GNP as an indicator of economic performance. Determining GDP for a given area in proximity to an NBS will involve establishing the appropriate 'buffer zone' around the NBS and determining the relevant source for GDP data at that scale. Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report GDP is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator *Distribution of public green space*, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011). Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or businesses within a 300-500 m distance from NBS (Tamosiunas et al., 2014). From a data availability standpoint, however, it is likely to be more convenient to define the impact area in relation to

	existing administrative boundaries for which GDP is already reported. Note that administrative areas are often established based on population numbers (e.g., electoral districts, community healthcare zones, etc.). This means that the economic data is available for pre-defined geographic areas that may – or may not – align with the expected impact 'buffer zone' or be comparable to other impact indicators' geographic span of impact. Therefore, it may be necessary to assess the proportion of a given administrative area's population / economy that is affected by the NBS in order to use existing data to represent overall impact. In Connecting Nature, we are trialling an approach that will establish thresholds of geographic coverage to determine what proportion of a given administrative area's measurements to include / what weight to assign. Our initial approach will be to set a maximum threshold of geographic coverage above which the entire administrative area's measurements will be included and a minimum threshold below which the area will not be included in the indicator measurement at all. In between these thresholds, it will be up to the relevant measurement body and NBS promoter to assess the relevant proportion of the population in the administrative area to include in the overall measurement. The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.
Scale of measurement	Regional - National
Data source	
Required data	As noted above, GDP is generally collected and reported by national statistics offices. The challenge is to define the area affected by the NBS and to map this to administrative boundaries within which GDP is reported.
Data input type	Quantitative
Data collection frequency	Annually (actual data) and quarterly (estimated)
Level of expertise required	Moderate
Synergies with other indicators	Synergies with *New Customers, Gross Value Added, Income per capita* and *numbers of businesses* indicators.
Connection with SDGs	SDG 8 Decent Work and Economic Growth

Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Eurostat (2010) European System of National and Regional Accounts (2010), EU – may be accessed at https://ec.europa.eu/eurostat/documents/3859598/5925693/KS-02-13-269-EN.PDF/44cd9d01-bc64-40e5-bd40-d17df0c69334 Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P. and Reuter, K., 2015. Nature-based solutions: new influence for environmental management and research in Europe. GAIA-Ecological Perspectives for Science and Society, 24(4), pp.243-248. Stiglitz, J., Sen, A.K. and Fitoussi, J.P., 2009. The measurement of economic performance and social progress revisited: reflections and overview.

24.5 Initial costs of NBS implementation

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Initial Costs	**New Economic Opportunities and Green Jobs**
Description and justification	Indicators of Cost-Benefit Analysis of the Intervention sub-criterion will assess the financial feasibility of the project scenario.
Definition	Project's initial costs are those occurring during the design and construction phases.
Strengths and weaknesses	+ Top-down synthetic approach could ensure rapid estimation but low accuracy; - Bottom-up analytical approach and parametric approach are very time-consuming.
Measurement procedure and tool	Different methods can be used to assess initial cost and the choice among them depends on the detail of the available data and of the evaluation itself. These methods can be classified in three different approaches:

	1) Top-down synthetic approach: when few and generic information is available, the estimation can be carried out by analogy with existing projects or by experts opinions; 2) Bottom-up analytical approach: when more and detailed information is available, the estimation can be carried out using the work (cost) breakdown structure; 3) Parametric approach: the estimation is carried out by analogy with existing projects but high quality data are needed.
Scale of measurement	€
Data source	
Required data	Parametric costs; Similar projects
Data input type	Quantitative
Data collection frequency	At the beginning of the project.
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	12
Opportunities for participatory data collection	Given the high degree of expertise needed to calculate this indicator, technical stakeholder can contribute to the provision of data needed for the estimation model implementation.
Additional information	
References	Cerezo-Narváez, A.; Pastor-Fernández, A.; Otero-Mateo, M.; Ballesteros-Pérez, P. Integration of Cost and Work Breakdown Structures in the Management of Construction Projects. Appl. Sci. 2020, 10, 1386.

24.6 Maintenance costs of NBS

Project Name: proGIreg (Grant Agreement no. 776528) and PHUSICOS (Grant Agreement no. 776681)

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Maintenance Costs	**New Economic Opportunities and Green Jobs**
Description and justification	Indicators of Cost-Benefit Analysis of an NBS Intervention enable assessment of the financial feasibility of a given project scenario. The maintenance costs indicator sums the total costs of sustaining the NBS implemented.
Definition	Maintenance expenses are the costs incurred to keep an item in good condition or good working order. This total maintenance cost must include total annual labour costs, land leasing costs, machinery, energy costs, licensing, etc.
Strengths and weaknesses	
Measurement procedure and tool	Data can be collected via an economic and labour questionnaire to be distributed to the entities in charge of long-term maintenance of the planned or implemented NBS. Estimation from project financial assessment.
Scale of measurement	NBS level (typically building plot-district scale)
Data source	
Required data	Cost estimates or actual cost reporting from entitles administering the NBS and sub-contractors.
Data input type	Quantitative
Data collection frequency	At least once after implementation. Potential to estimate maintenance costs during planning stage.
Level of expertise required	High. Generally, the financial officer of the administrating entity should be able to respond.
Synergies with other indicators	Connected to other economic and labour indicators

Connection with SDGs	SDG 8: Decent work and economic growth SDG 12
Opportunities for participatory data collection	None identified
Additional information	
References	

24.7 Replacement costs of NBS

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Replacement Costs	**New Economic Opportunities and Green Jobs**
Description and justification	Indicators of Cost-Benefit Analysis of the Intervention sub-criterion will assess the financial feasibility of the project scenario.
Definition	Replacement costs or replacement values refer to the amount that an entity would have to pay to replace an asset at the present time, according to its current worth.
Strengths and weaknesses	+ Replacement costs is straightforward to calculate (especially with a spreadsheet); If calculated using NPV, cash flows rather than net earnings will be used (which includes non-cash items such as depreciation). - A discount rate must be selected; NPV assumes you can accurately assess and predict future cash flows.
Measurement procedure and tool	Replacement cost refers to the price that it would cost to replace an existing asset with a similar asset at the current market price. The asset in question, in the project scenario, should be the NBS/Hybrid/Grey solution implemented. For a damaged asset, the replacement cost for that asset takes into consideration the pre-damaged condition of the asset. Replacement costs are common in insurance policies to cover assets that are damaged or destroyed in a disaster, such as an floods or earthquakes.

	The process of determining an appropriate cost estimate of replacing an infrastructure is complex, and it requires various pieces of data and knowledge of construction in order to make an informed assessment. When making a decision on the infrastructure to be replaced and the cost to be incurred, businesses use the net present value (NPV). The NPV method is used to analyze the cash inflows and outflows in order to make a purchase decision. It uses a discount rate to estimate the minimum rate of return on the asset. The formula for Net Present Value is: $$NPV_{XYZ} = \frac{Z_1}{(1+r)} + \frac{Z_2}{(1+r)^2} - X_0$$ where: Z_1 = Cash flow in time 1 Z_2 = Cash flow in time 2 r = Discount rate X_0 = Cash outflow in time 0 (i.e., initial cost)
Scale of measurement	€
Data source	
Required data	Model
Data input type	Cash flows of the project
Data collection frequency	At least once after project definition.
Level of expertise required	High
Synergies with other indicators	Connected to other economic indicators such as initial cost and maintenance costs.
Connection with SDGs	12
Opportunities for participatory data collection	Given the high degree of expertise needed to calculate this indicator, technical stakeholder can contribute to the provision of data needed for the estimation of the cash flows.
Additional information	
References	Daves, P. (2004). Net present value (npv). In M. J. Stahl (Ed.), *Encyclopedia of health care management* (pp. 386-386). Thousand Oaks, CA: SAGE Publications, Inc. doi: 10.4135/9781412950602.n533

24.8 Avoided costs due to NBS implementation

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Avoided Costs		New Economic Opportunities and Green Jobs
Description and justification	Indicators of Cost-Benefit Analysis of the Intervention sub-criterion will assess the financial feasibility of the project scenario.	
Definition	Avoided costs are essentially the costs of the damages, which a catastrophic event could provoke without the expected intervention.	
Strengths and weaknesses	+ It is a frequently used benefit estimation technique, both because it is a common sense approach and because the information needed to assess avoided costs is often readily achievable. - It could be very time consuming since many different models should be implemented to assess the expected damages.	
Measurement procedure and tool	The avoided costs method estimates the cost that the community would incur in the absence of project scenario implementation. Given that NBS could prevent multiple risks, the avoided costs is equal to the sum of costs associated with responding to each risk faced by NBS. Thus, for each hazardous phenomenon regarding the study area, it is essential to assess the expected damages and the cost of actions taken in response to the phenomenon after it occurs.	
Scale of measurement	€	
Data source		
Required data	Different type of data (spatial data, models, parametric costs, etc.), depending on the hazardous phenomenon taken into account.	
Data input type	Quantitative	
Data collection frequency	It could be assessed when the project scenario is clear and defined.	

Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	12
Opportunities for participatory data collection	Given the high degree of expertise needed to calculate this indicator, technical stakeholder can contribute to the provision of data needed for the estimation of the expected damages.
Additional information	
References	U.S. Environmental Protection Agency (1993), *A Guide for Cost-effectiveness and Cost-benefit Analysis of State and Local Ground Water Protection Programs*.

24.9 Payback period for NBS

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Payback Period	**New Economic Opportunities and Green Jobs**
Description and justification	Indicators of Cost-Benefit Analysis of the Intervention sub-criterion will assess the financial feasibility of the project scenario.
Definition	The length of time required for the expected intervention to recover the cost of an investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions.
Strengths and weaknesses	+ Easy to understand and to calculate; Once the calculation method is defined, it is unambiguous and does not lend itself to misinterpretation.

	- It does not consider the flows achieved in the periods following the payback period; it does not consider the financial value of time; it does not consider the amount of capital invested; it is an indicator of risk (temporal exposure), not of yield.
Measurement procedure and tool	The formula to calculate the payback period (PBP) of an investment depends on whether the periodic cash inflows from the project are even or uneven. If the cash inflows are even (such as for investments in annuities), the formula to calculate payback period is: *PBP = Initial Investment / Net Cash Flow per Period* When cash inflows are uneven, we need to calculate the cumulative net cash flow for each period and then use the following formula: *PBP = A + (B / C)* where: *A* is the last period number with a negative cumulative cash flow; *B* is the absolute value (i.e., value without negative sign) of cumulative net cash flow at the end of the period A; *C* is the total cash inflow during the period following period A Cumulative net cash flow is the sum of inflows to date, minus the initial outflow.
Scale of measurement	years
Data source	
Required data	Initial costs and cash flows for the proposed project.
Data input type	Quantitative
Data collection frequency	It could be assessed when the project scenario is clear and defined.
Level of expertise required	Medium
Synergies with other indicators	Connected to other economic indicators such as initial cost and maintenance costs.
Connection with SDGs	12
Opportunities for participatory data collection	Given the high degree of expertise needed to calculate this indicator, technical stakeholder can contribute to the

	provision of data needed for the estimation of the cash flows.
Additional information	
References	Williams, J.R., et al. (2012), *Financial and Managerial Accounting*, McGraw-Hill.

24.10 Reduced / avoided damage costs

Project Name: RECONECT (Grant Agreement no. 776866)

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Reduced / avoided damage costs from hydro-meteorological risk reduction	**New Economic Opportunities and Green Jobs**
Description and justification	Determining direct damage is commonly done using depth-damage curves, which denote the damage that would occur at specific water depths per asset or per land-use class.
Definition	Expected annual damage
Measurement procedure and tool	In general the damage costs are calculated as expected annual damage, EAD, to account for random fluctuations in actual occurrences of hydro-meteorological events. This is why calculated hazard maps are used rather than direct observations. The EAD is calculated by numerical integration between based on the following equation: $EAD = \frac{1}{2}\sum_{i=1}^{n}\left(\frac{1}{T_i} - \frac{1}{T_{i+1}}\right)(D_i + D_{i+1})$ where Ti and Di are return period and calculated damage for return period i. The required number of calculation points are discussed in e.g., Olsen et al (2015). In general the majority of the calculation points should be close to the return period where damages start to occur, since very high return periods rarely contribute substantially to the overall risk in spite of their high cost (when they occur).
Data source	

Required data	• Hazard maps covering the NBS site showing the hydro-meteorological hazard(s) as a function of return period before and after the NBS is introduced. Typically this will be in the form of raster of shape files in a GIS environment. • Value maps covering the NBS site showing what assets can be exposed and what cost is associated with exposure, typically as a function of e.g., inundation depth, (water) velocity, duration of exposure, etc. This data should be available in the same format as the hazard maps. • Land use map
Data collection frequency	
Synergies with other indicators	Flood hazard
Connection with SDGs	
Additional information	
References	

24.11 Social Return on Investment (SROI)

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Social Return on Investment (SROI)	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator seeks to capture the value of improvements in social well-being (in monetary terms) arising from nature-based solutions. It should be used only in cases where additional information relating to the notional monetary value of one or more social well-being indicators is needed for the purpose of funding applications, investor requirements (*see*

	Indicator 12.2.5 Private Finance / Private Investment in NBS / Bioeconomy) or comparing the value of different projects for which there are a range of different impacts.
Definition	*Social Return on Investment (SROI)* is generally reported as a ratio between the monetary value of outputs/outcomes and the monetary value of inputs. As such, it provides both a quantifiable cost-benefit analysis of a given project / programme, as well as a tool for comparing different investments either as a forecast or a post investment evaluation. Proponents of the SROI measurement approach claim that it takes a more 'holistic' view of the various impacts that a given project/programme has on beneficiaries, but this is a matter of debate – and also depends on the specific choices made by and resources available to the SROI assessment team. Calculating SROI can only be done if there are clearly identifiable social well-being output/outcome indicators of value arising from the target project/programme, and credible SROI reporting generally requires the services of a qualified SROI expert. While the product of an SROI assessment is a quantifiable and comparable measure of expected or achieved return on resources deployed, the *process* of conducting an SROI assessment is also seen as a valuable activity as it explicitly involves stakeholders and beneficiaries in the assessment process. This is generally thought to increase the credibility of the measurement and also to raise the awareness of all stakeholders of the aims and value of the project. The specifics of this process are described in the measurement and procedure section below.
Strengths and weaknesses	+ The indicator is a meaningful and comparable at multiple levels of aggregation and across different projects; + It is a powerful tool for assessing 'value for money' (VfM) of projects with a range of social benefits; + It is widely supported by a range of social investment NGOs, think-tanks, impact investors and associations, the EU and the WHO. - It is time-consuming and often quite expensive to conduct an SROI assessment; - it requires significant expertise to calculate, to explain and to evaluate its significance; - SROI – along with other approaches to social value measurement - has been widely criticised for incorporating estimated attributions of value, 'heroic' assumptions of causality and over-simplifying the unique and heterogeneous impacts of social innovation (see references section)
Measurement procedure and tool	Details on the procedure for measuring SROI are widely available through any number of public websites and associations. The website for the EU initiative "Responsible

	Research and Innovation (RRI)" is a good place to start when looking for further information. The RRI 'Toolkit' has a link to a seminal SROI guidebook from the UK, "A guide to Social Return on Investment", from which the summary procedure included here is drawn. SROI is a 6-stage process that begins with the definition of scope for the assessment and identifying the stakeholders who will be involved and the main outcomes (impacts) to be measured. If the work of defining the NBS project's 'theory of change' has already been done (as part of the development of another indicator measurement), then this should provide a good starting point for Stage 1: scope and stakeholder definition – which includes those expected to benefit from the project (beneficiaries) as well as those providing any maintenance or other services related to the NBS and those funding the project. Work on other social well-being indicators will also provide useful input to Stage 2: Mapping Outcomes. Each stage is outlined below – however this factsheet does not substitute for detailed step-by-step guidance available from the recommended sources if an SROI assessment is to be undertaken. **Stage 1: Establishing scope and identifying stakeholders.** There are three steps in this stage: 1) establishing the scope of the analysis; 2) identifying stakeholders and 3) deciding how to involve stakeholders. In this stage the purpose of the SROI should be explicit – not only whether it is a forecast or a post-investment evaluation, but also defining (and agreeing) the goal of producing the measurement and the resources that are available to undertake the assessment. The 'audience' for the resulting measurement(s) should also be defined in this step. This may simply be the group of stakeholders – or may go beyond that group if there are objectives that require this – such as policy influence and/or knowledge sharing. It is important to decide which of the various activities or components of the NBS will be included as it may be possible only to examine a subset of all possible value producing components due to time / resource constraints. When considering the stakeholders, be sure to include those who might be negatively affected as well as those who are expected to be positively affected. Lastly, the decision about how to involve stakeholders is critical to ensure that the SROI includes those impacts that really matter to stakeholders and you can be completely transparent about how the valuation was developed and calculated. **Stage 2: Mapping Outcomes.** As in the previous stage, this stage may be informed by work done in other indicator

development exercises – particularly those that addressed social well-being impacts arising from the NBS. However, to do a proper SROI, the definition of outcomes must be co-produced with the identified stakeholders, so if this was not done in other impact indicator activities it will need to be done here. 'Mapping outcomes' involves figuring out what each stakeholder contributes (inputs) and/or receives (outputs / outcomes) from the various activities included within the scope of the SROI assessment. Identifying these is best done with the stakeholders as they are most likely to know about the actual inputs / outputs affecting and important to them. If the SROI is a forecasting exercise, then it may be possible to find estimates from previous / similar activities, relevant research and/or databanks produced for this purpose. Note that there may be 'chains' of outputs, outcomes arising over time from the NBS – which will need to be identified here. For example, an accessible park may provide greater opportunities for exercise for older people, which are taken up by some proportion of the population, and as a result these individuals are fitter and happier – which results in less healthcare expense and feelings of social isolation. Each of these outcomes will need to be defined and valued as appropriate.

It is in this stage that a monetary value is assigned to inputs as this is the less complex of the valuation steps. Valuing a volunteer's time or the expected effort required by beneficiaries to generate outcomes can, of course, be complicated, but by and large, this aspect of valuation is generally much less challenging than the next stage of valuing outcomes.

SROI manuals recommend creating an 'Impact map' for the project being assessed, which is essentially a list of stakeholders, impacts (inputs/outputs) and activities that generate each impact for each stakeholder. Other approaches to measuring impact more generally begin with a 'Theory of Change' model, which supports SROI as well as other approaches to measuring social impact. A theory of change (ToC) model explains in a graphical way the causal links between inputs, activities, context and outcomes. Mayne (2015) provides a useful overview of Theory of Change models, which may be helpful in developing a wide range of impact indicators for NBS.

Stage 3: Evidencing and Valuing Outcomes. While the previous stages may be quite challenging for the assessment team to decide among the various alternatives for defining activities, stakeholders and outcomes, it is this stage that is the most complex stage of the SROI methodology and the one that creates the most controversy (although Stage 4 has its

	own unique challenges). Essentially this stage is about deciding how outcomes will be demonstrated and what represents their 'fair' value. Again, if there are already processes for gathering evidence of social well-being outcomes, then it would be advisable to 're-use' the data from these processes for assessing SROI. However, at a minimum, these indicators must be confirmed with the stakeholders identified in stages one and two and some effort needs to be made to balance objective and subjective indicators. More on this may be found in the Guide to Social Return on Investment (Nicholls et al 2012). Once the indicators of impact are agreed with stakeholders, the next step is to assign monetary values. While it is likely that the monetary values assigned to each non-monetary input/output will be specific to the project, stakeholders and context, there are some efforts at creating standard monetary values for widely produced social outcomes in a given country. An example of a monetary value databank for social outcomes in the UK is the HACT Social Value Bank – for activities related to housing - and a paper explaining the relationship between this databank and SROI may be found here. The methodology behind these valuations is found in Trotter et al (2014) and Fujiwara (2013). Most NBS projects, however will need to develop their own monetary values through using benchmarks, published or proprietary cost data or tools specifically developed for this purpose. An overview of tools for this purpose may be found on the 'Sopact' site. It should be noted here that the SROI ratio is generally formulated as the net present value of outcomes divided by the net present value of inputs. So it will be necessary to gather or estimate the ongoing delivery of outcomes over an agreed time period in order to fully align with the SROI approach (see Stage 5). If the purpose of the SROI assessment is to deliver a post-investment / implementation evaluation, the next step will be to collect the data required to 'evidence' the outcomes of interest. It will be up to the evaluation team to decide how many periods of data are required and this should be related to the expected time frame of the impact. **Stage 4: Establishing Impact.** This stage draws on the decisions and data collected in previous stages and then applies a calculation model that draws heavily on economics and social policy evaluation approaches to 'adjust' the raw impact figure for issues of deadweight, displacement, drop-off and attribution. As noted above, the steps for accomplishing this are detailed in Nicholls et al (2012) or any number of SROI guidebooks.

At the highest level, the SROI calculation multiplies each instance of an achieved outcome by the monetary value determined in Stage 3 and then adjusts this ‘gross’ valuation by estimates or evidence of:

5) *Deadweight* – a concept from economics that represents the outcomes that would have happened over time even if the activity being assessed had not taken place. This is generally measured via reference to control groups (or other benchmark measures) of people who were not beneficiaries of the activity / NBS;
6) *Displacement* – a concept from social policy (and economics) that represents the extent to which outcomes generated by the activity being assessed eliminated, shifted or replaced other outcomes. A typical example of displacement is when a benefit (e.g, job, access to services) is made available to one individual/group that would have otherwise gone to a different individual/group;
7) *Drop-off* – this concept comes from education / training policy analysis and is a measure of the decrease in impact over time of a given activity. An example of drop-off is decreasing impact of a sustainability awareness programme on an individual’s likelihood of changing their consumption patterns. This adjustment would only be used in cases where the expected impact of an NBS extends over multiple years;
8) *Attribution* – this is an assessment of how much of the outcome achieved was caused by the contribution of the NBS as opposed to other organisations / individual choices. Nicholls et al (2012) provides a good example: “alongside a new cycling initiative there is a decrease in carbon emissions in a borough. However, at the same time, a congestion charge and an environmental awareness programme began. While the cycling initiative knows that it has contributed because of the number of motorists that have switched to cycling, it will need to determine what share of the reduced emissions it can claim and how much is down to the other initiatives (p.59)”

These adjustments to gross outcomes are usually expressed as percentages and, again, Nicholls et al (2012) contains a good example of how the adjustments may be applied to the outcome values to calculate net impact.

Stage 5: Calculating SROI.

Having completed all of the previous steps, the SROI assessor should now be in a position to calculate SROI. An overview is provided here, but it is recommended that those undertaking an actual SROI calculation refer to Nicholls et al (2012).

The basic model is a based on a net present value (NPV) calculation which is arrived at by estimating (or measuring – if it is a post implementation assessment) the amounts and number of years in which costs will be incurred and social value achieved and then applying a 'discount rate' for the time-value of money. For more on NPV and choosing a discount rate see HBR article here or to go to Nicholls et al (2012) for SROI specific examples.

The monetary equivalent value of social impact was estimated in Stage 3 and this value must be adjusted in each year by applying the adjustment percentages determined in Stage 4. The present value calculation for outcomes should only be done after the adjusted financial value of the social outcomes are calculated for each year. By applying the discount rate to the adjusted annual financial values for outcomes, the total present value of the NBS project is produced. This figure is divided by the total costs of the NBS to produce the SROI for the project as a ratio of benefits to costs. If the SROI is greater than 1, then the NBS creates value. If it is less than 1, then it does not.

SROI guidelines suggest that assessors undertake two additional analyses in order to provide further information about the SROI measurement produced. These are: 1) a *sensitivity analysis* – which provides information on the extent to which the result would change if the assumptions in any of the previous steps were altered, and 2) a '*payback period'* calculation – which gives an idea of how long it would take for the NBS to pay back the initial investment. Both of these are standard financial calculations that may be applied to the figures generated (see Nicholls et al 2012).

Stage 6: Reporting, using and embedding measurement.

This last stage is an important one to build into to any SROI project plan as it will ensure that the hard work of the previous steps. The first step in this stage is to review the results with stakeholders and get their feedback on the credibility and significance of the measurement. There is also a degree of accountability to stakeholders given their significant interest in and contribution to the measurement. Beyond stakeholders the use of the SROI depends upon the aim of the original undertaking, with a forecast generally reported to potential investors / funders and an evaluation reported to this group plus others with an interest in how the project is meeting its aims. It is important to note that one of the main indicators of a successful SROI is the extent to which it is used to inform

	decisions and/or changes to the various elements of the NBS over time. Finally, it may be appropriate to get outside assurance of the validity of the SROI measure and this can be provided by an accredited SROI assurance provider. Information on assurance (or becoming an accredited SROI provider) may be found here – or by contacting SVI. "Social Value International" (SVI) is an association of member organisations that are interested and/or experts in approaches to valuing social outcomes and interested parties are encouraged to connect with their local SVI association for support in applying SROI in their location.
Scale of measurement	Will be defined based on the scale of measurement for the underlying social well-being indicators
Data source	
Required data	- Amount (in monetary terms) of investment in the NBS being assessed for SROI - indicators of social well-being value created by the NBS - stakeholder-based attribution of monetary value to a unit of the social well-being indicator - evidence-based attribution of the proportion of social well-being created to the NBS – generally linked to a clear theory of change, and examined for 'drop-off' over time - evidence-based
Data input type	Qualitative and Quantitative
Data collection frequency	If being used as a planning / forecasting tool then data collection will occur at the planning stages of the project
Level of expertise required	Very High
Synergies with other indicators	SROI is highly dependent upon the collection of relevant *Social well-being indicators* to provide the underlying drivers of valuation. Synergies with *Benefit/Cost* and *Private Finance* indicators as data collected for SROI may be useful for these measures and vice versa.
Connection with SDGs	SDG 3 Good Health & Well-being; SDG 4 Quality Education; SDG 5 Gender Equality; SDG 8 Decent Work & Economic Growth; SDG 10 Reduced Inequalities; SDG 9 Industry, Innovation & Infrastructure; SDG 16 Peace, Justice & Strong Institutions
Opportunities for participatory data collection	A core element of SROI assessment is the involvement of beneficiaries and stakeholders in the defining of value and of attribution of effects (see procedure section above). This engagement with stakeholders is generally seen to be a positive feature of the methodology as it increases stakeholder

	awareness of the project benefits and also accords beneficiaries with direct and meaningful input to the creation of the impact indicator.
Additional information	
References	Ebrahim, A.; Rangan, V.K. (2014) “What impact? A framework for measuring the scale and scope of social performance”. Calif. Manag. Rev. 2014, 56, 118–141. Fujiwara (2013) “The Social Impact of Housing Providers”. HACT Report accessed at: https://www.hact.org.uk/sites/default/files/uploads/Archives/2013/02/The%20Social%20Impact%20of%20Housing%20Providers%20report2013.pdf Hamelmann C, Turatto F, Then V, Dyakova M. Social return on investment: accounting for value in the context of implementing Health 2020 and the 2030 Agenda for Sustainable Development. Copenhagen: WHO Regional Office for Europe; 2017 (Investment for Health and Development Discussion Paper) Liket, K.C.; Rey-Garcia, M.; Maas, K.E. (2014) “Why aren’t evaluations working and what to do about it: A framework for negotiating meaningful evaluation in nonprofits. Am. J. Eval. 35, 171–188 Maybe, J. (2015) “Useful Theory of Change Models” *Canadian Jnl of Prgm Eval*. 30(2) 119-142. Nicholls J, Lawlor E, Neitzert E, Goodspeed T. (2012) “A guide to social return on investment”. 2nd ed. London: The Cabinet Office; 2012. https://ccednet-rcdec.ca/sites/ccednet-rcdec.ca/files/a_guide_to_social_return_on_investment_revised.pdf. Accessed 25 Aug 2020 Ruff, K. and Olsen, S. (2019) “The Next Frontier in Social Impact Measurement Isn’t Measurement at All” Standford Soc. Innov. Rvw, Online 10 May 2019 https://ssir.org/articles/entry/next_frontier_in_social_impact_measurement# Solorzano-Garcia, M., Navio-Marco, J., and Ruiz-Gomez, L. M. (2019) “Ambiguity in the Attribution of Social Impact: A Study of the Difficulties of Calculating Filter Coefficients in the SROI Method“. Sustainability, vol. 11, no. 2 (2019): 386-405 Totter, L., Vine, J., Leach, M. and Fujiwara, D. (2014) “Measuring the Social Impact of Community Investment: A Guide to using the Wellbeing Valuation Approach” UK: HACT https://www.hact.org.uk/sites/default/files/uploads/Archives/2014/3/MeasuringSocialImpactHACT2014.pdf?sid=9120

24.12 Income produced via application of green policies

Project Name: proGIreg (Grant Agreement no. 776528)

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Income produced by the application of green administrative policies within the LL district	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator aims to quantify the economic benefit obtained by the cities in ProGIreg with the implementation of in Turin and Zagreb.
Definition	NBS will be implemented in Turin and Zagreb with the general aim of including nature-based solutions in different local policies. Some of these could come in the form of compensation schemes, tax cuts for investing in certain environmental initiatives and others. The exact details of the actions to be implemented are not detailed yet. However this indicator aims to quantify the economic benefit of these actions.
Strengths and weaknesses	- There may be large differences in the schemes implemented by each city that may make the computation of the benefit extremely complicated.
Measurement procedure and tool	These data will be collected via the economic and labour questionnaire to be distributed in this case to the local government authorities that implement the policies.
Scale of measurement	At NBS or city level (depending on the city).
Data source	
Required data	Local authorities implementing NBS.
Data input type	
Data collection frequency	Once after implementation.
Level of expertise required	The person in charge of NBS implementation should be able to provide the information.
Synergies with other indicators	Connected to other economic and labour indicators and possibly to environmental indicators (depending on nature of schemes implemented).
Connection with SDGs	Goal 8: Decent work and economic growth Goal 11: Sustainable cities and communities

Opportunities for participatory data collection	None
Additional information	
References	

24.13 Subsidies applied for private NBS measures

Project Name: UNaLab (Grant Agreement no. 730052) and URBAN GreenUP (Grant Agreement no. 730426)

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Subsidies applied for private NBS measures	**New Economic Opportunities and Green Jobs**
Description and justification	This KPI, related to economic aspects measurements, evaluates how NBS interventions can influence private sector. When a positive externality on consumption is present in a market, the government can actually increase the value that the market creates for society by providing a subsidy equal to the benefit of the externality. (Such subsidies are sometimes referred to as Pigouvian subsidies or corrective subsidies.) This subsidy moves the market to the socially optimal outcome because it makes the benefit that the market confers on society explicit to producers and consumers, giving producers and consumers the incentive to factor the benefit of the externality into their decisions. For the purposes of this indicator, “subsidies applied for private NBS measures” are narrowly defined as direct (cash) subsidies or tax concessions (exemptions or credits) awarded to an individual or organisation to implement, or following implementation of, an NBS on privately-owned property.
Definition	Number or total value (in EUR) of direct (cash) subsidies or tax concessions applied to private NBS measures per annum.

Strengths and weaknesses	+ The indicator is easy to define - Medium or long term assessment. - Data are required from multiple different municipal departments. - This KPI may require input from citizens
Measurement procedure and tool	The subsidies applied for private NBS measures can be expressed either the number of subsidies, or as a monetary value (in EUR). Together with the total number or value of subsidies awarded, tracking the availability of subsidies for private NBS measures along with the number of applications for available subsidies can provide a qualitative measure of changing demand for NBS in the private sector. To determine the number of subsides implemented (by zone affected), collect data from the municipality's economic department and other relevant departments. Direct value on subsides (by zone), before and after implementation, during the established period are calculated as: *Number of subsides implemented = n * Z [(nº subsides) (€/m^2)]* Where *n* refers to the subsides total number multiplied by its value by zone Z (directly related to the each NBS)
Scale of measurement	Neighbourhood to city scale
Data source	
Required data	Local and national governments, as well as the individuals or organisations receiving the aforementioned subsidies, serve as sources of information for this metric. This may include City official data, city platforms, questionnaires, and/or small-medium enterprise accounts (related to de NBS investment zone)
Data input type	Qualitative and quantitative ▪ (number of subsidies) (number /year) (€/m^2) ▪ (number of subsidies or number of tax concessions) (number /year) (€/year)
Data collection frequency	Annually, both before and after NBS implementation
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the indicator group New *Economic Opportunities & Green Jobs* indicators

Connection with SDGs	SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure SDG1 / SDG4 / SDG5 / **SDG10** / **SDG11 / SDG12**
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	URBAN GreenUP Deliverable D2.4 - Monitoring program to Valladolid. https://www.urbangreenup.eu/insights/deliverables/d2-4---monitoring-program-to-valladolid.kl URBAN GreenUP Deliverable D3.4 - Monitoring program to Liverpool https://www.urbangreenup.eu/insights/deliverables/d3-4---monitoring-program-to-liverpool.kl URBAN GreenUP Deliverable D4.4 – Monitoring program to Izmir https://www.urbangreenup.eu/insights/deliverables/d4-4--monitoring-program-to-izmir.kl URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl An impact evaluation framework to support planning and evaluation of nature-based solutions rojects; An EKLIPSE Expert Working Group report, 2017 "The Model of the Environmental Sustainability Matrix" (“El Modelo de la matriz de Sostenibilidad Ambiental”); La ordenación Urbana y el Desarrollo Sostenible, Angel Ibañez Ceba, Fermín Cerezo Rubio, August 2009 “A Positive Externality on Consumption” (Science, Tech, Math, Social Sciences); https://www.thoughtco.com/positive-externality-on-consumption-overview-1147392 “Understanding Subsidy Benefits, Costs and Market Effect” (Science, Tech, Math, Social Sciences); https://www.thoughtco.com/analysis-of-a-subsidy-1147899

24.14 Private finance attracted to the NBS site

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Private Finance / investment in NBS / Bioeconomy	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator seeks to capture the level (in monetary terms) of non-public ("private") in nature-based solutions and/or the 'bioeconomy'. The indicator will provide information on the extent to which private investors (or philanthropists) value nature-based solutions or nature-based enterprises that have a positive, or at least a neutral impact on the environment. It will also provide information on the long-term sustainability of nature-based solutions.
Definition	*Private investment and/or finance* is defined as financial resources that are deployed by non-governmental agencies and sourced from monies that were not raised through taxes or other public fees / fines / assessments. Monies raised through the provision of goods/services relating to the NBS should not be included here. Note that this will include monies that are deployed with an expectation of financial return and those that are 'concessionary' – philanthropic grants and 'impact investments' that do not required a financial return. While nature-based solutions are defined elsewhere in this document, the definition of the 'bioeconomy' is less well-covered and is worth repeating here. The European Commission states that the "bioeconomy comprises those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisims – to produce food, materials and energy" (https://youmatter.world/en/definition/bioeconomy-definition/)
Strengths and weaknesses	+ The indicator is a meaningful and comparable at multiple levels of aggregation

	- The causal relationship between the NBS and other bio-economy private finance activities may be difficult to establish - The data will be widely dispersed and maybe difficult to collect
Measurement procedure and tool	Data collection will need to be planned with the NBS project team in order to identify firstly any private finance that has been deployed in the planning, development and/or maintenance of the NBS itself. If this has occurred, then it will be meaningful to report not only the absolute amount of private investment, but also the percentage of the total finance for the project arising from private sources. In addition to the private finance for the NBS itself, the evaluation team will need to consult with the project team - and perhaps more widely - to determine what, if any, other bio-economy related activities may be linked to the NBS and the period over which this influence may be reasonably expected to occur. If no other criteria are deemed relevant, then the evaluation team should set a geographic boundary around the NBS being evaluated and choose a relatively short time period that would begin with the development of the NBS and extend to some agreed period (defined in years) following completion. Any bio-economy related activities occurring within the time/space boundaries agreed would be surveyed to assess: a) the extent to which the stakeholders involved in the activity attribute their actions to the existence of the NBS, and b) the value of private finance attracted by this activity. In both cases (the NBS itself and related bioeconomy activities), the data collected should be categorised by the type and source of private finance received. While there are numerous typologies for classifying finance type, the main one is between 'grant' finance –requiring no financial return – and 'commercial' finance, which requires / expects a financial return. In the case of 'commercial' finance, this is generally sub-divided into loan vs. equity finance. 'Loan' finance is provided in return for a promise by the 'borrower' that the total amount of the loan ('principal') plus an agreed amount of interest will be paid back to the 'lender' over a specified period of time. 'Equity' finance is provided in return for an ownership percentage in the asset(s) being financed. Equity owners are generally entitled to a share of any income generated from the asset(s) and a percentage of the proceeds if the asset is sold.

	In the past, private 'grant' finance was largely provided by philanthropists with no further expectations on those being funded other than the money would be used for the purposes agreed. Recently, however, the emergence of 'venture philanthropists', 'crowd-financing' (which may or may not be commercial) and 'impact investors' has given rise to new expectations around what is required from those in receipt of grant finance. Again, there are many ways to classify the different conditions under which private grant funds might be provided and the evaluation team should be guided by their own context. If no other classification scheme is selected, then it is suggested that private grant funding be classified as either 'formal impact reporting' or 'other'. 'Formal impact reporting' is present when the grant finance comes with a requirement that those in receipt of the funding must provide the granting body with reports on the 'impact' of their activity using a standard set of procedures (e.g., Social Return on Investment) or indicators (e.g., IRIS or SDGs). 'Other' is any grant finance that does not have formal impact reporting requirements associated with the receipt of funding. The source of the finance may be classified in any number of ways that is relevant to the evaluation being undertaken. Again, if the evaluation team has no other preferred way of classifying the source of finance, then the sources might be typed as: 1) Firms; 2) Philanthropic organisations; 3) Individual / Community, or 4) Other.
Scale of measurement	NBS location to regional scale
Data source	
Required data	- Amount (in monetary terms) of investment in NBS-related bio-economy activities over a specified period - type of finance provided - source of finance provided
Data input type	Quantitative
Data collection frequency	Annually
Level of expertise required	Moderate
Synergies with other indicators	Synergies with *Benefit/Cost indicators and Social Return on Investment*
Connection with SDGs	SDG 9 Industry, Innovation & Infrastructure; SDG 13 Climate Action

Opportunities for participatory data collection	
Additional information	
References	

24.15 Increase in tourism

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Mary Lee Rhodes[1], Conor Dowling[1], Adina Dumitru[2], Stuart Connop[3], Catalina Young[4], Irina Macsinga[4]

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[2] *Sustainability Specialization Campus, University of A Coruña, Spain*

[3] *Sustainability Research Institute (SRI), University of East London, Docklands Campus, London E16 2RD, United Kingdom*

[4] *West University of Timisoara, Romania*

Increase in tourism	**New Economic Opportunities and Green Jobs**
Description and justification	Many EU countries rely on tourism as a major contributor to the economy. Area improvements brought about by NBS implementation may provide increased incentives for visitors to the area, thereby increasing the number and amount spent by tourists.
Definition	The increase (or decrease) in number of visitors per day that is seen as fully or partially connected to the NBS at a local or international level.
Strengths and weaknesses	
Measurement procedure and tool	
Scale of measurement	Location up to region
Data source	
Required data	number of visitors to NBS area (generally broken down by local / international)
Data input type	Quantitative

Data collection frequency	Anywhere from daily to annually
Level of expertise required	Moderate
Synergies with other indicators	*Replace with 12.2.9 New activities in the tourism sector and 12.2.10 Gross profit from nature-based tourism.*
Connection with SDGs	SDG 8 Decent Work and Economic Growth; may have negative impact on Goal 12: Responsible Consumption & Production and SDG13: Climate Action
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Ahn, B., Lee, B. and Shafer, C.S., 2002. Operationalizing sustainability in regional tourism planning: an application of the limits of acceptable change framework. Tourism Management, 23(1), pp.1-15. Moscardo, G., 2008. Sustainable tourism innovation: Challenging basic assumptions. Tourism and Hospitality Research, 8(1), pp.4-13

24.16 New activities in the tourism sector

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2,] Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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New Activities in the Tourism Sector	New Economic Opportunities and Green Jobs
Description and justification	Some NBS projects could promote a new touristic development of rural and mountainous area in many different ways: by creating a new qualified natural attraction (a riverside, a green infrastructure, a new sport trial in natural context), increasing accessibility to and/or connecting existing cultural heritage sites or landscape

	viewpoints. This could promote new activities in tourism sector (e.g., B&B, restaurants, café, and touristic guides).
Definition	In the Baseline Scenario this indicator is equal to the number of new activities in the tourism sector in the study area, and gives information about the dynamism of tourism sector in the study area before the project will be implemented. The indicator could be also estimated in the Design Scenario, using a probabilistic scale (e.g., Likert Scale). It also will be assessed in a Long Term Scenario, considering data made available some years after NBS/Grey/Hybrid solutions have been implemented, computing the number of new activities in the tourism sector in the study area.
Strengths and weaknesses	Collecting the data necessary to assess the indicator could be time and money consuming.
Measurement procedure and tool	In the Baseline Scenario, the indicator will be calculated consulting data on new enterprises, counting the number of new activities related to tourism sector in the study area. In the Design Scenario, the indicator will be assessed adopting a five-point Likert item with categories “Very Poor”, "Poor", "Average", "Good", and "Very Good to evaluate the likelihood of occurring the creation of new activities related to tourism sector in the study area. In the Long Term Scenario, the indicator will be calculated consulting data on new enterprises, counting the number of new activities related to tourism sector activities related to tourism sector in the study area.
Scale of measurement	Probabilistic scale; No.
Data source	National Statistical Institute, Chamber of Commerce
Required data	Data on new enterprises by categories of economic activities
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	High
Synergies with other indicators	New Employment in the Tourism Sector
Connection with SDGs	8

Opportunities for participatory data collection	
Additional information	
References	

24.17 Gross profit from nature-based tourism

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2,] Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Gross Profit from Nature-Based Tourism	**New Economic Opportunities and Green Jobs**
Description and justification	Some NBS projects could promote a new touristic development of rural and mountainous area in many different ways: by creating a new qualified natural attraction (a riverside, a green infrastructure, a new sport trial in natural context), increasing accessibility to and/or connecting existing cultural heritage sites or landscape viewpoints. This could increase gross profit from nature-based tourism.
Definition	The gross profit of a company is the total sales of the firm minus the total cost of the goods sold. The total sales are all the goods sold by the company. The total cost of the goods sold is the sum of all the variable costs involved in sales. This indicators express the ratio between the gross profit over a year of all the companies working in the nature-based tourism in the study area and the territorial surface of the study area. In the Baseline Scenario this indicator gives information about the dynamism of Nature-based in the study area before the project will be implemented. The indicator could be also estimated in the Design Scenario, using a probabilistic scale (e.g., Likert Scale).

	It also will be assessed in a Long Term Scenario, considering data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Strengths and weaknesses	Collecting the data necessary to assess the indicator could be time and money consuming.
Measurement procedure and tool	In the Baseline Scenario, the indicator will be calculated consulting data the gross profit over a year of all the companies working in the nature-based tourism in the study area, using the following formula: $$GP = \frac{\sum_{i=1}^{n} GP_i}{A_{sa}} \left[\frac{€}{year}/km^2\right]$$ where: GP_i is the gross profit over a year of the i-th company working in the nature-based tourism in the study area; A_{sa} is the territorial surface of the study area; common GIS software, given the vector data of the study area, allow calculating this surface. In the Design Scenario, the indicator will be assessed adopting a five-point Likert item with categories “Very Poor”, "Poor", "Average", "Good", and "Very Good to evaluate the likelihood of occurring the increasing of gross profit from nature-based tourism. In the Long Term Scenario, the indicator will be calculated, as in the Baseline Scenario, considering the data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Scale of measurement	Probabilistic scale; €/km^2/year
Data source	National Statistical Institute, Chamber of Commerce; Direct survey
Required data	Gross profits of the companies working in the nature-based tourism in the study area
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	8

Opportunities for participatory data collection	
Additional information	
References	

24.18 Number of new jobs in green sector

Project Name: PHUSICOS (Grant Agreement no. 776681) and UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3], Laura Wendling[4], Ville Rinta-Hiiro[4], Maria Dubovik[4], Arto Laikari[4], Johannes Jermakka[4], Zarrin Fatima[4], Malin zu-Castell Rüdenhausen[4], Ana Ascenso[5], Ana Isabel Miranda[5], Peter Roebeling[5], Ricardo Martins[5], Rita Mendonça[5]

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Number of new jobs in green sector	**New Economic Opportunities and Green Jobs**
Description and justification	'Green jobs' in areas directly connected to the environment such as resource conservation, waste management, water and green space management, and air quality can support economic growth and development. Some NBS projects may generate new jobs and new economic opportunities (Raymond et al., 2017; Byrd et al., 2017; European Commission, 2013). Large-scale and/or long-term NBS projects are likely to create new jobs through the development of activities related to enjoyment of the natural environment (e.g., outdoor activity instruction and guiding, bike and other outdoor equipment rental and/or repair, nature education, etc.). The United Nations Environment Programme (UNEP), International Labour Organization (ILO), International Organisation of Employers (IOE), and International Trade Union Confederation (ITUC) (2008, pp. 3) define green jobs as "work in agricultural, manufacturing, research and development (R&D), administrative and service activities

	that contribute substantially to preserving or restoring environmental quality. Specifically, but not exclusively, this includes jobs that help to protect ecosystems and biodiversity; reduce energy, materials, and water consumption through high efficiency strategies; de-carbonize the economy; and minimize or altogether avoid generation of all forms of waste and pollution." The employing company or organisation can either be in a 'green' sector (e.g., green infrastructure design), or in a conventional sector (e.g., engineering services) but be making genuine and substantial efforts to green its operations.
Definition	Total number or per cent increase in the (new) jobs related to environmental service activities that contribute substantially to preserving or restoring environmental quality
Strengths and weaknesses	+ Easy to measure - Requires extensive processing of input data if not already available
Measurement procedure and tool	This Indicator will be equal to 0 in the baseline scenario (i.e., prior to NBS actions) and will be assessed in a Long Term Scenario, using data made available after NBS have been implemented to determine the number of new jobs created in the green sector. The number of jobs, or number of new jobs, in the green sector can be counted or estimated for a given municipality based on business registrations and/or administrative documents as follows. • The total number of new jobs in the green sector is a simple count and is expressed as a number. • The per cent increase in green jobs is calculated as: $\left(\frac{Number\ of\ (new)\ green\ jobs}{Total\ number\ of\ (new)\ jobs}\right) \times 100$ Alternatively, this indicator may be qualitatively estimated in the Design Scenario, using a probabilistic (e.g., Likert) scale prior to NBS implementation, e.g., during the NBS co-creation phase. In the Design Scenario, a five-point Likert scale with categories "Very Poor", "Poor", "Average", "Good", and "Very Good", can be used to assess the potential realisation of new jobs in the green sector within the study area.
Scale of measurement	District to regional scale
Data source	
Required data	Data about the number of green jobs and total number of jobs from business registrations and/or administrative

	documents; National Statistical Institute; Chamber of Commerce.
Data input type	Quantitative
Data collection frequency	Before and after NBS implementation. Recommended annual assessment.
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the indicator group *Economic activity & Green Jobs* indicators
Connection with SDGs	SDG 8 Decent work and economic growth, and SDG 9 Industry, innovation and infrastructure
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Byrd C., Andersson E., Kronenberg J., Hansen R., Buijs A. (2017). Understanding and Promoting the Values of Urban Green Infrastructure: a learning module. GREEN SURGE project Deliverable 4.5, University of Copenhagen, Copenhagen, Denmark European Commission (2013). Rural Development in the European Union - Statistical and economic information – 2013. European Union, 2013. https://ec.europa.eu/agriculture/statistics/rural-development/2013_en Madureira, H., Nunes, F., Oliveira, J. V, Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. Urban Forestry & Urban Greening, 14(1), 56-64. Raymond C.M., Berry P., Breil M., Nita M.R., Kabisch N., de Bel M., Enzi V., Frantzeskak N., Geneletti D., Cardinaletti M., Lovinger L., Basnou C., Monteiro A., Robrecht H., Sgrigna G., Munari L., Calfapietra C. (2017). An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Niewenhuijsen, M.J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. Environmental Health, 13(1), 20. Tyler, P., Warnock, C., Provins, A., & Lanz, B. (2013). Valuing the benefits of urban regeneration. Urban Studies, 50, 169-190.

	United Nations Environment Programme (UNEP), International Labour Organization (ILO), International Organisation of Employers (IOE), & International Trade Union Confederation (ITUC). (2008). Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World. Nairobi, Kenya: United Nations Publishing Services Section. Retrieved from https://www.ilo.org/global/topics/green-jobs/publications/WCMS_158727/lang--en/index.htm

24.19 Jobs created in NBS construction and maintenance

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Jobs Created In NBS Construction and Maintenance	New Economic Opportunities and Green Jobs
Description and justification	Some NBS projects could have a potential to generate new jobs and new economic opportunities (Raymond et al., 2017; Byrd et al., 2017; European Commission, 2013). Literature reports many examples (OPPLA Case Studies). In detail, extended NBS projects are likely to create new jobs in the construction and maintenance of these interventions.
Definition	This Indicator will be equal to 0 in the Baseline Scenario and could be inferred in the Design Scenario by the different executive projects to be evaluated (if they contain an esteem of needs regarding number of workers to be employed). Otherwise it could be measured, through a probabilistic scale and inferred by statistical data in the Long-Term scenario.
Strengths and weaknesses	Collecting the data necessary to assess the indicator could be time and money consuming.
Measurement procedure and tool	In the Design Scenario, the indicator will be assessed consulting executive projects reports and counting the number of workers to be employed. If executive projects reports do not provide this esteem, a five-point Likert item with categories “Very Poor”, "Poor", "Average", "Good", and "Very Good", could be adopted to assess the likelihood of occurring the creation of new jobs

	in the nature-based solution construction and maintenance activities related to tourism sector in the study area. In the Long Term Scenario, the indicator will be calculated consulting: - construction site reports, counting the number of people that have been recruited to build the new infrastructure; - data on new jobs, counting the number of recruitments in activities related to new infrastructure maintenance.
Scale of measurement	Probabilistic scale; No.
Data source	National Statistical Institute, Chamber of Commerce; Municipality, Building companies
Required data	Construction Site Reports; Data on recruitments by categories of economic activities
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	
References	Byrd C., Andersson E., Kronenberg J., Hansen R., Buijs A. (2017). Understanding and Promoting the Values of Urban Green Infrastructure: a learning module. GREEN SURGE project Deliverable 4.5, University of Copenhagen, Copenhagen, Denmark European Commission (2013). Rural Development in the European Union - Statistical and economic information – 2013. European Union, 2013. https://ec.europa.eu/agriculture/statistics/rural-development/2013_en Raymond C.M., Berry P., Breil M., Nita M.R., Kabisch N., de Bel M., Enzi V., Frantzeskak N., Geneletti D., Cardinaletti M., Lovinger L., Basnou C., Monteiro A., Robrecht H., Sgrigna G., Munari L., Calfapietra C. (2017). An Impact Evaluation Framework to Support Planning and Evaluation of Nature-

	based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom

24.20 New employment in the tourism sector

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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New Employment in the Tourism Sector	New Economic Opportunities and Green Jobs
Description and justification	Some NBS projects could promote a new touristic development of rural and mountainous area in many different ways: by creating a new qualified natural attraction (a riverside, a green infrastructure, a new sport trial in natural context), increasing accessibility to and/or connecting existing cultural heritage sites or landscape viewpoints. This could promote new jobs in tourism sector (e.g., B&B, restaurants, café, and touristic guides).
Definition	In the Baseline Scenario this indicator is equal to the number of new employment in the tourism sector, and gives information about the dynamism of tourism sector in the study area before the project will be implemented. The indicator could be also estimated in the Design Scenario, using a probabilistic scale (e.g., Likert Scale). It also will be assessed in a Long Term Scenario, considering data made available some years after NBS/Grey/Hybrid solutions have been implemented, computing the number of new employment in the tourism sector activities related to tourism sector in the study area.
Strengths and weaknesses	Collecting the data necessary to assess the indicator could be time and money consuming.
Measurement procedure and tool	In the Baseline Scenario, the indicator will be calculated consulting data on new jobs, counting the number of recruitments in activities related to tourism sector activities related to tourism sector in the study area.

	In the Design Scenario, the indicator will be assessed adopting a five-point Likert item with categories “Very Poor”, "Poor", "Average", "Good", and "Very Good to evaluate the likelihood of occurring the creation of new jobs in the tourism sector in the study area. In the Long Term Scenario, the indicator will be calculated consulting data on new jobs, counting the number of recruitments in activities related to tourism sector activities related to tourism sector in the study area.
Scale of measurement	Probabilistic scale; No.
Data source	National Statistical Institute, Chamber of Commerce
Required data	Data on recruitments by categories of economic activities
Data input type	Quantitative
Data collection frequency	Annual
Level of expertise required	High
Synergies with other indicators	New Activities in the Tourism Sector
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	
References	

24.21 Turnover in the green sector

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Elizabeth Gil-Roldán[1]

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Turnover in the green sector	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator aims to detect how business activity has evolved in the “green sector” during the time before and after NBS implementations by ProGIreg. Measuring the

	change in economic activity can be done by looking at several economic outputs: turnover, employment creation, gross value added and the relations between them (Tyler et al., 2013). The indicator's name could be changed to production benefit.
Definition	
Strengths and weaknesses	Strengths: these indicators are derived from published data which is commonly available as part of the regional accounts and employment surveys. They're generally available from regional and even local statistics offices. Weaknesses: Update frequency of the data will be different across cities and may be so infrequent that it doesn't allow analysis or trend capture in the lifetime of the project. Spatial resolution (city, regional, district) is likely to vary largely across cities. The sectoral detail needed at NACE level 2 may not be available (district and city level).
Measurement procedure and tool	City/regional statistic offices will be consulted/enquired about the data needed. The input data needed is: Turnover, employment and gross value added in the following sectors: All data will be necessary at the smallest scale possible of the intervention area.
Scale of measurement	As close to the living lab area as possible. Although generally this data will be available at city and at the most district level.
Data source	
Required data	Turnover Gross value added Number of employees In NACE level 2 activities that correspond to Green economy.
Data input type	
Data collection frequency	As a minimum twice (before and after NBS implementations)
Level of expertise required	Low
Synergies with other indicators	This indicator is basic for most economic/labour indicators
Connection with SDGs	Goal 3: Good health and wellbeing Goal 11: Sustainable cities and communities Goal 8: Decent work and economic growth

Opportunities for participatory data collection	N/A
Additional information	
References	Tyler, P., Warnock, C., Provins, A., Lanz, B., 2013. Valuing the benefits of urban regeneration. Urban Stud. 50, 169–190. doi:10.1177/0042098012452321

24.22 Employment in agriculture

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: Guillaume Piton[1], Jean-Marc Tacnet[1], Beatriz Mayor[2], Laura Vay[2], Marisol Manzano[3], Virginia Robles[3], Mar García-Alcaraz[3], Javier Calatrava[4], Raffaele Giordano[5], Miguel Llorente[6], Africa de la Hera[6], Javier Heredida[6], Laura Basco[7], Marta Faneca[7], Tiaravanni Hermawan[7], Elena Lopez-Gunn[2]

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Employment in agriculture	**New Economic Opportunities and Green Jobs**
Description and justification	Provides an indication of the employment maintained/created in agriculture thanks to the NBS
Definition	Employments maintained/created in agriculture per unit of land surface (employments/ha) and per water use (employment/hm^3)
Strengths and weaknesses	
Measurement procedure and tool	Calculation using agro-economic model
Scale of measurement	Aquifer scale (Medina del Campo aquifer)
Data source	

Required data	Data on water abstractions and aquifer recharge, crop area and water needs, economic data on irrigation, labour demand per crop, etc.
Data input type	Number, databases
Data collection frequency	Yearly
Level of expertise required	Technicians
Synergies with other indicators	
Connection with SDGs	SDG 2, 6, 12
Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.3, DEMO Insurance Value Assessment Report. SC5-09-2016

24.23 Rural Productivity Index

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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Rural Productivity Index	**New Economic Opportunities and Green Jobs**
Description and justification	NBS implementation can improve the productivity of rural areas, in term of agricultural products quality and quantity. This Indicator takes into account the variation of productivity of rural areas.
Definition	The Rural Productivity Index describes the profits achievable from agricultural soils in the area. This Indicator could be calculated both in the Baseline Scenario taking into account the soils already cultivated, and in the Design Scenarios (e.g., NBS Scenario, Hybrid Scenario, Grey Scenario) considering the soils cultivated after project

	implementation. The indicator could also be assessed in a Long-term scenario considering data made available some years after NBS/Grey/Hybrid solutions have been implemented.
Strengths and weaknesses	It could be difficult to find site-specific data concerning the mean profit per hectare of the cultivations in the study area
Measurement procedure and tool	The Rural Productivity Index (RPI) can be calculated using the following formula $$RPI = \frac{\sum_{i=1}^{n}(k_i \cdot A_i)}{\sum_{i=1}^{n} A_i}$$ where: k_i is the mean profit per hectare of the cultivation taking place in the i-th agricultural soils in the study area [€/ha]; A_i is the area of the i-th agricultural soils in the study area.
Scale of measurement	€/ha
Data source	Project team; Farmers' Associations
Required data	Project layout map (vector data), Farmers' Associations Report
Data input type	Maps; Vectorial data; Reports
Data collection frequency	Annual
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	
References	

24.24 Economic value of productive activities vulnerable to risks

Project Name: PHUSICOS (Grant Agreement no. 776681)

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Economic Value of the Productive Activities Vulnerable to Risks	**New Economic Opportunities and Green Jobs**
Description and justification	Indicators of Potential Population Economic Effects Due to Risks sub-criterion will assess the potential economic losses due to risks.
Definition	Vulnerability of productive activities, such as the economic value of agricultural fields, workers number, etc. For instance, agricultural productivity along rivers is more vulnerable to floods than industrial productivity.
Strengths and weaknesses	
Measurement procedure and tool	Estimation from statistical data.
Scale of measurement	€/km^2
Data source	
Required data	Model/Statistical Data
Data input type	Quantitative
Data collection frequency	
Level of expertise required	High
Synergies with other indicators	
Connection with SDGs	8
Opportunities for participatory data collection	
Additional information	

References	

24.25 Innovation impact

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Innovation Impact	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator provides information about the impact that the NBS has had on innovation by firms / organisations involved in developing and/or maintaining the NBS. The expectation is that the challenges and opportunities presented by climate change and urban development – along with the disparate perspectives and knowledge brought by stakeholders to the NBS project - will result in innovations that can generate economic value as well as be deployed elsewhere.
Definition	'Innovation' is generally defined as "the generation, acceptance and implementation of new ideas, processes, products or services (Thompson 1965:2)". There is no indicator that could capture every type or aspect of innovation that might possibly arise out of an NBS project, but the economic focus of this indicator suggests that *new products and services* are the appropriate aspects of innovation in this case. Furthermore, we draw on literature that suggests specific types of inputs / processes that would be expected to result in new innovations, which may be measured as a proxy / leading indicators for the emergence of innovations at a later stage. This is consistent with the understanding that innovation is not just about discrete items, but also that it may be embedded in processes and that certain processes are core to innovation. Across the literature, all definitions of innovation – no matter their disciplinary source – will include the word 'new'. Therefore it is important to provide the definition of 'new' so that evaluators can clearly explain how they have designated something as an innovation. The OECD defines *new* products as those that "differ

	significantly in their characteristics or intended uses from products previously produced ...” (OECD 2005). Furthermore, patent offices generally require that inventors demonstrate that their inventions are: ‘novel’ (not published / made available previously); ‘inventive’ (non-obvious solutions to a problem); and useful/practical (has identifiable benefits and is possible to produce). In assessing whether something is an innovation or not, evaluators should keep these criteria in mind. It may also be helpful to consider the extent to which the problem being addressed by the innovation is well-understood. Satell (2017) suggests that there are 4 types of innovation – varying along two dimensions: 1) how well the problem is defined, and 2) how well the skills necessary to solve the problem are understood. Well-defined problems requiring well-defined skills will result in ‘Sustaining Innovation” – or innovation that creates incremental improvements to existing areas of activity. “Basic Research” is innovation that addresses undefined problems and requires unknown types/levels of skills. In between these two extremes (of defined problem/skills domains) are: “Breakthrough innovations” which address well-defined problems but require unusual / unexpected knowledge & skills and “Disruptive Innovations” which occur when things we know how to do are combined in unexpected ways and result in solutions to problems we didn’t know we had. Considering the type of innovation being counted will aid the assessment process and provide better evidence for why (or why not) an innovation was counted. Satell’s article highlights the fact that new ways of combining and fostering skills and knowledge are critical components of innovation processes and outcomes. Assessing the extent to which skills / knowledge are being combined / developed in new ways will provide a leading indicator of the likelihood of current/future innovation. Recent research confirms that 'knowledge distance’ is an important element of creativity which can lead to innovation (Taques et al 2020; Acar and van den Ende 2016). Looking more broadly at innovation indicators, Dziallas and Blind (2019) examined 226 articles relating to innovation indicators between 1980-2015 and found 82 different indicators for measuring innovation. They also found that there were more indicators looking at the ‘process’ of innovation than at the ‘products’ of innovation, and concluded that: “Despite the high number of well-known indicators and factors, concrete indicators to evaluate innovations are difficult to identify (p. 16)”. Hence, the measurement procedures recommended here should be reviewed regularly against emerging literature and best practice.
Strengths and weaknesses	+ The indicator is strongly aligned with public policy to encourage and deliver innovation

	+ The indicator provides leading information about the potential for future economic gain + The indicator is a meaningful and may be aggregated (depending upon measurement used) - Depending upon the measurement used, it may require significant resources to collect and analyse - Depending upon the measurement used, there may be challenges in comparing measures across projects.
Measurement procedure and tool	The assessment team will first need to confer with NBS project management to determine which of the recommended measures to use. It may be that multiple indicators are selected – which would be consistent with recommended practice in industry, but extremely time consuming. The five measurement options are: - No. of patents; - No. of new products / services; - Annual revenue arising for sales of new products / services; - No. of hours spent by relevant individuals in research, ideation and/or innovation training; - Range of knowledge / perspectives involved in design, development or ongoing governance of NBS. Choosing between these will generally be driven by relevance for the NBS and NBS-related activities; resources and data availability; and interest from relevant stakeholders. Data on patents filed is publicly available in most jurisdictions and so may be the least expense / time-consuming to collect. The challenge will be to attribute patents to the NBS project and this will require determining the firms/organisations that have worked with the NBS and the period over which any patents filed could reasonably have been influenced by their involvement with the NBS. Data on new products and services will need to be collected through interviewing the relevant firms/organisations just after the implementation of the NBS and throughout the operations (maintenance) period to ask for the number (No.) of new products and services and the Annual Revenue (in relevant currency) from sales of these. The evaluation team should use the guidance provided in the definition above – and any other sources at their disposal – to provide the definition of new products and services to firms / organisations in order to ensure comparability across respondents. Data on hours spent on research, ideation or innovation training should be collected from firms/organisations involved in the NBS during the planning and development phases on an as-agreed basis and would generally be reported upon the completion of the

	development phase and (if-desired) on an annual basis throughout the maintenance phase. Reporting the range of knowledge / perspectives brought together by the project will be more of a qualitative assessment by the project team and may be difficult to compare across projects. Nevertheless, it could be of significant interest to assess the relationship between this measure and a number of other measures across the spectrum of NBS indicators. It is likely that – should this indicator be chosen – the evaluation team will need to discuss how best to assess this. The decision to use this indicator will need to be done as close as possible to the beginning of the project as it would be very difficult to credibly assess this on a post-project basis. For those wishing to explore more quantitative ways of measuring knowledge distance, Acar & van den Ende (2020) used a survey instrument developed by Jeppesen & Lakhani (2010) to measure knowledge distance in relation to a given problem – which in this case could be the NBS itself. Respondents rated the extent to which the problem they are addressing was within their field of expertise on a scale from 1 to 7 (1 = inside my field of expertise , 4 = at the boundary of my field of expertise , 7 = outside my field of expertise). While the resulting measure is a number, it cannot be said that it is an 'objective' measure. Another way of quantifying the range of perspectives involved would be to determine the number of individuals involved in the design, development and/or governance of the NBS from different stakeholder groups. Sectors could be defined in any number of ways including the 5 groups in the Quintuple Helix: Academic; Industry; Government; Media; Nature (Carayannis et al 2012); 3 sectors of civil society: State; Market; Civil Society (including non-profit organisations and households); or other typologies of stakeholders as appropriate.
Scale of measurement	Site/Project and may be aggregated across projects and over time.
Data source	
Required data	No. of patents produced by NBS-related firms/organisations (output – quantitative) No. of new products / services created by NBS-related firms/organisations (output - quantitative) Annual revenue from new products / services created by NBS-related firms/organisations (output - quantitative) No. of hours spent by NBS-related firms/organisations' employees / project members on research/ideation and/or innovation training (process – quantitative)

	Range of knowledges / perspectives involved in design, development or ongoing governance of NBS (process – qualitative)
Data input type	Quantitative (4); Qualitative (1)
Data collection frequency	Post implementation and then periodically (suggest every 2-3 years) during the maintenance phase
Level of expertise required	High
Synergies with other indicators	Synergies with *GDP, Jobs, Income per capita and Skills & related earnings increase* indicators. Note that innovation process indicators (Hours spent on research, etc., and Range of knowledge/perspectives involved) may have synergies with indicators in other NBS Indicator groups.
Connection with SDGs	SDG 8 Decent Work and Economic Growth; SDG 9 Industry, Innovation and Infrastructure
Opportunities for participatory data collection	
Additional information	
References	Acar, O.A. and van den Ende, J. (2016) "Knowledge Distance, Cognitive-Search Processes, and Creativity: The Making of Winning Solutions in Science Contests", Psychological Science, vol. 27(5), pp. 692-699. https://doi.org/10.1177/0956797616634665 Carayannis, E. G., Barth, T. D., & Campbell, D. F. (2012). The Quintuple Helix innovation model: global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, *1*(1), 1-12. Dziallas, M. and Blind, K. (2019) "Innovation indicators throughout the innovation process: An extensive literature analysis", *Technovation*, vol. 80-81, pp. 3-29 Jeppesen, L. B., & Lakhani, K. (2010) "Marginality and problem-solving effectiveness in broadcast search", *Organization Science,* vol. 21, pp. 1016–1033. OECD (2005) "The Measurement of Scientific and Technological Activities: Guidelines for Collecting and Interpreting Innovation Data: Oslo Manual, Third Edition" prepared by the Working Party of National Experts on Scientific and Technology Indicators, OECD, Paris, para. 158 Satell G. (2017) "The 4 Types of Innovation and the Problems They Solve" *Harvard Business Review Digital Articles,* June 2017:1-6.

	Taques, F. H., et al. (2020) "Indicators used to measure service innovation and manufacturing innovation", *Journal of Innovation & Knowledge*. https://doi.org/10.1016/j.jik.2019.12.001 Thompson, V.A. (1965), "Bureaucracy and innovation", *Administrative Science Quarterly*, vol. 10, pp. 1-20.

24.26 Income / Disposable income per capita

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Income / Disposable Income per Capita	New Economic Opportunities and Green Jobs
Description and justification	This indicator provides information about the change in individual's incomes living in proximity to the NBS. Although not a providing a complete picture – this information will provide input into assessments of the extent to which people are being pulled out of poverty and income inequality is being addressed in the vicinity of the NBS.
Definition	'Income' is defined as the total monetary payments received for labour, use of an individual's capital/land and any financial transfers (state or otherwise) over a specified period (usually one year). This measurement may also be called 'Gross Income'. 'Disposable income' is the amount of income remaining minus taxes and social security payments. Note that 'Discretionary Income' is a third measure that is often found in public reports on income levels and this is calculated as Disposable Income minus 'Necessary Expenses'. Necessary expenses may be defined differently in different jurisdictions and so this is not included in the indicator as measurements would not be comparable. Finally, Income/Disposable Income per Capita is the average of total incomes across the relevant population.
Strengths and weaknesses	+ The indicator is widely reported and generally understood

	+ The indicator is a meaningful and comparable at multiple levels of aggregation - The causal relationship between the NBS and per capita incomes may be difficult to establish - The geographic scale at which the data is available may not be adequate for reporting NBS impact
Measurement procedure and tool	Income/Disposable Income per Capita are regularly calculated and reported by national statistics offices based on income reported to Revenue Offices. The specific components of Income / Disposable Income are **Income** = I_e (Income from Employment) + I_l (Income from Land) + I_c (Income from Capital invested) + Is (Income from state or other transfers). **Disposable Income** = I (Income) – T (taxes, including social security payments) **Income per Capita** is calculated by dividing total income for all persons living in the area by the total number of persons. Note that *Disposable Income per Household* may also be reported, which is total income for all persons divided by total number of households. Determining Incomes per Capita for a given area in proximity to an NBS will involve establishing the appropriate 'buffer zone' around the NBS and determining the relevant source for Income & Population data at that scale. Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report GDP is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator *Distribution of public green space*, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011). Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator *Accessibility of urban green spaces*, i.e., land or businesses within a 300-500 m distance from NBS (Tamosiunas et al., 2014). From a data availability standpoint, however, it is likely to be more convenient to define the impact area in relation to existing administrative boundaries for which Income data is already reported. Note that administrative areas are often established

	based on population numbers (e.g., electoral districts, community healthcare zones, etc.). This means that the economic data is available for pre-defined geographic areas that may – or may not – align with the expected impact 'buffer zone' or be comparable to other impact indicators' geographic span of impact. Therefore, it may be necessary to assess the proportion of a given administrative area's population / economy that is affected by the NBS in order to use existing data to represent overall impact. In Connecting Nature, we are trialling an approach that will establish thresholds of geographic coverage to determine what proportion of a given administrative area's measurements to include / what weight to assign. Our initial approach will be to set a maximum threshold of geographic coverage above which the entire administrative area's measurements will be included and a minimum threshold below which the area will not be included in the indicator measurement at all. In between these thresholds, it will be up to the relevant measurement body and NBS promoter to assess the relevant proportion of the population in the administrative area to include in the overall measurement. The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.
Scale of measurement	Regional - National
Data source	
Required data	Total Income / Disposable Income and Population in a given area
Data input type	Quantitative
Data collection frequency	Annually (actual data) and quarterly (estimated)
Level of expertise required	Moderate
Synergies with other indicators	Synergies with *GDP, Jobs and Skills & related earnings increase* indicators.
Connection with SDGs	SDG 1 No Poverty; SDG 8 Decent Work and Economic Growth; SDG 10 Reduced Inequality
Opportunities for	No opportunities identified

participatory data collection	
Additional information	
References	Eurostat (2010) European System of National and Regional Accounts (2010), EU – may be accessed at https://ec.europa.eu/eurostat/documents/3859598/5925693/KS-02-13-269-EN.PDF/44cd9d01-bc64-40e5-bd40-d17df0c69334 Klasen, S., 2008. Economic growth and poverty reduction: Measurement issues using income and non-income indicators. World development, 36(3), pp.420-445 Milanovic, B., 2006. Global income inequality: What it is and why it matters. The World Bank.

24.26.1 Monthly disposable income

Project Name: proGIreg (Grant Agreement no. 776528)

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Monthly disposable income	**New Economic Opportunities and Green Jobs**
Description and justification	We would like to know whether the monthly disposable income of the in the area of intervention where the NBS are being implemented is changing and which manner. Essentially we'd like to know whether people in the neighbourhood are better off financially as the years go by. We will be getting this information from the General Questionnaire where we ask 2 questions that will help to calculate this indicator. Questions 44 asks how many people in the household make an income. Question 45 asks the respondent what is the net income per month of all members of the household together. Net income is explained to the interviewers in the guidelines as their income after labour taxes have been discounted. This amount would general coincide with the paycheck that gets transferred/deposited monthly in the participant's account. If the participant is self-employed, the interviewer is suggested to ask them to calculate their approximate average monthly earnings after taxes. The per capita amount will be obtained by dividing the answer given to answer 45 by the number of members of the household (Q8 of the GQ)
Definition	We will assume the definition offered by Eurostat for monthly disposable income.

	Household disposable income is the total amount of money households have available for spending and saving after subtracting income taxes and pension contributions.
Strengths and weaknesses	Weaknesses: Since we decided the easiest for respondents would be to fit their income in set categories in the GQ (instead of giving us a global amount), it's possible that a small improvement in disposable income will not be captured by the questionnaire.
Measurement procedure and tool	Monthly disposable income / capita: = Net disposable income (Q45) / number of members of family (Q8) We will also compute as an accessory indicator the following: Monthly disposable income / member of family that makes an income: = Net disposable income (Q45) / per capita making income (Q44)
Scale of measurement	Same as GQ. NBS implementation district (300 respondents) and control district (300 respondents)
Data source	
Required data	Answers to GQ.
Data input type	
Data collection frequency	Twice in life of project: before implementation (pre-GQ) and after implementation (post GQ)
Level of expertise required	That of the interviewers conducting the GQ. Computation of final indicator is simple
Synergies with other indicators	Connected to other economic and labour indicators.
Connection with SDGs	Goal 8: Decent work and economic growth
Opportunities for participatory data collection	Not envisioned.
Additional information	
References	

24.27 Upskilling and related earnings increase

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

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Upskilling & related earnings increase	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator provides information about the change in an individual's skills and related earnings potential arising from activities directly related to the NBS. It is envisioned that this would arise from opportunities for people to receive training in new ('green job'?) skills via participation in activities organized directly by the NBS promoter or by organisations that are providing training at the behest of the NBS promoter.
Definition	This indicator is divided into two parts: one is a measure of training provided and/or skills acquired by individuals and the second is a measure of the increased earnings arising from the training/skills. Note that the earnings increase may be reported on either/both an actual or potential basis.
Strengths and weaknesses	+ The indicator provides a direct measure of the increased economic opportunities available to individuals arising from NBS activity + The indicator is a meaningful and comparable at multiple levels of aggregation - Data collection is a bespoke process (not generally collected) and may be costly to produce measurements on an ongoing basis
Measurement procedure and tool	This is essentially a 'before-after' indicator that captures the impact of training and/or 'on-the-job' skills development opportunities afforded to individuals by the NBS. If the change in skills is being directly measured, then a baseline measurement of the relevant skills level(s) should be collected from all individuals participating in the training activities. Note that only training activities directly provided via the NBS promoter – or by third-parties at the behest of the NBS promoter – should be included. A base line earnings level (current salary / earnings from work) should also be gathered from individuals participating in the training. There are numerous ways of measuring skills levels – more even that the range of different skills that are possible to define given that there are many composite measures of skills. In public reporting,

	measurements of qualifications achieved (level of education) are often used as a proxy measurement for skills in the population (See Eurostat 2016). There has also been a significant body of work on defining and measuring "21st Century Skills" or 'competencies' – which has been particularly active in the United States and Asia (Soland et al 2013). This has generally been applied at primary and secondary school levels. The measurement tool can only be determined by the NBS promoter based on the type of training being provided. References for the above tools / approaches are found at the end of this fact sheet. If the administration of a skills assessment is not deemed necessary or feasible, then a proxy for this component of the indicator may be the number of training / 'on-the-job learning' hours provided (usually within a calendar year) to individuals by NBS-related entities. This is generally more easily captured than before/after skills measurements, but is not as meaningful as it represents inputs to skills-development which may – or may not – result in the target skills development. As mentioned above, current or most recent salary levels should be collected from individuals prior to their training / work opportunity and again following completion of the training programme. This is best done twice: once relatively soon after the training (within 6 months of completion) and again after a few years have passed to assess the long-term impact on earnings. This approach to data collection will provide 'actual' change in earnings information, but may be difficult to capture from individuals. If actual data are not available, then estimated earnings impact may be calculated by using salary /earnings averages for the jobs for which individuals with the target skills are qualified and using this as a proxy for the earnings potential of these individuals. The (actual / potential) change in earnings is then calculated by subtracting the baseline earnings / salary from the post-training actual or potential earnings / salary. If this is measured at two different periods then then the length of time between post training earnings measurements should be reported.
Scale of measurement	Site / individual specific – may be aggregated by programme over time.
Data source	
Required data	- Training hours provided by NBS-related organisations - Skills assessments of individuals before / after participation in NBS training / work - Self-reported actual earnings by individuals before / after participation in NBS training / work - Average earnings for specific jobs in the relevant area
Data input type	Quantitative

Data collection frequency	Ideally, at least 3 times: 1) prior to the NBS training (skills and earnings); 2) immediately (within 6 months of completion) following the training (skills and earnings); 3) several (3-5) years following completion of training (earnings only)
Level of expertise required	High – significant expertise is needed for the design / administration of the skills assessment (e.g., survey method, question selection). Once the initial data is collected, though, it is relatively straight-forward to repeat the data collection processes and analyse the data.
Synergies with other indicators	Synergies with *GDP, Jobs and Income/Disposable Income per capita* indicators.
Connection with SDGs	SDG 1 No Poverty; SDG 8 Decent Work and Economic Growth; SDG 10 Reduced Inequality
Opportunities for participatory data collection	Unknown
Additional information	
References	Elliott, D.S., Levin, S.L. and Meisel, J.B., 1988. Measuring the economic impact of institutions of higher education. Research in Higher Education, 28(1), pp.17-33 Eurostat (2016) Statistical Approaches to the Measurement of Skills – may be accessed at https://ec.europa.eu/eurostat/documents/3888793/7753369/KS-TC-16-023-EN-N.pdf/438b69b5-2fcb-4923-b9e2-fa7b59906438 Martinaitis, Ž., 2014. Measuring skills in Europe. European Journal of Training and Development, 38(3), pp.198-210 Soland, J., Hamilton, L.S., Stecher, B.M. (2013) "Measuring 21st Century Competencies: Guidance for Educators" Rand Corporation, accessed 1 July 2020 at http://asiasociety.org/files/gcen-measuring21cskills.pdf

24.28 Population mobility

Project Name: proGIreg (Grant Agreement no. 776528)
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Population mobility	**Place Regeneration** **New Economic Opportunities and Green Jobs**
Description and justification	One of the aims of T4.4 is to look at how gentrification can be happening in the cities where the NBS will be implemented through proxy indicators. The quantification of gentrification is a very lively subject of scientific research at the moment and is out of the scope of the proGIreg project. However, it will be possible to extract several lines of intuition on what's happening with the population in the NBS implementation areas in terms of mobility between rented/owned property, frequency of moving and the reason for moving.
Definition	For the purpose of this project we will consider population mobility to be: The % of people whose last move was in the past 1 year, 2 years and 5 years.
Strengths and weaknesses	
Measurement procedure and tool	In the GQ we ask respondents to tell us when was the last time that they moved (Q51) and the reason for moving (Q52). To 51 they will answer with the year.
Scale of measurement	Same as GQ. NBS implementation district (300 respondents) and control district (300 respondents)
Data source	
Required data	Answers to GQ
Data input type	Respondent answer year of last move
Data collection frequency	Twice in life of project: before implementation (pre-GQ) and after implementation (post GQ)
Level of expertise required	That of the interviewers conducting the GQ. Computation of final indicator is simple and will be done by T4.4 leaders.
Synergies with other indicators	Connected to other economic and labour indicators
Connection with SDGs	Goal 8: Decent work and economic growth

Opportunities for participatory data collection	None
Additional information	
References	

24.29 Avoided cost of run-off treatment

Project Name: URBAN GreenUP (Grant Agreement no. 730426)

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Recommended citation: The Mersey Forest, Natural Economy Northwest, CABE, Natural England, Yorkshire Forward, The Northern Way, Design for London, Defra, Tees Valley Unlimited, Pleasington Consulting Ltd, and Genecon LLP (2010). GI-Val: the green infrastructure valuation toolkit. Version 1.6 (updated in 2018). https://bit.ly/givaluationtoolkit

Estimated value of energy and CO_2 emissions savings from reduction in the volume of water entering combined sewers	**Climate Resilience** **New Economic Opportunities and Green Jobs**
Description and justification	GI-Val is The Mersey Forest's green infrastructure valuation toolkit. The current prototype is free and open source, and can be downloaded under a Creative Commons License from: https://www.merseyforest.org.uk/services/gi-val/. It takes the form of a spreadsheet calculator and a user manual. Drainage of stormwater run-off into combined municipal sewers results in a proportionate level of energy use and CO_2 emissions associated with stormwater transport and treatment. GI-Val Tool 2.1 estimates the energy savings (in kW hr/y) associated with the impact of vegetation on reducing the amount of stormwater entering combined sewers, along with the equivalent carbon emissions savings (in tonnes CO_2e/year). The tool further estimates the economic values of carbon and energy savings. An independent assessment of GI Val by the Ecosystems Knowledge Network is available from this link, along with links to other tools: https://ecosystemsknowledge.net/green-infrastructure-valuation-toolkit-gi-val

Definition	The estimated decrease in energy use and associated CO_2e emissions due to implementation of NBS (increase in land surface vegetation).
Strengths and weaknesses	- Tool developed using English data. - The toolkit remains a prototype and this means there are some green infrastructure benefits for which it cannot calculate a direct financial value. While there is a rich body of evidence that illustrates and demonstrates the different types of benefits deriving from quality green infrastructure, robust valuation techniques do not yet exist for all benefits. Therefore some valuations come with detailed caveats as they are based on limited evidence at this stage. - The toolkit's calculation is designed to be useful for initial, indicative project appraisal, providing a range of figures indicating the potential impact of a green infrastructure intervention or the value of an existing green infrastructure asset. The toolkit does not assess the quality of the design or detailed management requirements of green infrastructure. It does not replace a full cost benefit analysis, but it provides a basic valuation at a much lower cost. - Valuations such those made with a toolkit or cost benefit analysis also need to be seen as part of a much bigger picture. The valuation should not replace community engagement and local dialogue about what is valued about a place. Calculating economic value of green assets will always be a controversial technique and financial value should only be seen as one factor in decision-making. - The reported GVA values include transfers from one organisation to another, which means that although GVA increases for the beneficiaries, it may not increase for the study area as a whole.
Measurement procedure and tool	The toolkit provides a set of calculator tools to help assess an existing green asset or proposed green investment. Tool 2.1 uses Forestry Commission data about water use by trees and other types of land cover to estimate the reduction in runoff to sewers. Input data for estimation of energy and carbon emissions savings as a result of decreased stormwater inflow to combined sewers include: • Land use, including surface cover characteristics • Average local rainfall • Water treatment costs (energy and other inputs) The toolkit uses standard valuation techniques to assess the potential benefits provided by green infrastructure within a defined project area. These benefits are assessed in terms of the functions that the green infrastructure may perform, support or encourage, depending upon the type of project.

	Once data is entered into the toolkit, it generates financial values for many of the green infrastructure benefits, included the improvement in air quality. The toolkit identifies the marginal benefit, the additional value of the green infrastructure, and also tries to ensure that there is no 'double counting' of value.
Scale of measurement	Street to district scale
Data source	
Required data	Land use and land surface cover characteristics for the area under esxamination; local rainfall data (yearly mean rainfall); water treatment unit costs, including energy use.
Data input type	Numeric data.
Data collection frequency	Individual assessments
Level of expertise required	Technical / Expert
Synergies with other indicators	
Connection with SDGs	SDG3 / SDG11
Opportunities for participatory data collection	Developing the toolkit's next iteration will require wide and sustained collaboration. To facilitate this process, interested parties are invited to pass the toolkit to others who might be able to incorporate it into their work and to provide feedback on their experience in using the toolkit, good and bad! Sources of improved evidence Suggestions for improving the tools Ideas for new tools The consortium who led the development of this toolkit has handed over the responsibilities for co-ordinating future work to the Green Infrastructure Value Network (GIVaN). Further information on the network can be found at: www.bit.ly/givaluationtoolkit
Additional information	
References	URBAN GreenUP Deliverable D5.3: City Diagnosis and Monitoring Procedures https://www.urbangreenup.eu/insights/deliverables/d5-3-city-diagnosis-and-monitoring-procedures.kl http://www.merseyforest.org.uk/services/gi-val/ Nowak, McPherson and Rowntree, Chicago's urban forest ecosystem: results of the Chicago urban forest climate project, USDA,1994 Air Pollution in the UK 2015. https://uk-air.defra.gov.uk/library/annualreport/index

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24.30 Correction Cost of Groundwater Quality

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: Guillaume Piton[1], Jean-Marc Tacnet[1], Beatriz Mayor[2], Laura Vay[2], Marisol Manzano[3], Virginia Robles[3], Mar García-Alcaraz[3], Javier Calatrava[4], Raffaele Giordano[5], Miguel Llorente[6], Africa de la Hera[6], Javier Heredida[6], Laura Basco[7], Marta Faneca[7], Tiaravanni Hermawan[7], Elena Lopez-Gunn[2]

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Correction Cost of Groundwater Quality	New Economic Opportunities and Green Jobs
Description and justification	Provides an indication of the cost incurred to treat groundwater to meet the drinking water quality standards
Definition	Cost of the required treatment to upgrade groundwater quality to meet the drinking water quality standards (EUR/m^3)
Strengths and weaknesses	
Measurement procedure and tool	Literature review and extrapolation
Scale of measurement	Groundwater body/aquifer scale, but measure only in domestic supply wells needing quality

	treatment
Data source	
Required data	Literature and results of the biophysical water quality indicators. Time data from the SINAC database (National Information System about Drinking Water). Water volume supplied and cost of water treatment
Data input type	Numerical value for each catchment
Data collection frequency	Annual
Level of expertise required	
Synergies with other indicators	With ASRENi and with ASREAs quality indicators
Connection with SDGs	With SDGs 2, 6, and 12
Opportunities for participatory data collection	Not applicable
Additional information	
References	NAIAD, Deliverable D6.3, DEMO Insurance Value Assessment Report. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

24.31 Dissuasive cost of water abstraction

Project Name: NAIAD (Grant Agreement no. 730497)

Author/s and affiliations: Guillaume Piton[1], Jean-Marc Tacnet[1], Beatriz Mayor[2], Laura Vay[2], Marisol Manzano[3], Virginia Robles[3], Mar García-Alcaraz[3], Javier Calatrava[4], Raffaele Giordano[5], Miguel Llorente[6], Africa de la Hera[6], Javier Heredida[6], Laura Basco[7], Marta Faneca[7], Tiaravanni Hermawan[7], Elena Lopez-Gunn[2]

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Dissuasive cost of water abstraction	**New Economic Opportunities and Green Jobs**
Description and justification	Provides an indication of the water cost that would avoid the externalities by dissuading from non-renewable extractions from the aquifer for irrigation, with positive impacts on groundwater recovery
Definition	Cost that avoids externalities because it will prevent non-renewable water use (EUR/m^3)
Strengths and weaknesses	
Measurement procedure and tool	Calculation using agro-economic model
Scale of measurement	Aquifer scale
Data source	
Required data	Data on water abstractions and aquifer recharge, crop area and water needs, economic data on irrigation, etc.
Data input type	Numerical, data bases
Data collection frequency	Yearly
Level of expertise required	Technicians
Synergies with other indicators	

Connection with SDGs	SDG 2, 6, 12
Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.3, DEMO Insurance Value Assessment Report. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497

24.32 Average water productivity

Project Name: NAIAD – Nature insurance value: Assessment and demonstration (Grant Agreement no. 730497)

Author/s and affiliations: Guillaume Piton[1], Jean-Marc Tacnet[1], Beatriz Mayor[2], Laura Vay[2], Marisol Manzano[3], Virginia Robles[3], Mar García-Alcaraz[3], Javier Calatrava[4], Raffaele Giordano[5], Miguel Llorente[6], Africa de la Hera[6], Javier Heredida[6], Laura Basco[7], Marta Faneca[7], Tiaravanni Hermawan[7], Elena Lopez-Gunn[2]

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Average water productivity	**New Economic Opportunities and Green Jobs**
Description and justification	Provides an indication of the economic return provided by each m^3 used in a certain sector or activity. Proxy indicator of water resources economic use efficiency
Definition	Water productivity indicates how much economic output is produced per cubic meter of fresh water abstracted (in EUR per m^3)
Strengths and weaknesses	
Measurement procedure and tool	Extrapolation from secondary data sources (literature review and official data)
Scale of measurement	Aquifer scale (Medina del Campo aquifer)

Data source	
Required data	Hydrological data on water abstractions and statistics on economic activities.
Data input type	
Data collection frequency	Yearly (if available)
Level of expertise required	Technicians
Synergies with other indicators	*Irrigation water use efficiency*
Connection with SDGs	SDG 6
Opportunities for participatory data collection	
Additional information	
References	NAIAD, Deliverable D6.3, DEMO Insurance Value Assessment Report. SC5-09-2016 Operationalising insurance value of ecosystems. Grant Agreement nº 730497 Eurostat, 2019

24.33 New areas made available for traditional productive uses

Project Name: PHUSICOS (Grant Agreement no. 776681)

Author/s and affiliations: Gerardo Caroppi[1,2], Carlo Gerundo[2], Francesco Pugliese[2], Maurizio Giugni[2], Marialuce Stanganelli[2], Farrokh Nadim[3], Amy Oen[3]

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[3] *Norwegian Geotechnical Institute (NGI), Oslo, Norway*

New Areas Made Available For Traditional Activities (Agriculture, Livestock, Fishing…)	New Economic Opportunities and Green Jobs
Description and justification	This indicator allows to estimate if a project, reducing hazard condition, could make available, for traditional productive uses, such as agriculture, fishing, pastures, etc., areas that were previously at risk.
Definition	This Indicator will be equal to 0 in the Baseline Scenario and will be assessed in the Design Scenarios (e.g., NBS Scenario,

	Hybrid Scenario, Grey Scenario) computing the size of spaces, in terms of square kilometres, that were previously not accessible and now are free from any hazard and dedicated to traditional economic activities (e.g., agriculture, fishing, pastures, etc.).
Strengths and weaknesses	It is easy to be estimated and rapidly provides information concerning the benefits achievable in terms of local economy reinforcement.
Measurement procedure and tool	The indicator is equal to the size of the parts of the study area that were previously not used for economic purposes due to they were hazardous and that are made exploitable to local entrepreneurs by the project since they are free from any hazard. Given the vector data of the project and of hazard map, common GIS software tools allow calculating these areas.
Scale of measurement	km^2
Data source	
Required data	Project layout map (vector data); Hazard map
Data input type	Maps; Vectorial data
Data collection frequency	
Level of expertise required	Medium
Synergies with other indicators	
Connection with SDGs	2, 8
Opportunities for participatory data collection	
Additional information	
References	

24.34 Value of food produced

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Elizabeth Gil-Roldán[1]

[1] *Starlab Barcelona SL, Barcelona, Spain*

Value of food produced	**New Economic Opportunities and Green Jobs**
Description and justification	This indicator will evaluate the benefit obtained from the production of food in some of the NBS. The food produced in some cases may be sold but other methods of distribution may also be possible (self-consumption, donation, etc.).
Definition	In the cases of the selling of food, the value will of course be the revenue obtained. However in the case of food that is not sold, the market value that the food would have had will be estimated. For this reason we will need the volume (kg) produced of each kind of product (whether honey, fruit, fish, etc.) to be able to find the average market price of these products and estimate the market value.
Strengths and weaknesses	Weaknesses- this indicator depends on concrete collection of data on the production of food at the NBS. Many of these installations are social projects where responsibilities are distributed; so precise monitoring of the kg of produce may be a challenge.
Measurement procedure and tool	This data will be collected via the economic and labour questionnaire to be distributed to the entities in charge of the management of those NBS where food will be produced.
Scale of measurement	At NBS level.
Data source	
Required data	Entities administrating NBS.
Data input type	
Data collection frequency	Once after implementation.
Level of expertise required	The person in charge of food production of the NBS should be able to respond.
Synergies with other indicators	Connected to other economic and labour indicators

Connection with SDGs	Goal 2: Zero hunger. Goal 8: Decent work and economic growth
Opportunities for participatory data collection	None
Additional information	
References	

24.35 Renewable energy produced

Project Name: proGIreg (Grant Agreement no. 776528)

Author/s and affiliations: Gabriele Guidolotti[1], Elizabeth Gil-Roldán[2], Chiara Baldacchini[1,3], Carlo Calfapietra[1]

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[3] *Università degli Studi della Tuscia, Viterbo, Italy*

Renewable energy produced		New Economic Opportunities and Green Jobs
Description and justification	This indicator will evaluate the benefit obtained in terms of production of new energy on the NBS.	
Definition	Some of the NBS in proGIreg entail the installation of solar panels and other renewable energy producing installations. Therefore, the amount of energy produced (and therefore not demanded from the grid) will be accounted for.	
Strengths and weaknesses		
Measurement procedure and tool	This data will be collected via the economic and labour questionnaire to be distributed to the entities in charge of the management of those NBS where energy production installations will be installed.	
Scale of measurement	At NBS level.	

Data source	
Required data	Entities administrating NBS.
Data input type	
Data collection frequency	Once after implementation.
Level of expertise required	The person in charge of administrating the NBS should be able to respond.
Synergies with other indicators	Connected to other economic and labour indicators and environmental indicators looking at energy savings.
Connection with SDGs	Goal 7: Affordable and clean energy Goal 8: Decent work and economic growth
Opportunities for participatory data collection	None
Additional information	
References	

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This *Evaluating the Impact of Nature-based Solutions: Appendix of Methods accompanies the Handbook* for Practitioners for evaluating the impact of nature-based solutions (NBS). The overarching objective of the *Handbook* and this accompanying *Appendix of Methods* is to provide standardised guidance and methods to aid the selection and implementation of indicators to assess impacts of NBS, and, over time, establish a robust European evidence base on NBS performance and impact. In order to compare impacts of different types of NBS, implemented in different contexts, and to draw valid, evidence-based conclusions regarding NBS impact, similar indicators, methods, and types of measurement are needed. The *Evaluating the Impact of Nature-based Solutions: Handbook for Practitioners* and accompanying *Appendix of Methods* identifies indicators and briefly details methodologies to assess impacts of nature-based solutions across 12 societal challenge areas: Climate Resilience; Water Management; Natural and Climate Hazards; Green Space Management; Biodiversity; Air Quality; Place Regeneration; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance; Social Justice and Social Cohesion; Health and Well-being; and, New Economic Opportunities and Green Jobs.

Evaluating the Impact of Nature-based Solutions: Appendix of Methods provides a brief description of each indicator and recommends appropriate methods to measure specific impacts, along with guidance for end-users about the appropriateness, advantages and drawbacks of each method in different local contexts. As such, it is intended to guide the implementation of selected indicators to assess NBS performance and impact.

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