DTU Library

Holistic and replicable quantitative assessment of non-tangible benefits of Nature-Based Solutions

Viti, Martina

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

DTU Sustain

Holistic and replicable quantitative assessment of non-tangible benefits of Nature-Based Solutions

Martina Viti

PhD Thesis

Holistic and replicable quantitative assessment of non-tangible benefits of Nature-Based Solutions

Martina Viti

PhD Thesis
June 2023

DTU Sustain
Department of Environmental and Resource Engineering
Technical University of Denmark

Holistic and replicable quantitative assessment of non-tangible benefits of Nature-Based Solutions

Martina Viti

PhD Thesis, June 2023

The synopsis part of this thesis is available as a pdf-file for download from the DTU research database ORBIT: http://www.orbit.dtu.dk.

Address:	DTU Sustain Department of Environmental and Resource Engineering Technical University of Denmark Bygningstorvet, Building 115 2800 Kgs. Lyngby Denmark
Phone reception:	+45 4525 1600
Homepage:	https://www.sustain.dtu.dk
E-mail:	info@sustain.dtu.dk

Cover photo: NBS in Hovmarksparken, Lystrup, Denmark by Signe Iversen

Preface

The work presented in this PhD thesis was conducted at the Technical University of Denmark, at the Department of Environmental and Resource Engineering. The PhD project was supervised by Professor Karsten Arnbjerg-Nielsen and former Associate Professor Ursula S. McKnight (now Scientific research lead in the area of nature-based solutions at the Swedish Meteorological and Hydrological Institute), along with two co-supervisors: Associate Professors Roland Löwe and Hjalte J.D. Sørup. The work was carried out from November 2019 to April 2023.

This PhD project was financially supported by the European Union's Horizon 2020 Research and Innovation program under grant agreement No. 776866 for the RECONECT (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion) project.

This thesis is organized in two parts: the first part puts the results of the research objectives into context in an introductive review; the second part consists of the papers listed below. These will be referred to in the text by their paper number indicated by the Roman numerals **I-III**.

I **Viti, M.**, Löwe, R., Sørup, H. J. D., Rasmussen, M., Arnbjerg-Nielsen, K., & McKnight, U. S. (2022). Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies. *Science of the Total Environment*, 841(February), 156636. https://doi.org/10.1016/j.scitotenv.2022.156636

II **Viti, M.**, Löwe, R., Sørup, H. J. D., Iversen, S., Gebhardt, O., Ladenburg, J., McKnight, U. S., & Arnbjerg-Nielsen, K. (2023). Holistic valuation of Nature-Based Solutions accounting for human perceptions and nature benefits. *Journal of Environmental Management*, 334, 12 p., 117498 https://doi.org/10.1016/j.jenvman.2023.117498

III **Viti, M.**, Ladenburg, J., Löwe, R., Sørup, H. J. D., McKnight, U. S., & Arnbjerg-Nielsen, K. (2023). Beyond meta-studies: learnings from a large multi-site primary dataset on non-tangible benefits of Nature-Based Solutions. *Manuscript.*

Additionally, the following contributions to conference proceedings, not included in this thesis, were also carried out during this PhD study:

- **Viti, M.**, Löwe, R., Sørup, H. J. D., Arnbjerg-Nielsen, K., & McKnight, U. S. (2020). Assessment of People Indicators. 4th RECONECT General Assembly, Virtual Meeting, 19-20, 26-27 November 2020. Oral presentation.
- **Viti, M.**, Löwe, R., Sørup, H. J. D., Arnbjerg-Nielsen, K., & McKnight, U. S. (2021). Co-creation and co-adaptation of a survey to assess People benefits and their links to Nature benefits. 5th RECONECT General Assembly, Virtual Meeting, 10-11, 17-18 June 2021. Oral presentation.
- **Viti, M.**, Löwe, R., Sørup, H. J. D., Rasmussen, M., Arnbjerg-Nielsen, K., & McKnight, U. S. (2021). Inclusion of non-market benefits of nature-inspired strategies in urban water management: how far are we? Abstract from 15th International Conference on Urban Drainage, Virtual Meeting, 25-28 October 2021. Oral presentation.
- **Viti, M.**, Löwe, R., Sørup, H. J. D., McKnight, U. S., and Arnbjerg-Nielsen, K. (2022). Results from the application of the survey in the Aarhus case study. 7th RECONECT General Assembly, Zurich, Switzerland, 23-25 May 2022. Oral presentation.
- **Viti, M.**, Löwe, R., Sørup, H. J. D., McKnight, U. S., and Arnbjerg-Nielsen, K. (2022). Assessing the interconnections between the characteristics, perception, and valuation of Nature-Based Solutions: A case study from Aarhus, Denmark, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-3784, https://doi.org/10.5194/egusphere-egu22-3784, 2022. Oral presentation.
- **Viti, M.**, Löwe, R., Sørup, H. J. D., McKnight, U. S., and Arnbjerg-Nielsen, K. (2022). Outcomes of the assessment of the indicator "enhancing attractiveness of places for living and working, and to visit". 8th RECONECT General Assembly, Nijmegen, The Netherlands, 21-23 November 2022. Oral presentation.
- **Viti, M.**, Sørup, H. J. D., Löwe, R., Ladenburg J., McKnight, U. S., and Arnbjerg-Nielsen, K. (2023) Non-tangible benefits of Nature-based Solutions for hydro-meteorological risk reduction: an assessment focusing on interconnectivity and replicability, Danish Water Forum 2023, Bjerringbro, Denmark, 8 February 2023. Oral presentation.

Acknowledgements

As a pandemic PhD, my project was carried out during a quite challenging time. I would therefore like to thank my whole supervision team: you have been able to navigate these unpredictable three years with me and support me through them. Thank you to Karsten Arnbjerg-Nielsen, Roland Löwe and Hjalte Jomo Danielsen Sørup. A special acknowledgement is due to Ursula S. McKnight, who was always present for me despite the adverse conditions. Your drive and your kindness are inspiring.

Thank you to the brilliant co-authors who supported us in the production of papers. In a time where it was difficult to reach out and create connections, your willingness to participate in my research was extremely appreciated. The outcomes of this project are so much better thanks to your input. I am particularly grateful to Jacob Ladenburg for his great insights, and for always having the door open for me.

Thank you to the RECONECT team, despite the few possibilities to see each other in person it was lovely to know that there were passionate people on the other side of the computer screens, working for a better future. A special thanks to all of the partners who closely collaborated on the survey design, without you we would have never made it! Also, a big thank you to Signe Iversen, who went the extra mile as our first co-design sparring partner.

My social life at DTU had a delayed start, but I have appreciated every day at the office with my amazing colleagues coming and going from room 118. Thanks for the lunches, the runs, the iced coffees, and the resurrected parties. You all made this PhD journey so much better! A special thank you to my chief motivators Anastasia, Nafsika, Anna, not to be cheesy, but without you the good days would have been half as nice, and the bad days twice as hard.

Thank you to my family, cheering me on from far away, and my friends here and elsewhere. You remind me to take things with perspective, and to have fun. To the Wednesday dinners crew, thank you for not letting me take myself too seriously, for listening to my worries, and for all the evenings spent together.

Finally, Jonathan, I am not even sure I would have started this journey without you, let alone finish it. For all your trust, your support, your patience, thank you!

Summary

In order to contrast the negative impacts of climate change, the concept of Nature-Based Solutions (NBS) has emerged as one of the favored available options. NBS are defined as "the use of natural or modified ecosystems to address societal challenges while at the same time providing a range of long-term benefits to human well-being and biodiversity". NBS's central concept of providing many different benefits makes them very interesting tools for adaptation, which lead them to be recommended in international environmental policy agendas, disaster risk and research programs. However, despite their potential, their implementation is lagging behind. This may be due to various reasons, but uncertainties regarding the economic feasibility of NBS are deemed to be a substantial barrier to their uptake. Therefore, the monetary quantification of NBS benefits that are not directly connected to a market (e.g., increased recreation and enhanced biodiversity – also called non-tangible benefits) is seen as a possible strategy to get closer to a complete assessment of NBS and support their prioritization. However, the complexity of setting a monetary value to non-tangible benefits often leads this kind of assessment to be left out, causing NBS to be perceived not only as less economically feasible, but also as less multi-functional.

This PhD research is part of the EU Horizon 2020 project RECONECT, and it focuses on developing and applying a new method for assessing the non-tangible benefits of NBS. The main aim is to ease the economic assessment of these solutions to support their implementation. This was achieved through a series of processes, starting with a literature review of the state-of-the-art of non-tangible benefits assessment, proceeding with the creation and application of a new methodology, and concluding with the analyses of its outcomes.

In the review of the current literature on NBS, it was found that the valuation of non-tangible benefits is not that widespread, and that the connection between the different benefits of NBS is mostly overlooked. Moreover, most of the examined studies assessed just one site at a time, thus producing very site-specific evaluations, which in turn hinder benefit transfer and upscaling of these strategies.

In order to make a step towards closing these gaps, we developed a survey directly eliciting a monetary value, in the form of willingness-to-pay (WTP), from the general public living close to and/or using an NBS site. The novelty of this method resides in the holistic approach to the information collected (i.e.

spacing from socio-demographic characteristics to personal preferences on the various benefits of NBS) and in its modularity, allowing it to be tailored to different NBS while at the same time collecting the same data.

We co-designed and distributed the survey in 6 different NBS projects (both completed and under construction): two in Denmark, one in Germany, one in Italy, one in Austria, and one in the Netherlands.

The outcome of such a distribution campaign was a unique dataset, allowing for the full comparison of factors that influence the value of NBS across different European case studies. In our analyses, it was found that income, personal preferences (specifically regarding nature, e.g., the importance attributed to the increase in biodiversity), and uses of the area were the biggest influences over the value attributed to NBS across sites. Based on these results, we developed joint models to summarize and ease the upscaling of our findings.

Our survey can be further replicated and used to collect the same data in other sites, which then will be directly comparable to the information gathered in this study. Ideally, the survey could be applied in very different settings (i.e., also outside of Europe), to compare results across much diverse contexts. Thus, it could contribute to the creation of a more holistic knowledge base for secondary data analyses (e.g. meta-analyses) to develop on.

Overall, the outcomes of this project are believed to be useful, complementarily to market benefit assessments, to maximize the potential and support the implementation of NBS.

Dansk sammenfatning

For at modvirke de negative konsekvenser af klimaændringer er naturbaserede løsninger (Eng: Nature-Based Solutions, NBS) opstået som en af de foretrukne tilgængelige muligheder. NBS defineres som "brugen af naturlige eller modificerede økosystemer til at løse samfundsmæssige udfordringer og samtidig skabe en række langsigtede fordele for menneskers velvære og biodiversitet". NBS's indlejrede fokus på at levere mange forskellige fordele gør disse løsninger meget interessante i forbindelse med klimatilpasning, hvorfor de anbefales i internationale miljøpolitiske programmer, katastroferisiko- og forskningsprogrammer. På trods af deres potentiale halter implementeringen. Dette kan skyldes forskellige årsager, men usikkerheder vedrørende økonomisk gennemførlighed af NBS anses for at være en væsentlig barriere for deres udbredelse. Derfor ses den monetære kvantificering af NBS-fordele, der ikke er direkte forbundet med et marked (f.eks. øget rekreation og øget biodiversitet – også kaldet ikke-markedsomsatte fordele) som en mulig strategi til at komme tættere på en komplet vurdering af NBS og understøtte deres prioritering. Kompleksiteten i at sætte en monetær værdi på ikke-håndgribelige fordele fører imidlertid ofte til, at denne form for vurdering udelades, hvilket medfører, at NBS ikke kun opfattes som mindre økonomisk gennemførligt, men også som mindre multifunktionelt.

Dette ph.d.-projekt er en del af EU Horizon 2020-projektet RECONECT, og fokuserer på at udvikle og anvende en ny metode til at vurdere de ikke- markedsomsatte fordele ved NBS. Hovedformålet er at lette den økonomiske vurdering af disse løsninger for at understøtte deres implementering. Dette blev opnået gennem en række processer: for det første en litteraturgennemgang af state-of-the-art inden for vurdering af ikke- markedsomsatte fordele, dernæst udviklingen og anvendelsen af en ny metodologi og afslutnignsvis analyserne af dens resultater.

I gennemgangen af den aktuelle litteratur om NBS viste det sig, at værdiansættelsen af ikke- markedsomsatte fordele ikke er så udbredt, og at sammenhængen mellem de forskellige fordele ved NBS for det meste overses. Desuden evaluerede de fleste af de undersøgte undersøgelser kun én NBS af gangen, hvilket resulterede i meget kontekstuelt specifikke evalueringer. Dette hindrer overførsel af fordele og opskalering af disse strategier.

For at tage et skridt i retning af at lukke disse videnshuller udviklede vi en metode til værdiansættelse i form af willingness-to-pay-undersøgelse for de

mennesker, der bor tæt på og/eller bruger et NBS-område. Det nye ved denne metode ligger i den holistiske tilgang til den indsamlede information (herunder socio-demografiske karakteristika og personlige præferencer vedrørende de forskellige fordele ved NBS) samt i dens individuelle bestanddele, som gør det muligt at tilpasse den til forskellige NBS-områder men samtidigt indsamle sammenlignelige data.

Vi co-designede og distribuerede undersøgelsen i 6 forskellige NBS-projekter (både afsluttede og under opførelse): to i Danmark samt et i hvert af landene Tyskland, Italien, Østrig og Holland.

Resultatet er et unikt datasæt, der giver mulighed for fuld sammenligning af faktorer, der påvirker værdien af NBS på tværs af forskellige europæiske case-studier. Analysen viser, at indkomst, personlige præferencer med hensyn til naturen (f.eks. betydningen tillagt stigningen i biodiversiteten) og anvendelsen af området var de største påvirkninger af den værdi, der tillægges NBS på tværs af lokaliteter. Baseret på disse resultater udviklede vi en fælles model til at opsummere og lette opskaleringen af vores resultater.

Vores undersøgelse kan repliceres yderligere og benyttes til at indsamle samme type data på andre NBS-områder, som derefter vil være direkte sammenlignelige med oplysningerne indsamlet i denne undersøgelse. Ideelt set kunne undersøgelsen anvendes i meget anderledes omgivelser (dvs. også uden for Europa) til at sammenligne resultater på tværs af meget forskellige sammenhænge. Desuden kunne det bidrage til at skabe et mere holistisk vidensgrundlag som sekundære dataanalyser (f.eks. metaanalyser) kan bygge ovenpå.

Samlet set skønnes resultaterne af dette projekt at være umiddelbart brugbare og giver mulighed for i højere grad at maksimere potentialet og dermed understøtte implementeringen af NBS.

Table of contents

Abbreviations

CE	Choice Experiment
CV	Contingent Valuation
EC	European Commission
EEA	European Environment Agency
ESS	Ecosystem Services
GHG	Greenhouse Gases
NBS	Nature-based Solutions
RP	Revealed Preference
SP	Stated Preference
WTP	Willingness to pay

1 Introduction

The warming of our planet is, in the words of the IPCC, unequivocal, and is bound to carry with itself a number of serious impacts for ecosystems and humans (IPCC, 2021b). Despite the current efforts to reduce the global GHG emissions and invert this trend, we have already committed to a certain degree of climate change that we will not be able to avoid. Warmer climate, sea level rise, and changes in the precipitation patterns are some of the changes that we will see concretizing in the coming decades. For these impacts, adaptation has to be a part of the human society's response (European Commission, 2021b).

Adaptation is a structured effort to reduce the negative and increase the positive impacts of climate change, striving to find solutions that could benefit society against more than just one negative impact (Ayers & Dodman, 2010). Adaptation efforts tend to focus on impacts that have materialized, but waiting to implement measures until the impacts are unavoidable is more expensive than adapting in advance, and adaptation cannot be considered a wholly local response, as a climate impact in a specific region could very well have global repercussions (e.g. on the global economy) (Dessler, 2021). Therefore, tackling these impacts is a global challenge, which will need a variety of actions to be taken across the world. For the research summarized in this thesis, however, we will be focusing on the European region: on the risks that are going to increase there and the strategies that have been selected to counteract them.

1.1 Nature-Based Solutions: an integral part of Europe's climate change adaptation strategy

Like the rest of the world, Europe will suffer from the impacts of climate change (IPCC, 2021a). Figure 1.1 below sums up the observed and projected climate trends for the European region.

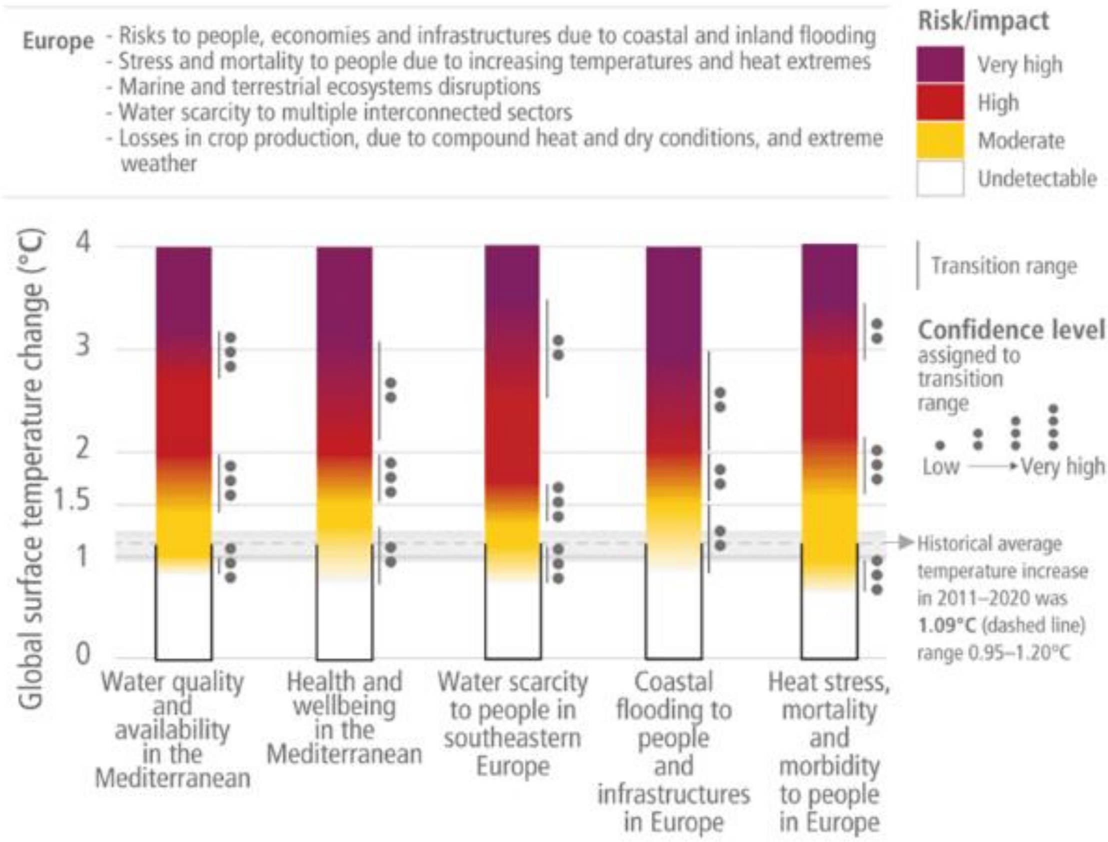


Figure 1.1 Regional key risks in Europe for increasing levels of global warming. Source: (IPCC, 2022).

Warming is "virtually certain" to continue in Europe, as extreme heat will exceed critical thresholds in sectors such as agriculture and health. Other foreseen impacts across European regions are the increase of heavy precipitation and pluvial flooding, severe windstorms, as well as coastal and oceanic impacts, e.g. coastal floods and relative sea level. On the other hand, cold spells and ice and snow cover are projected to decrease across the whole region (IPCC, 2021b; Ranasinghe et al., 2021).

These phenomena translate into very concrete damages, which will seriously harm the economy and the livelihoods of people. The European Union has therefore had to select strategies to counteract and mitigate these risks. In the latest report on the adaptation strategy of the EU, Nature-Based Solutions (NBS) are being indicated as a fundamental tool for responding to these impacts (European Commission, 2021a; Faivre et al., 2017).

The term NBS has first been used by the World Bank in 2008, and various other organizations, such as the IUCN, have been active in integrating this concept into policy debates (IUCN, 2012). The EC has defined NBS as a way to address the current social challenges with "*solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions*" (European Commission, 2015). This concept builds upon earlier ecosystem-based initiatives such as Green Infrastructure, Ecosystem-Based Adaptation and Natural Water Retention Measures, but it takes a step forward by using an integrated perspective, and promoting a transition towards a more resource-efficient, inclusive, and sustainable growth model (Faivre et al., 2017; Hanson et al., 2020).

Inherent in this definition is the idea that NBS include conservation and rehabilitation of natural ecosystems, as well as the enhancement or creation of natural processes in modified or artificial ecosystems. NBS span a range of scales and work with conventional infrastructure. Some examples are: construction and/or restoration of reefs that protect coastal settlements, vegetation management to reduce flooding and purify water for downstream communities, and urban green roofs to increase building isolation, contrast heat island effect and increase biodiversity in cities (European Commission, 2021b; Nelson et al., 2020).

Briefly, NBS provide integrated, multifunctional solutions to many of our current urban and rural challenges through the use of nature and natural processes, as represented in Figure 1.2. This concept aligns very well to European standards and future sustainability goals. Therefore the EU is well placed to take decisive actions towards the implementation of these solutions (Faivre et al., 2017). In fact, the EC has included NBS in the Research and Innovation program which has led to the funding of important projects, tackling different aspects of NBS research, such as OPPLA, Naturvation, EKLIPSE, OPERANDUM, PHUSICOS, and RECONECT (European Commission, 2021b; Ruangpan et al., 2019).

The latter is of particular interest, as the research discussed in this thesis was conducted as part of the RECONECT ("Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion") project. The following section describes in more detail this project's characteristics.

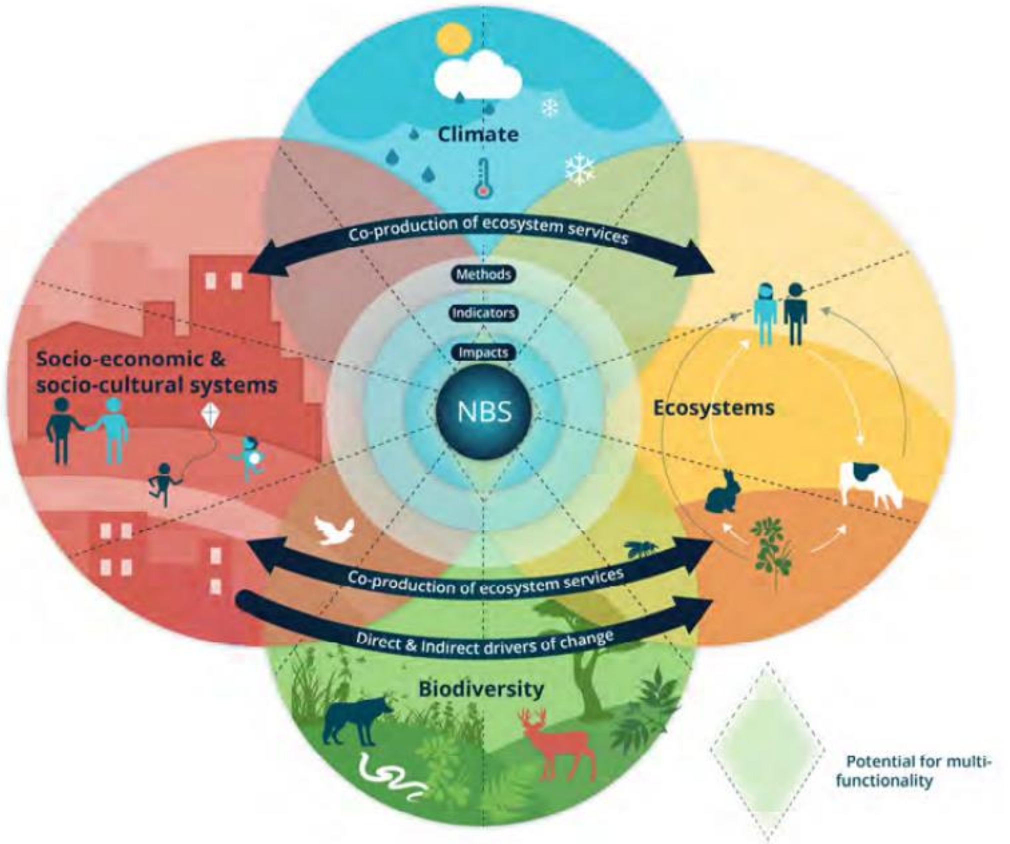


Figure 1.2 Schematization of the relationships among elements of biophysical and social systems, climate resilience challenges within which NBS actions, impacts, indicators and methods are placed. Source: EKLIPSE project (Raymond et al., 2017).

1.2 The context of RECONECT

Between 1980 and 2020, damages from hydro-meteorological events amounted to ca. 78% of the total economic loss caused by weather and climate-related extreme events in EEA member countries (EEA, 2022). Given that the occurrence of these events is bound to increase in the future (IPCC, 2021b), there appears to be an urgent need to implement new, effective strategies to cope with hydro-meteorological risk, since “grey infrastructures” alone are not always effective, adaptive and sized against climate changes (RECONECT, 2021). As mentioned in section 1.1, NBS are now in focus in the EU as the most feasible strategy to tackle the challenges linked to climate change impacts, thanks to their multidimensional and integrative approach. Nevertheless, to support a complete and effective uptake of these solutions, our current understanding of NBS implementation and benefits is still far from exhaustive. Identified knowledge gaps include, for example: the integration of stakeholders’ perspectives, how to bring scientific evidence of NBS benefits into policy-making and the assessment of specific benefits of large-scale NBS (Hanson et al., 2020; Nelson et al., 2020; Ruangpan et al., 2019).

The RECONECT project aims at reducing these knowledge gaps. Its final goal is to link the reduction of hydro-meteorological risk with local and regional development objectives in a sustainable and financially viable way; as well as to upscale and exploit large-scale NBS in rural and natural areas, based on demonstrations and knowledge sharing from its Network of Cases (RECONECT, 2021). The RECONECT project aims to (1) demonstrate, monitor and evaluate large-scale NBS and their effectiveness for reducing hydro-meteorological risks; (2) develop a platform that provides information about the performance of the NBS, providing the evidence to facilitate their planning, replication, and upscaling; (3) define a roadmap for NBS implementation and operation; and (4) apply this roadmap to several cases across and beyond Europe (RECONECT, 2021; Turconi et al., 2020).

In demonstrating, monitoring and evaluating large-scale NBS, the RECONECT project focuses on the benefits related to three challenge areas tackled by NBS, referred to as: water, nature and people. Water benefits refer to the reduction of negative impacts of hydro-meteorological events (e.g. flood/landslide risk reduction). Nature benefits refer to the benefits for nature (e.g. biodiversity enhancements, habitat provision and distribution improvements). Lastly, people benefits are defined as benefits for humans (e.g. increase in recreational opportunities, economic benefits, psychological and physical well-being). It is also noted that these benefits overlap to a certain extent, as shown in Figure 1.3. The definitions “water”, “nature” and “people” benefits will also be used throughout this thesis in the same way as they have been defined for the RECONECT project.

As indicated in Figure 1.3, the water and people benefits groups fit well to the framework of Ecosystem Services (ESS), which are defined as the direct and indirect contributions of ecosystems (with their outputs, conditions and processes) to human well-being and/or social welfare (Boyd & Banzhaf, 2007). However, a part of the nature benefits cannot be categorized as services to benefit society directly (i.e. improvement of habitat for certain species, connectivity/fragmentation of habitat structure), as they relate, and are assessed as, improvements for nature regardless of their impact on people well-being or economy. These benefits are therefore referred to as “nature for nature (’s sake)”.

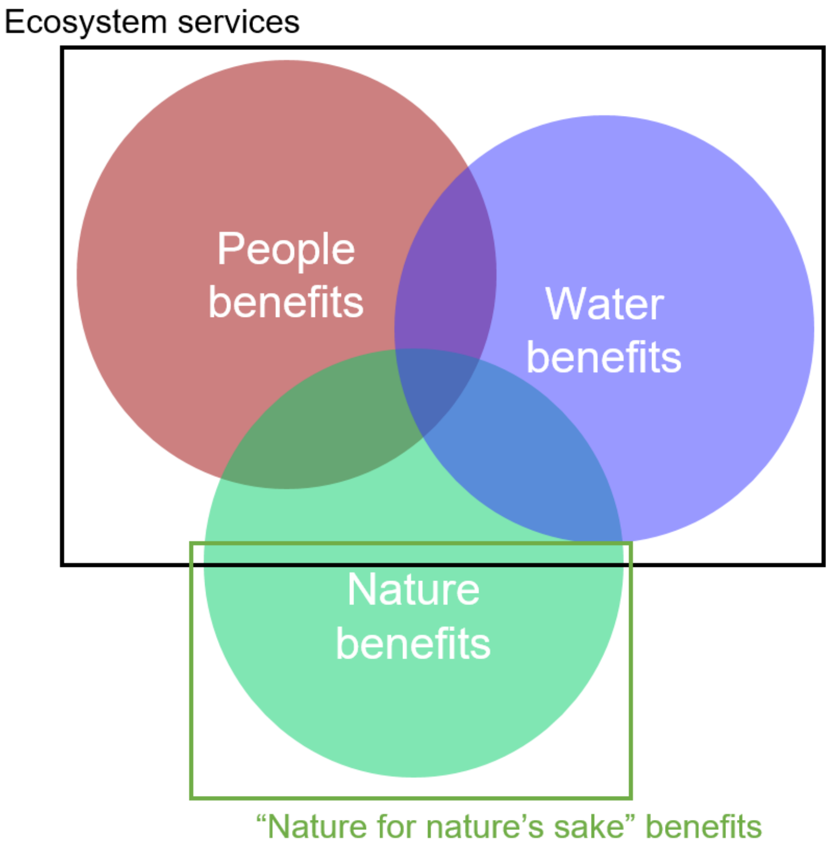


Figure 1.3 Overlapping of the three RECONECT challenge areas.

1.3 Relevance of the assessment of non-tangible NBS benefits

RECONECT, and most of the above-mentioned European projects, have as a fundamental aim that of prioritizing the use of NBS for risk reduction, at least in a European context. This requires an influence on the decision-making processes, which are inevitably limited by cost-benefit tests due to resource constraints (Bateman et al., 2011). Therefore, it is fundamental to create good business cases for NBS. As shown in a simplified manner in Figure 1.4, in most cases, NBS implementation requires significant investments for construction and maintenance (since they are responding to multiple challenges), resulting in higher costs than for their “grey” counterparts (Alves et al., 2019; Li & Gao, 2016). Despite the decrease in the residual risks (e.g. damages to public and private property), if the increasing costs are not offset by the quantification of the extra benefits generated, NBS may appear to be hardly economically viable for the level of risk reduction offered.

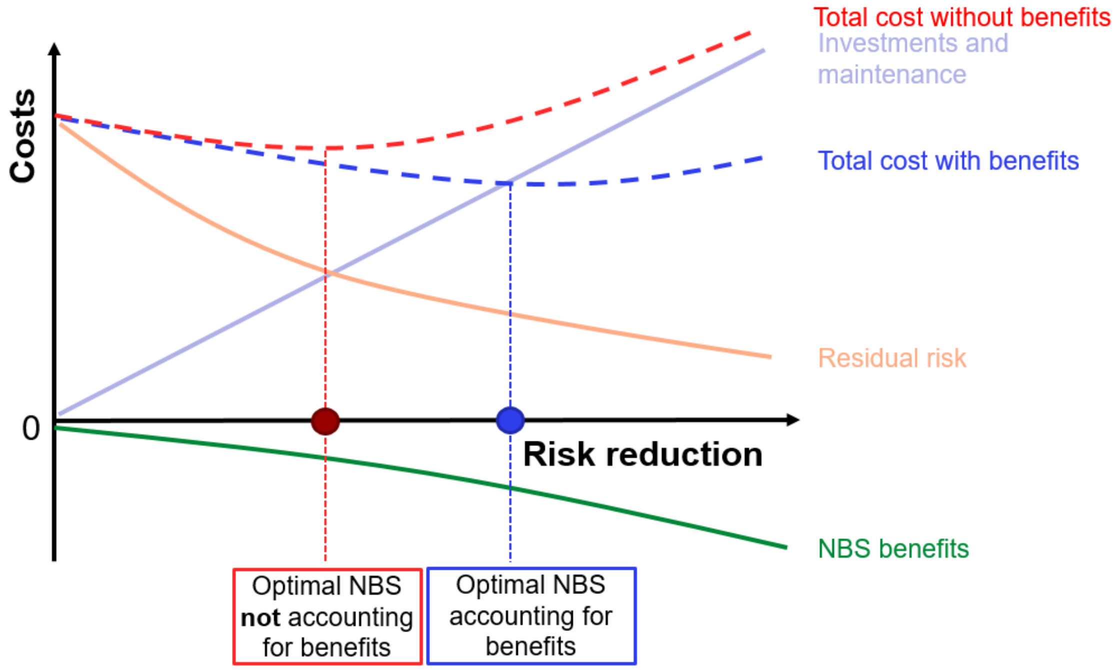


Figure 1.4 Schematization of a simplified Cost-Benefit Analysis for a NBS.

An assessment of all benefits of NBS is thus fundamental to support advocacy of these solutions, influence policies, calculate damages for liability compensation and identify extractable revenues (Chenoweth et al., 2018; van Beukering et al., 2015). However, while the monetary quantification of benefits that are connected to a market (e.g. reduction of costs of damages, increase/decrease of property values) is quite straightforward, the valuation of non-market benefits (i.e. benefits that do not have a reference market – also called non-tangible or intangible benefits) is more complex, due to the uncertainty of the results and its high resource intensity (Dehnhardt, 2014; Feuillette et al., 2016). A large part of NBS benefits belongs to the second group (e.g. human physical and psychological well-being, biodiversity improvement, habitat restoration, etc.) (Raymond et al., 2017), and this makes carrying out a complete quantitative assessment quite challenging. Nevertheless, failure to determine economic values to communicate the non-market benefits of NBS is seen as a barrier for the maximization of NBS's multiple benefits and the implementation of these strategies in general (Hansen et al., 2019; Nesshöver et al., 2017; Van Oijstaeijen et al., 2020).

Accordingly, this PhD project did not aim at assessing the entirety of NBS benefits, but rather focused on developing solutions to account for the non-tangible benefits of these strategies (Fig. 1.5). The majority of the examined benefits belong to either the people or the nature challenge areas, since these groups include the highest number of non-tangible benefits. Importantly, the overlap between benefit groups is central in this study, as many of the key non-tangible NBS benefits were found to exist in the interconnections between the different areas (e.g. decrease in stress over hydro-meteorological risks, increase in recreational/educational opportunities due to the reestablishment of habitats/species).

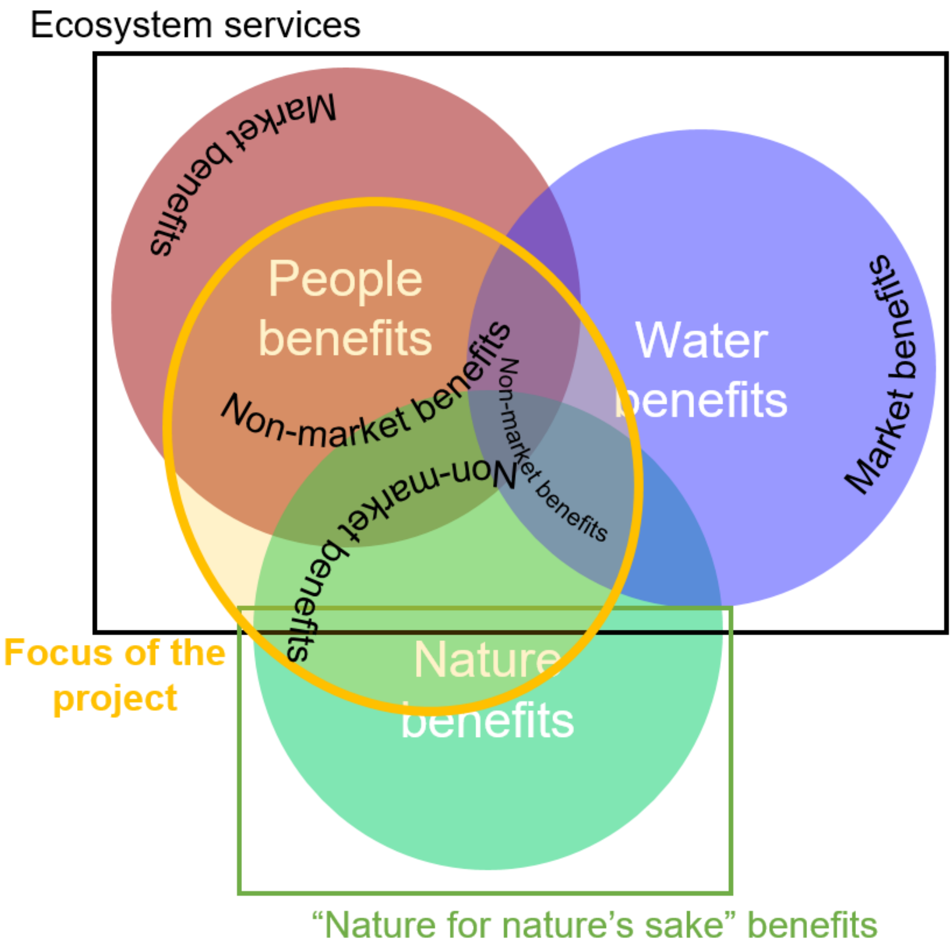


Figure 1.5 Representation of the focus of this project in relation to the challenge areas assessed by the RECONECT project.

1.4 Research questions and thesis structure

The main objective of this PhD project was to outline a comprehensive strategy to quantify the interconnected non-tangible benefits generated by NBS used for hydro-meteorological risk reduction, supported by application in various case studies across Europe.

The research questions (RQ) of this PhD project were:

RQ1: Are there any gaps and/or biases in the current literature on the assessment of non-tangible benefits of NBS?

RQ2: Is it possible to create and apply a holistic and replicable assessment methodology for the non-tangible benefits of NBS?

RQ3: Focusing on non-tangible benefits, and especially on the connection between people and nature benefits, what variables influence the valuation and preference heterogeneity for NBS across different sites and contexts?

RQ4: Is it possible to determine a common value function for the upscaling of the valuation of NBS non-tangible benefits, starting from our results?

The main body of this thesis consists of four chapters (2, 3, 4 and 5) each exploring the findings related to each research question with reference to **Papers I-III**. Specifically, chapter 2 focuses on the literature review and its findings connected to RQ1 and **Paper I**. Chapter 3 presents the new methodology that was developed in this project, based on observations and lessons learned from **Paper II** and **III**. In chapter 4, RQ3 is addressed through the discussion and contextualization of the results of the methodology application, as reported in **Paper II** and **III**. In chapter 5, the upscaling possibilities of our method are explored, based on the findings shown in **Paper III**. Lastly, section 6 summarizes the main findings and section 7 offers recommendations and suggestions for further research on the topic.

The connection between research questions and papers reported in this thesis have been summarized in Figure 1.6.

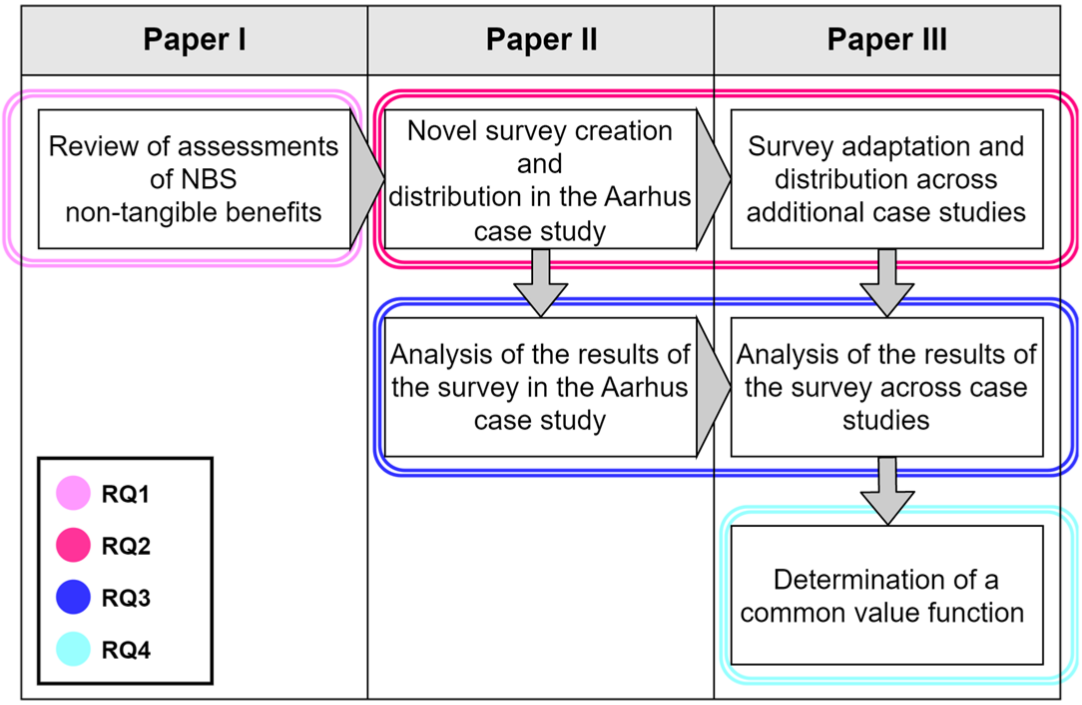


Figure 1.6 Overview of the steps undergone during this research and their connection with papers, research questions and objectives.

2 State-of-the-art of non-tangible benefits assessment for NBS

The first step of this project was to determine the state-of-the-art for the quantitative valuation of non-tangible benefits of NBS (**Paper I**). Various studies describing the methods to be used for this kind of evaluation have been produced (Bateman et al., 2011; Hérivaux & Le Coent, 2021; Venkataramanan et al., 2020). Nevertheless, there appears to be a lack of reviews of their application. The missing assessments of the current approaches risks perpetuating gaps and biases in NBS evaluation that we may not be aware of. We therefore researched these possible knowledge gaps before defining a new approach.

This chapter offers an overview of the existing approaches for the assessment of non-tangible benefits of NBS, before presenting our findings and discussing their plausible causes and impacts.

2.1 Existing approaches

For the estimation of non-market benefits of NBS, two main approaches are presented in the literature: on the one hand collecting primary data, on the other, applying secondary data analysis in value transfer or meta-analyses.

Examples of primary data collection are surveys and interviews conducted on site, or the gathering of statistical data from the area (e.g. property values, population density). The gathering of primary data offers a complete value estimate and reflects closely the specific context it is used in. However, it is a time and resource intensive approach (Johnston et al., 2015; Pearce et al., 2006), that also may not be applicable or available everywhere (e.g. in remote rural contexts).

Secondary data approaches require less resources and their outcomes can be more easily transferred to other case studies; however, they cannot be developed without the input of primary collected data. Benefit transfers refer to the projection of benefits from one original study to the same location at another time or to a new location (i.e. policy site) with similar characteristics (Richardson et al., 2015). Lastly, meta-analyses are statistical methods which rely on a selection of primary valuation studies to investigate the contribution and significance of different variables on derived values (Brander et al., 2013).

In the context of this research, we focused on primary data collection methods, as the gathering of primary data is the first step in the development of a new approach. Among these, two main approaches are used for the assessment of non-tangible benefits: Revealed Preference (RP) and Stated Preference (SP). RP approaches are used to indirectly derive market prices through the use of proxy markets. An example of an RP method is hedonic house pricing, where the value of a house is used as a proxy of the value attributed to the features of, e.g., an urban park. Another example is the travel time method, which discloses the willingness of the respondent to spend time and money to reach/visit an area with determined characteristics (Koetse et al., 2015). Because RP methods can only assess values connected to benefits created by the actual use of an area, they are quantifying use values only. Moreover, these values can be estimated ex-post, i.e. after the completion of a project (Pearce et al., 2006).

The other major type of non-market valuations, SP, focuses on quantifying goods that have no related markets by creating an hypothetical market where the respondents themselves state a value (i.e. willingness-to-pay) for the good in question (Johnston et al., 2017). With their flexible survey-based approach, SP methods can assess both use and non-use values ex-post and ex-ante to the completion of a project (Pearce et al., 2006). Many different SP approaches exist, but the most commonly used in practice are: contingent valuation (CV) and choice experiments (CE) (Arrow et al., 1993).

CE models are based on random utility theory (Ben-Akiva & Lerman, 1985), and the quantification of the benefit is obtained by asking respondents to choose between different attributes of a good. The value is then inferred from the resulting series of observed choices. On the other hand, the aim of CV models is to obtain a total value of the good in question by directly eliciting a monetary estimate for the change in the environmental good from the respondents (del Saz Salazar & García Menéndez, 2007; Koetse et al., 2017).

Figure 2.1 presents a summary of the different methods discussed in this section. This study focuses on the relevance of assessing both use and non-use values of NBS to support a complete evaluation of these strategies. Therefore, to assess the state-of-the-art of the quantification of non-tangible NBS benefits, it was chosen to review only primary studies using SP methods to assess the benefits of NBS and NBS-like strategies, as described in **Paper I**.

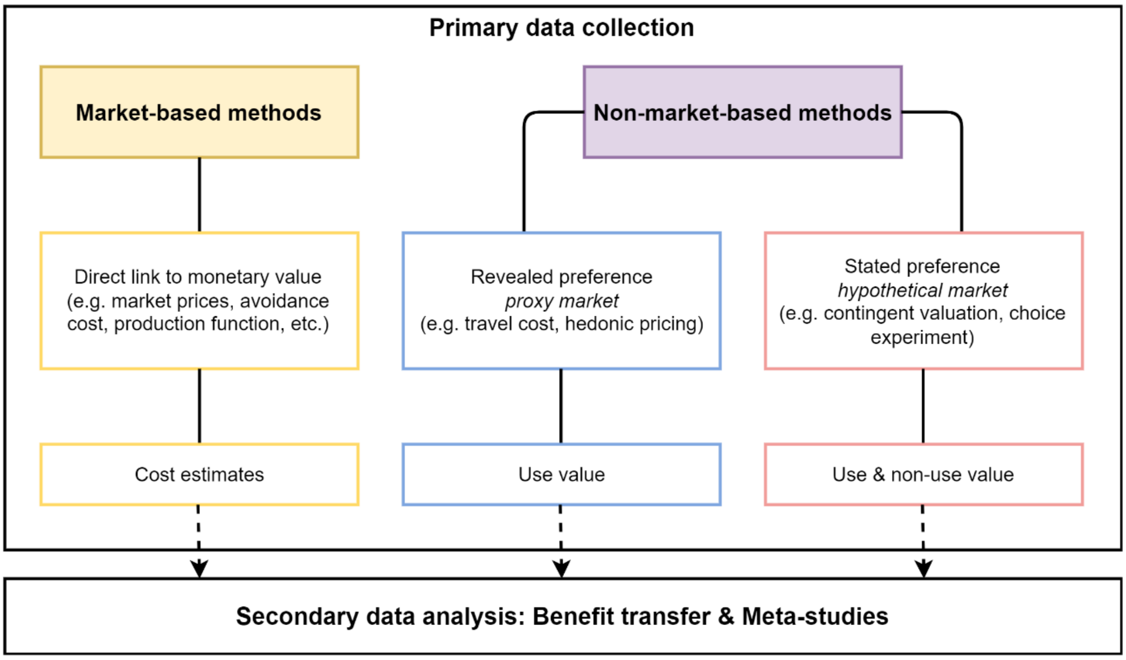


Figure 2.1 Overview of the different methods used for the economic quantification of benefits. The focus of this research is on the squares in pink. Source: adapted from (Koetse et al., 2015).

2.2 Gaps and biases in the current approaches

A structured literature review of the last 20 years of peer-reviewed publications on SP methods applied to assess non-market benefits was the first step in this research. This approach was chosen in order to find out which variables are collected in primary studies assessing NBS (or equivalent strategies not using the same term) (**Paper I**).

The literature was first searched for studies conducted specifically on NBS. This first search returned too few studies to conduct any kind of meaningful analysis. Therefore, we opted to expand our search by integrating other kinds of multidisciplinary/multi-benefits strategies (defined as NBS-like strategies). There are various factors that could be influencing this lack of studies focusing on NBS (e.g., NBS is a term used mainly in a European context (Hanson et al., 2020)), however, they alone cannot explain such a clear gap in a rapidly expanding research area as that of NBS. Therefore, this outcome seems to point out that within the research focusing on NBS, the quantification of non-market benefits via primary data collection (specifically SP methods) is lagging behind.

With the intention of taking a snapshot of the current way of assessing NBS, we classified the retrieved studies based on their approach to the quantification of non-market benefits. We created three categories:

- Studies assessing only benefits for people (e.g. recreation, psychological well-being);
- Studies assessing benefits for people and for nature, where the latter are framed as benefits for people (e.g. the increase in biodiversity as an encouragement for recreation; the improvement of water quality to a swimmable quality);
- Studies assessing benefits for people and for nature, where the latter are framed as benefits regardless of their direct impact on people (e.g. the willingness to contribute for the creation of a protected area).

The outcomes of such a classification are shown in Figure 2.2.

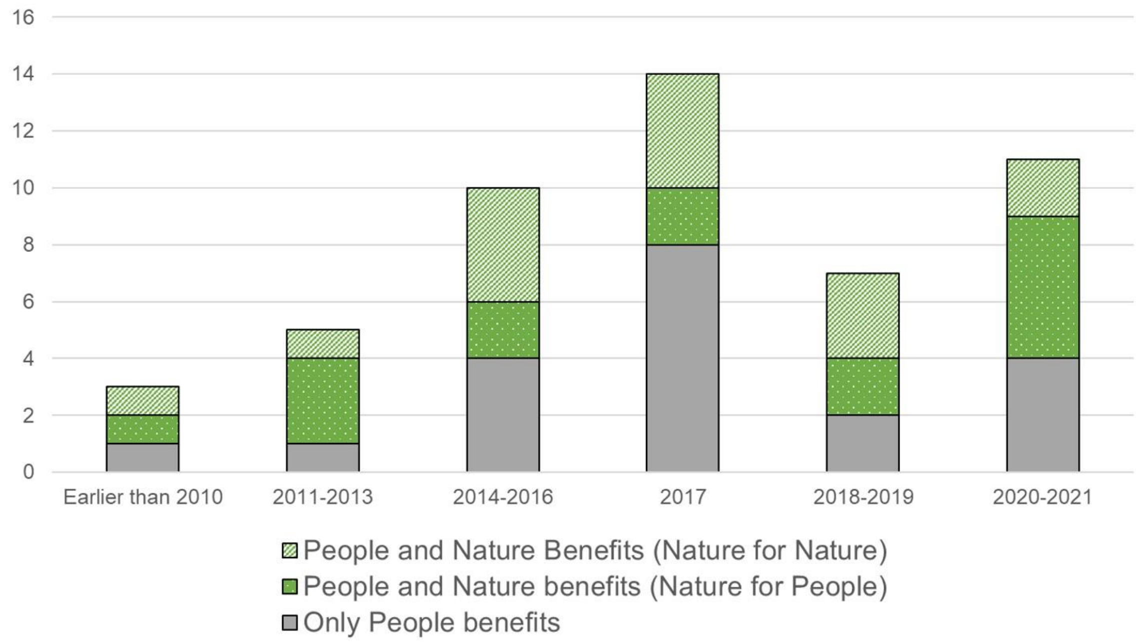


Figure 2.2 Summary of types of studies divided by publication year. Source: adapted from **Paper I**.

As expected, non-tangible benefits assessments start to get used more frequently after the popularization of the NBS concept (or rather that of multidisciplinary strategies counteracting the impacts of climate change), with the year 2017 being a particularly prolific one. There doesn't appear to be a linear trend over the years regarding the way non-market benefits are assessed. However, some other patterns can still be discerned, e.g. the assessment of "people for nature” benefits seems to decrease until 2019, and it comes back in 2020-2021. The cause of this recent increase could not be explained through our review. Potentially, it could be due to a renewed interest in proving the economic feasibility of NBS, and doing so through the assessment of people benefits (e.g. recreation possibilities) has been the preferred approach. Moreover, despite the pervasive quantification of nature benefits (i.e. in 30 of the 50 examined studies), most of the assessments stop at the quantification of benefits directly influencing people well-being, leaving out the “nature for nature” assessment. This lack of valuation of benefits for nature “decoupled” from human benefits could be problematic, as it risks creating a bias in the perception of NBS impacts. More specifically, it subordinates “nature for nature” benefits as extra, rather than central aspects of NBS. Additionally, a more detailed examination of the quantified benefits in the collected studies showed a tendency to use a “silos” approach that compartmentalizes the benefits of NBS, rather than working on the overlaps of these strategies’ benefits (**Paper I**).

Overall, the review of the current literature on the subject of non-tangible benefits’ quantification showed how the application of these methods is not as widespread as one might expect, or as holistic. There is a clear gap in the assessment of specifically NBS cases, and consequently in the development of an approach that could be “NBS-specific” and replicable across study sites (more on the latter point is presented in section 2.4). As for the current evaluations on NBS and NBS-like strategies, they appear to be biased towards a more anthropocentric valuation of NBS, while the nature aspects are left behind. In the long run, these shortcomings risk to slow down implementation and upscaling of these strategies, and it is therefore imperative for a successful uptake of NBS to improve the methods used for the assessment of non-tangible benefits of NBS.

As a last remark, despite the limitations of its current use, our review highlighted the flexibility and potential of SP assessments as quantification tools. These methods can be easily tailored to accommodate a vast range of hypothetical valuation scenarios (i.e. including the quantification of both people, nature for people and nature for nature benefits), and we therefore decided to build upon this (for the most part) unexploited potential to create a more holistic methodology for future non-market benefits assessments.

2.3 Challenges to a holistic non-tangible benefits assessment

In this chapter, we analyse some of the plausible underlying reasons for the detected biases presented in the previous section.

2.3.1 The NBS definition(s)

The conceptual foundation of NBS is rooted in a transdisciplinary collection of ideas, which results in a broad range of different objectives, definitions and applications. However, the very transdisciplinary nature of NBS makes this concept prone to ambiguity, and its definition is seen as somewhat blurry by different studies (Sowińska-Świerkosz & García, 2022). For example, as Hanson et al. (2020) point out, the EU and IUCN (among the first to take up the NBS concept) present two quite different definitions of the same strategy. The EU appears to prioritize innovations and economical concerns (e.g. "NBS involve innovative governance, institutional, business, and finance models and frameworks, leveraging both public and private funding", (European Commission, 2015)), while the IUCN highlights the use of existing ecosystems as well as the protection of biodiversity (Cohen-Shacham et al., 2016). Moreover, experts with different backgrounds tend to see NBS through their expertise-specific lenses, with some focusing e.g. on their socio-cultural aspects, while others look mainly at their risk reduction potential or impacts on ecosystems. Nevertheless, quite a lot of work has been put into trying to standardize and organize the benefits of NBS with the creation of guidelines (European Commission, 2021b; IUCN, 2020) for the implementation and assessment of NBS, which will hopefully succeed in the creation of a more universally accepted NBS definition.

2.3.2 Are there limits to what we *can* monetarily quantify?

Moving on to the non-tangible benefits assessed in the reviewed studies, it is fair to ask whether the labels (e.g., ESS) applied to these benefits are influencing the way they are quantified, and if there are alternative ways to do so. ESS are the framework through which the vast majority of the analysed studies looks when it comes to assessing and quantifying benefits (**Paper I**). However, critics of this approach point out that classifying NBS benefits only through ESS risks excluding a range of overlapping impacts (e.g. co-produced benefits), as well as benefits for nature independent from benefits for humans, economy or society (Díaz et al., 2018; Raymond et al., 2017) (see also Fig. 1.3).

It is therefore suggested to integrate other approaches (e.g. qualitative, non-monetary evaluations; dialogues with local knowledge-holders) for the assessment of non-ESS benefits, especially nature for nature benefits (Raymond et al., 2017). In fact, whether the quantification of "pure" nature for nature benefits is possible through a SP approach is debatable, as when asking respondents to value a specific (nature) benefit, we are reverting to an anthropocentric (or utilitarian) view of NBS benefits (e.g., supporting the creation of a new forested area close to my residence makes *me* happy, even if it is off-limits for visitors; making a donation for a natural reserve in another Municipality makes me feel like I contribute to something positive and increases *my* satisfaction, etc.). Nevertheless, it is still possible to continue striving for a more holistic and "NBS-specific" SP assessment method while at the same time recognizing that it is not always feasible to identify a clear distinction between the valuation of nature for nature benefits and nature for people benefits.

2.3.3 Are there limits to what we *should* monetarily quantify?

So far our discussion has focused on ways of improving the assessment of non-tangible benefits of NBS, in order to make it as holistic as possible. However, the necessity to monetarily quantify benefits for or originating from nature is opposed by some experts, often due to the perceived risks of commodification of nature, and social equity concerns (Lele et al., 2013; Pascual et al., 2014). Critics argue that putting a price on nature is too anthropocentric, as it implies nature only harbours value if it generates a service for humans, and that monetary valuation is unethical. More nuanced critiques point out a growing distance between the initial concept of ESS (i.e. interconnected, holistic), and their application in practice (i.e. increasingly narrow, focusing on ecology and economics, and leaving out perspectives from social sciences and local knowledge) (Díaz et al., 2018).

On the other hand, defenders of the monetary valuation of benefits (mostly in the form of ESS assessment) argue that the critics focus on monetary valuation as the most important component of ESS, while it is mostly meant to raise awareness about the relative importance of nature and ESS compared to man-made services and to highlight the common undervaluation of externalities (Schröter et al., 2014). Explicit valuation of NBS benefits is not seen as much different from what all of us already do in our daily decision-making. When having to make a choice, we identify the costs and benefits of each option, we value and weigh them, and finally choose the option that yields the highest (perceived) well-being for ourselves and/or others. As Costanza et al. (2017)

summarizes: "as long as we are forced to make choices, we are going through the process of valuation."

Furthermore, in the current economic and societal context, the most direct way to obtain the needed focus on the importance of functional ecosystems (or more generally, of "nature") is to attach a monetary value to it, so that it can be more easily integrated in policy making processes (Hoff et al., 2021). In order for this approach to be discarded in favour of less "economic-centric" methods, there would need to be a global paradigm shift, which is still not foreseeable in the near future. Therefore, for the time being, integrated monetary quantification is the best available medium to reach the equilibrium in sustainable development that is advocated in frameworks such as the Planetary Boundaries and Doughnut Economics, where social improvements are counterbalanced by a respect of the environmental boundaries (Raworth, 2017; Rockström et al., 2009).

2.4 Potential repercussions on secondary data analyses

The biases and gaps highlighted in our review are not only relevant for the quality of primary assessments. As mentioned in section 2.1, primary data is the basis on which secondary data analyses (i.e. benefit transfers and meta-analyses) are built upon. Therefore, limitations in primary collection approaches will likely cascade into these assessments, potentially further hindering the prioritization of NBS. For example, meta-analyses allow for a greater generalization of values/results and provide smaller confidence intervals than primary collection methods (Brander et al., 2013), which makes them useful tools for the transferability and upscaling of NBS values, especially in contexts where the resources necessary for a primary data collection are scarce. Thus, if primary studies do not complete a holistic assessment of NBS benefits, there is a concrete risk of secondary data analysis not picking up on some of the NBS positive impacts or features, not "upscaling" them for application in other sites and so forth, thus entering into a negative feedback loop, which in the long run could inflict lasting damages on the valuation (and also perception) of these solutions.

Another trend observed in the current literature that could likely limit the development and precision of meta-studies is the lack of easily comparable data. In fact, the majority of the analysed papers only assessed a single study site (Fig. 2.3) and did not seem to contemplate a replicable application of their methods. While this is not unusual and often taken as a necessity for the site-specificity of SP methods, it leads to the production of a series of "stand-alone" studies that may be assessing widely different features of NBS.

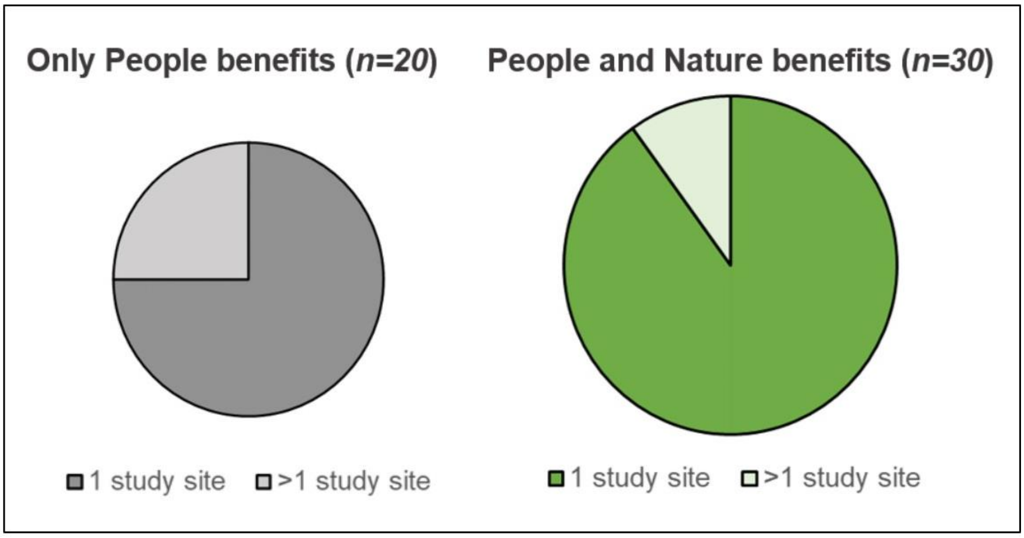


Figure 2.3 Representation of the number of primary studies on the assessment of non-tangible benefits of NBS targeting only one or more study sites. The majority of the studies assessing more than 1 study investigated 2 study sites. Source: adapted from **Paper I**.

Meta-analyses in particular rely on the comparison between different primary studies, but if the studies analysed do not include the same variables, the creation of new value functions is greatly limited, and the exclusion of relevant (especially non-tangible) variables more likely. Studies using meta-analyses point out this gap as a hindrance to creating truly holistic assessments (Bockarjova et al., 2020; Skrydstrup et al., 2022). The risk is then to prevent the upscaling potential of these analyses to be developed at its fullest.

The take-away message is not that all the primary collection analyses should always be replicable, but rather that we should at least try to reach a balance between site-specificity and a holistic assessment "standardized" to a point where a comparison between the data from different studies is possible.

3 Creation and application of a novel quantification method

Having highlighted the current issues and the overall challenges in regards to the assessment of non-tangible benefits of NBS, we moved onto creating a novel methodology aiming at closing the identified gaps and biases. The main goals were for the novel methodology to be: (i) easily tailorable to maximize its potential application across a wide variety of NBS, and (ii) focused on people and nature non-market benefits, and their interconnections (**Paper I**).

In order to test the replicability of our method, we applied it to different case studies. Being that this research is part of RECONECT, we relied on the NBS sites developed as part of the project. This chapter offers a short description of these case studies, and an overview of the process and challenges connected to the creation of a replicable CV survey for the assessment of non-tangible benefits of NBS (**Papers II** & **III**).

3.1 Case studies

The RECONECT project relies on several case study sites, called Demonstrators within the project and referred to as such in this thesis. All Demonstrators are large-scale European NBS implementations built to reduce various kinds of hydro-meteorological risks (e.g. pluvial floods, coastal floods, landslides). They are divided into two groups:

- Demonstrators A. They are NBS that are fully created and validated during the RECONECT project lifetime (2018-2024).
- Demonstrators B. They are existing NBS projects to be further monitored, evaluated and validated during the RECONECT project.

A third type of cases are the Collaborators, which are a network of European and international cases (5 EU and 13 International) where prefeasibility studies and knowledge sharing activities are performed within RECONECT. They will not be discussed in depth in this thesis. A map of all the RECONECT NBS projects that have been directly involved in the research reported in this thesis are shown in Figure 3.1 and listed below together with a brief description.

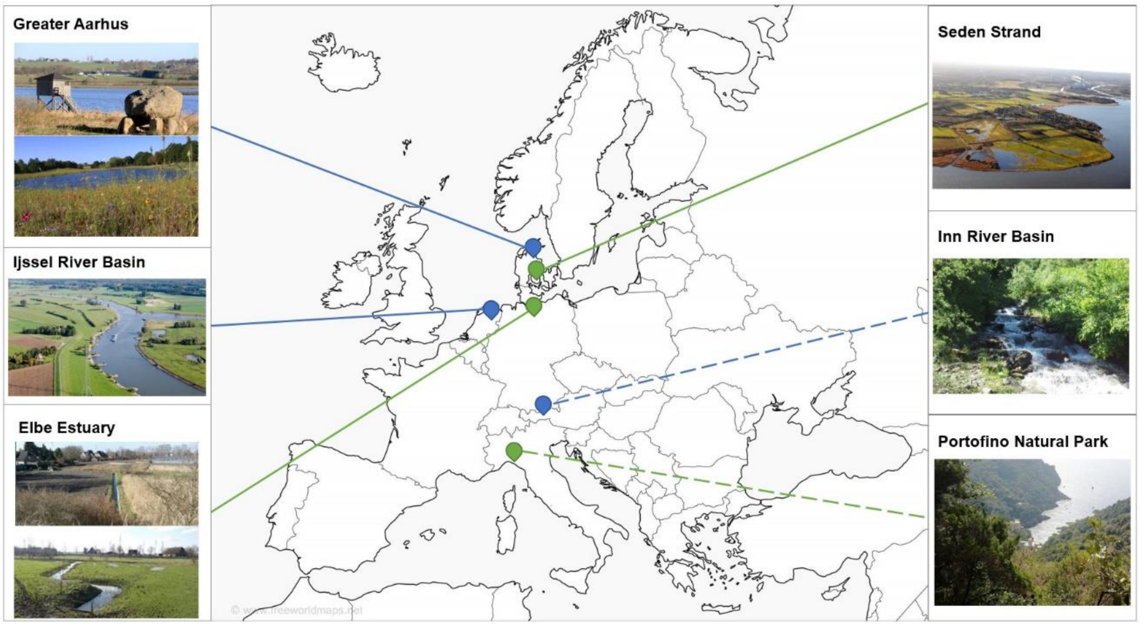


Figure 3.1 Map of the RECONECT Demonstrators A and B involved in this project. The green lines indicate Demonstrators A, the blue lines indicate Demonstrators B. The full lines indicate residential sites, while dashed lines indicate touristic sites. Source: **Paper III**.

Greater Aarhus (Demonstrator B)

This case study is comprised by two different sites: a peri-urban lake (Lake Egå), and an urban park (Hovmarksparken). They are both found in the river catchment area of River Egå in the northern part of the city of Aarhus, and both are contributing to the reduction of flood risk from cloudburst events. Lake Egå is an artificial waterbody first established in 2006 as a large water reservoir (155 ha). The area adjacent to the lake has been reconverted into wetlands and meadows and is now a protected natural area. Hovmarksparken, is the largest (6 ha) of 11 local climate adaptation sites in the suburb of Lystrup, and is part of a larger urban cloudburst adaptation strategy. Hovmarksparken includes a rainwater pond and rainwater dikes, as well as fields and green areas with biodiversity-enhancing elements (Aarhus Kommune, 2014; Knudsen et al., 2019). Within RECONECT, these two strategies are monitored and evaluated.

Seden Strand (Demonstrator A)

The project area in Seden Strand is located on the coast 8 km from the Danish city of Odense, and is threatened by flooding due to the rising sea level. 142 private homes are at the direct risk of flooding, as well as up to 66 ha of agricultural areas and 10 ha of salt meadows habitats. The NBS project completed during RECONECT implemented the following measures: relocation of low coastal dikes on higher inland ground, promoting a rehabilitation process of the new marine foreland (27 ha) to create more salt meadows (fulfilling Natura 2000 habitat re-creation), removing the dikes and re-creation of meanders in the stream draining the catchment, and construction of a new observation tower and a trail to access the site.

IJssel River Basin (Demonstrator B)

The NBS projects implemented along the IJssel River Basin ("Stroomlijn") are part of the "Room for the River" program. This is a government design plan started in 2007 addressing flood protection, master landscaping and the improvement of environmental conditions in the areas surrounding Dutch rivers. A variety of different methods have been used in over 30 projects, the majority of which have been completed, mostly focusing on giving the river a space to flood safely (Rijkwaterstaat, 2022). Within the RECONECT project, 9 of the interventions on the river Ijssel, distributed over 6 sites, are assessed. Some of the specific measures implemented in these sites are: relocation of dikes to create wider floodplains (Zuphten and Zwolle), lowering of floodplains (Deventer and Kampen), creation of deeper side channels and gullies (Veessen-Wapenveld), removing obstacles, inclusion of nature areas, addition of hiking and cycling paths.

Elbe Estuary (Demonstrator A)

The river system of Dove and Gose Elbe, located in the south-eastern part of the City of Hamburg, Germany, is part of the complex drainage system of the area Vier- und Marschlande, including also the river Bille and the surface waters of Schleusengraben, as well as the Old and New Brookwetterung. The regulation of the water levels in this area is fundamental in order to avoid both floods and droughts in the catchment. Therefore, the main goal of the NBS project is to reactivate the storage capacity of the rivers Bille, Dove and Gose Elbe, their tributaries, trenches and floodplains in an area of 11000 ha, to create more retention volume for water. To obtain this, the complex monitoring and control system of the area will be improved through the conversion of grey infrastructure into hybrid solutions and the adaptation to a more holistic approach, at the same time as creating (natural) floodplains and storages.

Inn River Basin (Demonstrator B)

The NBS is located in the Geroldsbach-Götzens sub-catchments, near Innsbruck (Austria). The area includes the torrential catchments Geroldsbach (12 km^2) and Marbach (1.2 km^2) with two urban catchment parts (Götzens and Neu-Götzens). In the past, major catastrophic events have taken place in the

Geroldsbach catchment, which is particularly subject to flash floods and landslides. Therefore, since the early 1950s flood protection activities have been taking place in the area. NBS projects such as reforestation and creation of grasslands have been implemented in combination with large-scale technical solutions, such as retention basins. Within RECONECT, the benefits of these long-term NBS are demonstrated and evaluated.

Portofino Natural Park (Demonstrator A)

The Portofino Natural Regional Park is a protected coastal area, the most northern in the western Mediterranean Sea, located in the Ligurian Appennines in Italy. It is a unique natural landscape with high social, ecologic and economic (touristic) value, and it is severely endangered by flash floods and landslides. The NBS actions in this case study are being implemented within the RECONECT project, and they are carried out in 4 different catchments. They are: construction of dry stone walls and restoration of abandoned terraces, hydraulic-forestry arrangements on water courses, riverbed and tributary arrangements, natural engineering interventions along hiking paths, reforestation, and hydrogeologic and meteo-climatic monitoring.

3.2 Building a replicable, holistic questionnaire

The first step to create a novel methodology for the assessment of non-tangible benefits to be applied across study sites was to determine the data collection approach to adopt. The aim of our research was to assess both use and non-use values of NBS, as well as projects ex-ante and ex-post implementation. Moreover, we had to take into consideration the necessity of replicating the same valuation question in different contexts, so the adaptability of the approach was also very relevant. Considering these needs and given the different SP methods discussed in section 2.1, a Contingent Valuation (CV) approach was deemed the most fitting.

However, we went beyond applying a well-established methodology, and produced a new method that would be able to address the gaps described in the literature (**Paper I**, see chapter 2). Below we list the major novelties of our approach.

3.2.1 The modularity

A big challenge for our survey was to find a way to assess the same variables in all case studies, in order to obtain easily comparable results. The capacity of CV methods to assess the value attributed by respondents to non-tangible benefits is based on the creation of an ad-hoc, credible hypothetical scenario, plausibly describing the good or the change to be assessed (Johnston et al., 2017). Therefore, we needed to find a balance between creating a replicable questionnaire that collected the same data across sites and a site-specific questionnaire supplying the right amount of information to allow respondents to make an informed evaluation. We found a solution in creating a modular survey including sections that were highly site-specific, which had to be (almost) completely re-written for each case study, and sections that could be re-used across sites with minimal adjustments (e.g. substituting the name of the site in the question, adjusting the hydro-meteorological risk counteracted in the project) (Table 3.1).

Table 3.1 Overview of the different modular blocks of the survey, their description and their "site-specificity" level.

Sections of the survey	Brief description and/or examples of contents	Level of site-specificity
Description of the site	Short paragraph and map to describe the NBS project(s) in the site	High
Relationship to and use of the NBS area	Questions such as: distance from the NBS, frequency of visit, reason of visit, level of concern and previous experience regarding hydro-meteorological risks	Low
Personal preferences of the respondent	Preference regarding recreation facilities, green areas and benefits for nature, etc.	Low
Hypothetical WTP scenario	Setting of the valuation scenario specifying the changes brought by the NBS	High
WTP questions	Contingent valuation and a protest vote question	Moderate
Socio-demographic information of the respondent	Age, income, household size, etc.	Low

3.2.2 The co-design

An enhanced participation of stakeholders at the local level has been highlighted as a desirable practice for reaching the desired implementation goals and efficient local solutions, but is rarely carried out in practice (Nielsen et al., 2013; Voulvoulis et al., 2017). Thus, there needed to be a focus on co-design in shaping a new approach, in order to best integrate the assessment of the socio-cultural context, and avoid missing out on the incorporation of local knowledge.

Therefore, once the basic structure of the survey was determined, we reached out to the project partners responsible for each Demonstrator site listed in section 3.1, in order to adapt the general structure of the survey to the specific site characteristics of each case. The entire process is schematized in Figure 3.2.

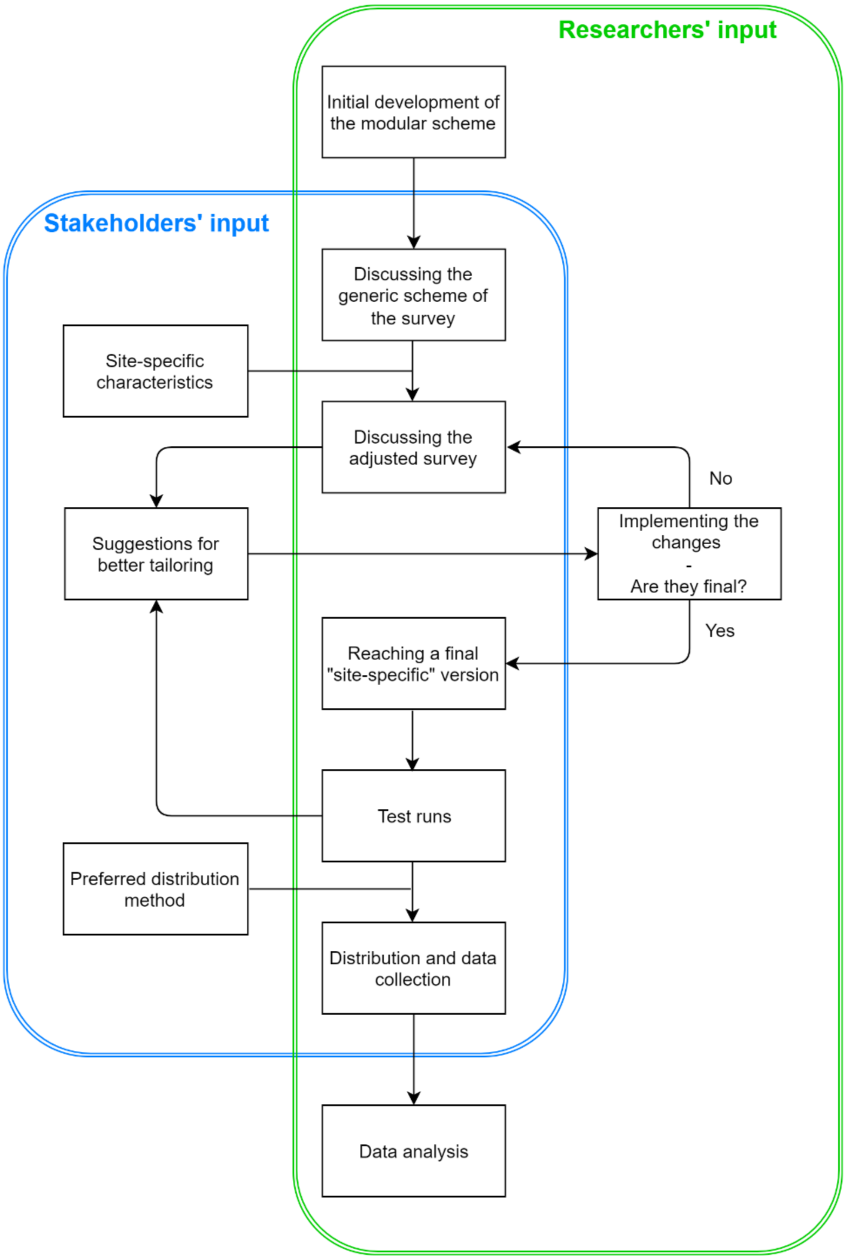


Figure 3.2 Schematization of the process of co-design of the novel survey.

The main inputs from the Demonstrators' side consisted in supporting the definition of the highly site-specific "blocks" of the survey (e.g. the introductory text describing the characteristics of the NBS, see Table 3.1) and providing the distribution method (e.g. if they had access to online distribution methods, social media, traditional mail distribution, etc.). Moreover, they provided inputs regarding the overall wording of the questions and options for the answers, and they supported the test-runs of the survey. However, in order to maintain the replicability and comparability of the study as much as possible, it was not allowed to remove questions or to modify their overall objective in the general scheme. Nevertheless, the Demonstrators could add other site-specific questions that would not be replicated in the other sites, as long as they stayed within certain survey length limits.

3.2.3 Assessing variables across challenge areas

According to the suggestions expressed in various studies and guidelines (Hanson et al., 2020; IUCN, 2020; Raymond et al., 2017), the valuation of non-tangible benefits should endeavour to determine what people's perceptions are with regards to the risk the NBS is designed to counteract, the value allocated to improved human well-being, and last but not least, the significance the respondents attribute to changes made that will benefit nature itself.

Despite these guidelines, our literature review had pointed out quite a "silos" approach to the assessment of the non-market benefits of NBS (**Paper I**). We therefore made sure to include in our survey the assessment of variables throughout the NBS challenge areas (i.e. water, nature and people) and their overlaps. For example, we included both assessments of the relationship between the respondents and the NBS area and quantifications of the personal preferences of the respondents across water, nature and people challenge areas (e.g. in terms of previous experience of the respondent with the hydro-meteorological risks in the area, importance attributed to increased recreation opportunities and to the presence of no-access areas set aside for nature) (**Paper II**). These assessments completed a survey scheme containing more "traditional" questions such as those collecting the socio-demographic characteristics and the relationship of the respondents with the site. All of these data are required to get a full overview of the factors influencing the evaluation of a NBS (Fig. 3.3) (Venkataramanan et al., 2020).

Inspiration for the creation of the questions was drawn from the literature on the topic (e.g. Bateman et al., 2011; Bernath & Roschewitz, 2008; del Saz Salazar & García Menéndez, 2007; Derkzen et al., 2017; Reynaud et al., 2017).

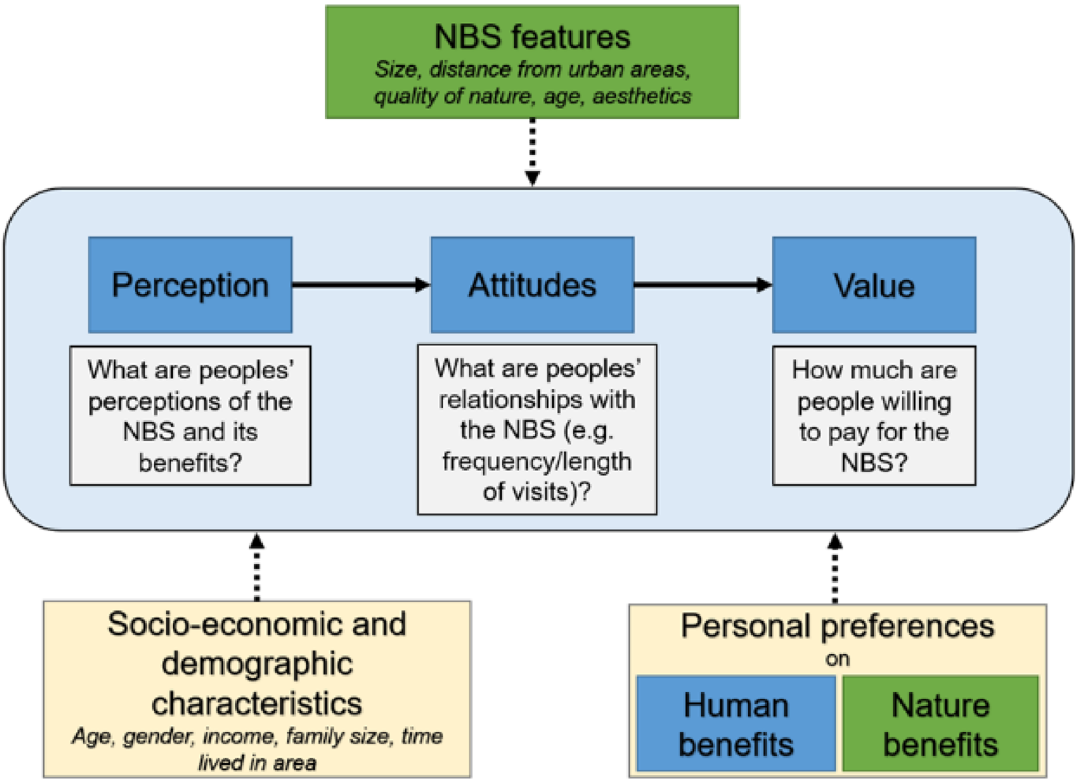


Figure 3.3 Overview of the factors influencing the valuation of NBS, also corresponding to the data collected through our survey. Source: **Paper II**.

3.3 Overview of the resulting dataset

Table 3.2 shows the list of collected variables though our survey across study sites. To our knowledge, this is a unique dataset of fully comparable data on the non-tangible benefits of NBS collected across various peri-urban case studies.

However, it is important to note that we are reporting here only the variables that were registered the same way across all study sites. Some surveys included additional questions that are not reported here, since they were added during the co-design process to address some very specific features of the NBS area that were of interest for the Demonstrator partners, but not necessarily for the assessment of non-tangible benefits (e.g. asking about the use of a specific item in the site; qualitative questions to elaborate on why respondents were not visiting the site). Therefore, Table 3.2 is not an exhaustive report of all the registered variables, but it is the "cleared" dataset on which the analyses described in the following sections (4 & 5) are built upon.

Table 3.2 Summary of all the collected variables through the surveys and the methods used to quantify them. Source: adapted from **Paper II**.

Section	Variable name	Description	Answer method
Relationship between people and the study site			
	Distance	Distance from the study site chosen	Multiple options
	Frequency	Frequency of visit to the study site	Multiple options
	Travel time	Length of travel time to the study site	Multiple options
	Visit time	Time spent visiting the study site	Multiple options
	Visit nature	Visiting the area to enjoy nature	Dichotomous
	Visit social	Visiting the area to spend time with family/friends	Dichotomous
	Visit sport	Visiting the area to practice sport	Dichotomous
	Visit pass	Visiting the area just passing by (e.g. on the way to work)	Dichotomous
	Risk worry	Respondent's concern regarding the hydro-meteorological risk	Likert scale (1-7)*
	Risk direct	Direct experience with the hydro-meteorological risk	Dichotomous
	Risk indirect	Knowing someone who had a direct experience with the hydro-meteorological risk	Dichotomous
People's preferences			
	Green areas	How important it is for the respondent to access green areas	Likert scale (1-7)
	Recreation	How important it is for the respondent to have access to recreation facilities	Likert scale (1-7)
	Biodiversity	How important it is for the respondent that biodiversity enhancement features are in place	Likert scale (1-7)
	Nature only	How important it is for the respondent that areas set aside for nature (i.e. without access for people) are present	Likert scale (1-7)
Valuation questions			
	WTP base	Respondent's WTP for the maintenance of the area	Multiple options
	WTP nature	Respondent's WTP for the enhancement of nature benefitting features (additive)	Multiple options

	Protest	Respondent's reason for expressing 0 WTP in both valuations	Multiple options
Socio-demographic information			
	Post	Postal code	Open ended
	Age	Age	Multiple options
	Sex	Sex	Dichotomous
	Residence time	Time living in the area	Open ended
	People household	Number of people in the household	Open ended
	Children	Presence of people younger than 18 in the household	Dichotomous
	Income	Household income	Multiple options

*1 being the lowest score and 7 being the highest

The complete text of the survey, as it was distributed in the Aarhus case study, can be found in the Supplementary Information for **Paper II**.

3.4 Challenges and limitations setting up a replicable survey

3.4.1 Regarding the creation of the survey

Various challenges emerged through the entire process of tailoring the survey to the different case studies. First, establishing a contact with the Demonstrators and convincing them to join the co-design and distribution of a survey addressed to the general public was quite complex. Reaching out to the public was seen as a delicate task by various Demonstrators. This was due to a number of reasons, not least related to previous negative interactions with the public in some cases. A widespread concern was that involving the general population would uncover scepticism and opposition, potentially harming the progress of the NBS implementation. Specifically, this was relevant for some Demonstrators A, where the projects are still ongoing. However, despite some initial resistances, the assessment was completed in all the sites where a collaboration was initiated. During this process, the use of a co-design approach was fundamental to gain the trust and the final agreement of the partners, who were integral contributors to the definition of the survey, rather than having something imposed from the top-down. This was in fact the most likely reason why we could successfully implement the survey in all sites where the collaboration was initiated.

As for the survey's co-design process, the most challenging questions to pose in a replicable way were the ones connected to the evaluation of the respondent's WTP. Some of the Demonstrator partners (e.g. Municipalities) were very wary regarding the hypothetical use of taxes as the medium for the assessment of WTP, although it is quite conventional within CV methods (Arrow et al., 1993). Their concern was that this approach would cause the respondents to think that the Municipality was "testing the waters" through the survey in order to actually increase taxation. Eventually, we settled for a more generic phrasing focusing on a monthly "fee", and avoiding the definition of "tax". Regarding the other questions, most of the different approaches to them could be linked to cultural contexts. For example, some Demonstrators opposed the idea of asking respondents to directly state their household income, in fear of refusals to complete the questionnaire.

Finally, when assessing the overall replicability of our survey scheme, it is necessary to address some observable limitations. Because of time restrictions but especially due to the emergence of the COVID-19 pandemic, the in-person meeting schedule of the RECONECT project was disrupted and the partners were forced to meet only online for a year and a half. We were therefore prevented from organizing collective co-design sessions, and we had to touch base with each site one by one. Once the first co-design process was completed and the survey was distributed, we could not change the question scheme anymore, in order to keep the comparability across sites. Our first co-design partner was the Aarhus site, a mainly residential area with access to online survey distribution. Therefore, some bias towards residential sites can be observed, especially in the answer options (e.g. the intervals to select the distance to the NBS site, the activities done in the NBS area, etc.). A more truly transversal co-design and a more structured agreement on the questions and answer options across sites could have strengthened our survey design and the analyses that followed.

3.4.2 Regarding the distribution of the survey

The initial goal of this study was to collect the responses of both users (i.e. people with a direct relationship with the area, and living close to it), non-users (i.e. people living close to the site but not interacting with it) and visitors (i.e. people not living close to the area but travelling there with the specific aim of visiting it) of the investigated NBS areas. This was expected to be achieved by distributing the survey both online (through the means provided by the Demonstrator) and in person (through the PhD student and/or other collaborators' presence on the field), to capture the potential and the actual users of the site respectively. However, this plan was disrupted by the COVID-19 pandemic during the early planning phases of the study. Therefore, we had to resort to relying only on the online distribution.

The different Demonstrators had access to very different means of distribution for the survey. In the case of the two Danish sites (both managed by Municipalities), there was the possibility of using official online distribution methods, while for other partners (e.g. the ones where the Universities were the responsible partners) the choice was much more limited. The overview of the outcomes of the distribution campaigns is shown in Table 3.3.

Table 3.3 Overview of the outcomes of the distribution campaigns across sites. Source: adapted from **Paper III**.

Study sites	Number of respondents	Type of respondents	Distribution method	Collection period
Greater Aarhus – Lake Egå	576	Users and non-users	Digital mailbox	June/July 2021
Greater Aarhus - Hovmarksparken	258	Users and non-users	Digital mailbox	June/July 2021
Seden Strand	360	Users and non-users	Digital mailbox	November/December 2021
Elbe River Delta	433	Users	In person and physical letters	July/August/September 2022
IJssel River Basin	180	Users	In person, flyers and through social media	July 2021
Portofino Natural Park	99	Visitors	Digital newsletter and social media	June/July/August 2022
Inn River Basin	48	Users	Digital newsletter	May/June 2022

Clearly, the type of assessment used closely reflected the type of respondents that were registered, as it was proven through the analysis of the responses. This difference within our sampled populations was a limitation to the comparability of our results, and it was a complex issue to work with in the following analyses (as described in sections 4 & 5). As the type of distribution is crucial to ensure a replicable assessment, it would be recommendable for future studies to carefully consider the distribution options, preferably using only one approach across all sites. This is one of the most challenging aspects of replicating a survey across different sites.

4 NBS valuation: the influence of socio-cultural and physical contexts

Despite the discussed shortcomings, our survey allowed us to collect a remarkable dataset. Specifically, we gathered a lot of information on users' preferences and behaviours (i.e. socio-cultural context of NBS) across sites and types of NBS, which is data that are increasingly recognized as crucial for the prioritization and support of NBS (Derkzen et al., 2017; Hérivaux & Le Coent, 2021). However, large, multi-site studies on this topic have been lagging behind because this information is very complex to collect if not in the form of primary data. Thus, our study offers a unique insight into a rarely analysed set of variables and a chance to determine their influence on the valuation of non-tangible benefits of NBS.

This chapter presents the methods and some of the main outcomes of our analyses (**Papers II** & **III**).

4.1 Statistical methods employed in this project

During this study, the outcomes of the survey were analysed in two main stages. The first focusing on the results from the Aarhus case study, which defined the methods for the data analysis (**Paper II**); and the second one focusing on the replication of (the majority of) the analyses across all case studies, and on testing whether their outcomes could be summarized in joint value functions for the valuation of non-tangible benefits of NBS (**Paper III**).

Table 4.1 summarizes all the methods used, which were inspired by various sources (Bateman et al., 2011; Bernath & Roschewitz, 2008; Crawley, 2005; Saz-Salazar & Rausell-Köster, 2008).

Table 4.1 Summary of the methods used as part of the statistical analyses. The analyses have been carried out in R using the *car* and *ggplot2* packages. Table adapted from **Paper II**.

Aim	**Methods**
Step 1 – Description of the samples	
Summarize the characteristics of our dataset.	Descriptive statistics of the results of the surveys.
Step 1bis – Analysis of the protest votes – Applied only to the Aarhus case study	
Is the sample biased compared to the general population in Aarhus?	Descriptive statistics of the respondents' socio-demographic characteristics relative to the general population.

Are protest votes (i.e. respondents who do not accept the hypothetical valuation scenario and therefore refuse to state a WTP) associated with particular characteristics and would their exclusion thus bias the results in any direction?	Logistic regression model, with the binary protest variable as response variable. The entire Aarhus dataset was used, and the final model was obtained through backwards selection. $\log\left(\frac{p}{1-p}\right) = a + bX + cY + dZ + \varepsilon$ (1) *p*= stating a protest vote; *X, Y, Z* = vectors of explanatory variables regarding preferences, uses and socio-demographic characteristics of the respondents, respectively; *a, b, c, d*=vectors of parameters to be estimated in the logistic regression model; *ε*=error term.
Step 2 – Analyse willingness to pay values	
Do respondents increase their original WTP bid (WTP_{base}) if further actions to improve the quality of the nature in the NBS are included in the valuation scenario ($WTP_{total} = WTP_{base} + WTP_{nature}$)?	Compare sample means using t-tests and bootstrapping. WTP bids were corrected for differences in purchasing power parity (PPP) between countries using indices from the European Statistical Office (Eurostat, 2022b) and converted into 2021 Euros. $H_0: WTP_{base} = WTP_{total}$ (2)
*Given its small sample (i.e. 48 respondents) the Inn River Basin case study was not included in the following analyses, and used for qualitative comparisons only (**Paper III**).*	
Which explanatory variables influence the WTP bid levels across sites?	Multiple linear regression models, two for each site, each pair separately using one of the two WTP bids (WTP_{base} and WTP_{total}) expressed for each site as dependent variables. Protest votes were excluded from the dataset. WTP values were log-transformed due to the skewed data distribution. The final models were obtained through backwards selection. $\log(WTP_{base} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon$ (3) $\log(WTP_{total} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon$ (4) where $y_0 = 1$ is introduced to allow *WTP* bids of zero value, *X, Y, Z* = vectors of explanatory variables regarding preferences, uses and socio-demographic characteristics of the respondents; *α, β, γ, δ*=vectors of parameters to be estimated in the linear regression models; *ε*=error term.
Is the quality of our models satisfactory?	Sensitivity analyses including model diagnostics and F-tests were conducted for all the models.
Step 3 – Create a joint model for all sites	
*The Portofino site was excluded from the last steps, as its respondents' sample presented characteristics too different from those of the other sites for it to be meaningfully aggregated to any of them (**Paper III**).*	
To what extent can the single-site models overlap? Is it possible to summarize their results in a common value function?	Two multiple linear regression models, one for each WTP bid, using the aggregated datasets of the sites (excluding Portofino). The case studies were aggregated in two groups based on the type of responses collected (i.e. users and non-users, and users only). A dummy variable for the "users only" group was added to the model. All the variables (including

	WTP) were standardized and the explanatory variables were interacted with the dummy variables in the model. $\log(sWTP_{base} + y_0) = \alpha + USER + \beta(sX) + \gamma(sY) + \delta(sZ) + \eta(USER * (sX, sY, sZ)) + \varepsilon$ (5) $\log(sWTP_{total} + y_0) = \alpha + USER + \beta(sX) + \gamma(sY) + \delta(sZ) + \eta(USER * (sX, sY, sZ)) + \varepsilon$ (6) where *USER* indicates the dummy variable for the group of Demonstrators "users only"; *sWTP* = standardized WTP; *sX, sY, sZ* = vectors of standardized explanatory variables regarding preferences, uses and socio-demographic characteristics of the respondents; *α, β, γ, δ, η* = vectors of parameters to be estimated in the linear regression models; N*n denotes interaction terms between two explanatory variables; *ε*=error term.
Can the previous model be defined in another way, more specific to the users of the site?	Two multiple linear regression models, using the same dataset and applying the same variable transformations. The only difference was the use of two dummy variables instead of one, namely a dummy for the "users only" of Danish sites (A) and a dummy for the "users only" of the other sites (B). $\log(sWTP_{base} + y_0) = \alpha + A + B + \beta(sX) + \gamma(sY) + \delta(sZ) + \eta((A, B) * (sX, sY, sZ)) + \varepsilon$ (7) $\log(sWTP_{total} + y_0) = \alpha + A + B + \beta(sX) + \gamma(sY) + \delta(sZ) + \eta((A, B) * (sX, sY, sZ)) + \varepsilon$ (8) where *A* indicates the dummy variable for the group of "users only" from Danish sites, and B is for the group of "users only" for the other sites; *sWTP* = standardized WTP; *sX, sY, sZ* = vectors of standardized explanatory variables regarding preferences, uses and socio-demographic characteristics of the respondents; *α, β, γ, δ, η* = vectors of parameters to be estimated in the linear regression models; N*n denotes interaction terms between two explanatory variables; *ε*=error term.
Can a "predictive" model be created for the upscaling of valuation, using easily retrievable parameters only?	Two multiple linear regression models, one for each WTP bid, using the same datasets and dummy as for equations 5 and 6. $\log(sWTP_{base} + y_0) = \alpha + USER + \beta(sW) + \eta(USER * (sW)) + \varepsilon$ (9) $\log(sWTP_{total} + y_0) = \alpha + USER + \beta(sW) + \eta(USER * (sW)) + \varepsilon$ (10) where *USER* indicated the dummy variable for the group of Demonstrators "users only"; *sWTP* = standardized WTP; *sW* = vectors of standardized explanatory variables regarding easily "up-scalable" characteristics of the respondents; *α, β, η* =vectors of parameters to be estimated in the linear regression models; N*n denotes interaction terms between two explanatory variables; *ε*=error term.

4.2 Respondents' preferences and uses of NBS

As presented in Chapter 3, a distinctive characteristic of our dataset is the inclusion of the preferences of the respondents, which are very complex to measure in the same way across different sites, and therefore are often left out from multi-site assessments (Bockarjova et al., 2020; Skrydstrup et al., 2022). We thus focus here on a descriptive overview of these data specifically, before proceeding into the analyses of NBS evaluation.

Figure 4.1 shows the feelings and preferences of the respondents across the three challenge areas of NBS (i.e. water, people and nature). The concern over the specific hydro-meteorological risk for each area (i.e. fluvial or coastal flooding, landslides, etc.) was found to be quite low across sites, with the exception of Elbe and Portofino, which, interestingly, are Demonstrators A (meaning that the NBS in those areas are still being constructed). In the other sites the risk of being flooded is not that present, and especially in the Danish sites the concern over the risk appears to be lower than elsewhere.

As for the other variables, the respondents' preferences appear more homogeneous across sites. The importance of having access to green areas and of the presence of biodiversity-enhancing features obtained a more unmistakably positive score in comparison to the importance of recreation facilities and of no-access nature for nature areas, which divided the opinions slightly more.

Figure 4.1 Representation of the respondents’ personal preferences registered across sites. 1 means that the respondent associated a low concern/importance to the object of the question, 7 means that the respondent associated a high concern/importance to the object of the question. LE=Lake Egå; HP= Hovmarksparken; SS=Seden Strand; EE=Elbe Estuary; IJ=IJssel River Basin; PP=Portofino Park; IN=Inn River Basin.

Another interesting insight was given from the information regarding the use of the NBS by the respondents. This is another example of data that is challenging to collect across sites, except through the use of primary data collection. The results are shown in Figure 4.2.

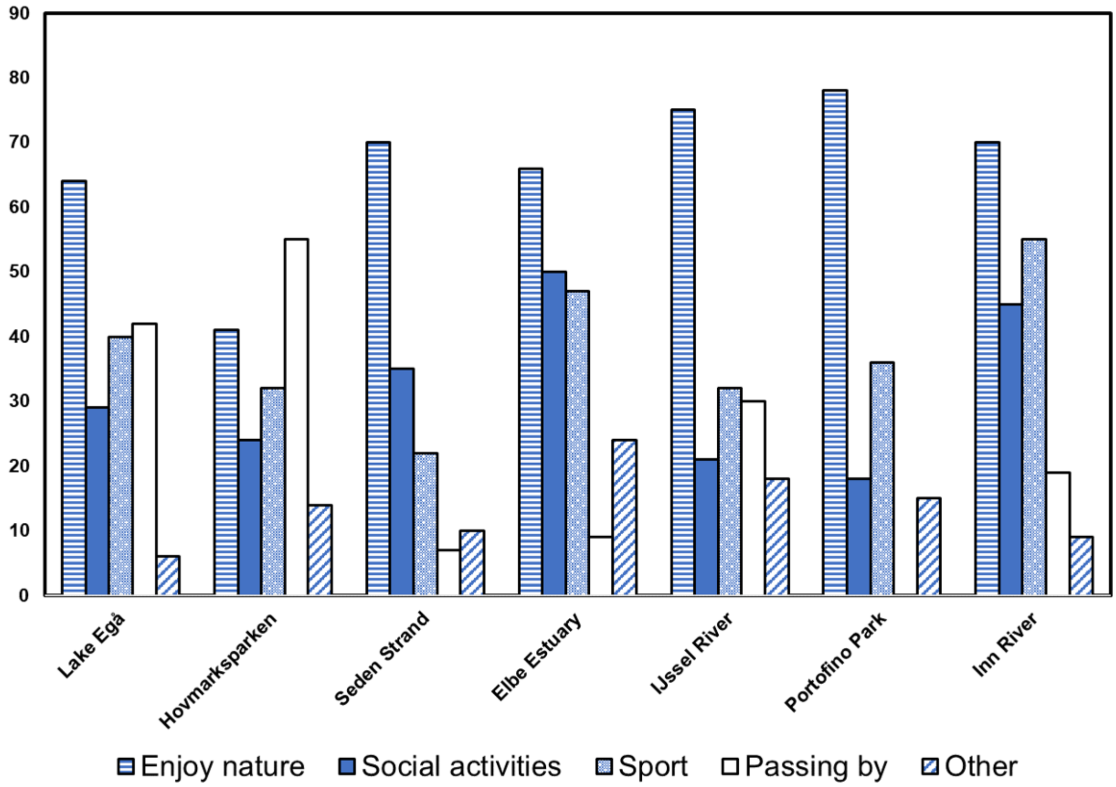


Figure 4.2 Percentages of respondents undergoing each of the specified activities in the various sites (multiple answers were allowed).

Visiting the NBS to enjoy nature was the most frequently chosen option, while using the area for sport or social activities followed. A high number of people just passing by the area (e.g. on their way to work or to walk the dog) can be noticed in the most "urban" of our sites, i.e. Lake Egå and particularly Hovmarksparken, which are also the sites where the appeal of nature is felt the least. In brief, the registered uses well paired up with the sites' different features.

When taking into consideration also the results from the socio-economic, demographic data and the relationship between the respondents and the NBS (e.g. distance to the site, frequency of visit, etc.), the collected responses did not provide much heterogeneity (**Paper III**). Rather, our survey appeared to have gathered a quite homogeneous set of responses from individuals slightly older than the median age (Eurostat, 2022a), living with a partner but not necessarily with children, with a majority (excluding Portofino Park) of male respondents.

Similarly, in respect to the relationship to the site, the survey mainly collected responses from respondents that live within 10 km from the NBS, take less than 30 minutes to reach the site, and have frequent visit times. An exception to this pattern is the site of Portofino Park, where the survey captured people living further away from the NBS, traveling and staying longer at the site. The latter characteristics were at the base of the differentiation between non-users, users and visitors made in Table 3.3.

4.3 Major influences on NBS valuation across sites

Various studies point out the relevance of the socio-cultural context in the evaluation of NBS and the importance of gathering knowledge on variables such as people preferences, and attitudes towards NBS and their non-tangible benefits (Anderson et al., 2022; Derkzen et al., 2017; Hérivaux & Le Coent, 2021; Venkataramanan et al., 2020; Vollmer et al., 2015). A novelty of our study was the possibility to look specifically into these variables through a quantitative lens, thanks to the elicited WTP bids, and across many different sites at the same time. To our knowledge, usually assessments of NBS are either qualitative (e.g. Anderson et al., 2022), or they are assessing one single site (e.g. Vollmer et al., 2015), but very rarely combine these two aspects.

In this section we will first look at our dependent variable (the value associated to the NBS by the respondents) and then we will present the results of the models used to determine what are the factors influencing these evaluations.

4.3.1 The valuation

As we have described previously, we assessed two separate WTP bids, one regarding the WTP for the NBS as it is, and the other for an additive bid if the NBS were to include further improvements for nature. We chose to report *WTPbase* (i.e. the bid to maintain the NBS or its project as it is) and *WTPtotal* (i.e. the sum of *WTPbase* and the additive bid for an increase in the natural features of NBS – *WTPnature* in Table 3.2). Table 4.2 shows the outcomes across all sites.

Table 4.2 Overview of the WTP means registered in all case studies, including the difference between means with respective 95% confidence interval. These values were obtained excluding the protest votes (i.e. the respondents who do not accept the hypothetical valuation scenario and therefore refuse to state a WTP) from the dataset.

Type of WTP	Mean (EUR/month/household)	Median (EUR/month/household)	Difference of WTP means	2.5%	97.5%
WTP base Egå	3.74	2.83	2.49	1.98	2.99
WTP total Egå	6.23	2.84			
WTP base Hpark	3.27	1.42	2.19	1.47	2.92
WTP total Hpark	5.46	2.84			
WTP base Seden Strand	3.95	1.42	2.7	2.05	3.36
WTP total Seden Strand	6.65	2.83			
WTP base IJssel	4.15	3.36	7.63	5.51	9.75
WTP total IJssel	11.78	5.04			
WTP base Elbe Estuary	11.32	7.37	7.13	5.71	8.54
WTP total Elbe Estuary	18.45	10.14			
WTP base Portofino	4.44	1.96	4.36	2.19	6.46
WTP total Portofino	8.8	3.91			
WTP base Inn River	5.8	6.7	4.8	3.16	6.24
WTP total Inn River	10.6	10.04			

As expected, in those areas where the sampling was randomized (i.e. Lake Egå, Seden Strand), the WTP was lower than in the areas where only the users of the site were interviewed (i.e. Elbe Estuary, IJssel River). The latter sites registered a higher WTP than even the touristic sites (e.g. Portofino Park and Inn River Basin). This outcome is likely due to the fact that in the "users" sites, many of the respondents live on site (particularly in the Elbe Estuary case), and therefore have an extra incentive to express higher bids. Throughout all the sites *WTPtotal* results significantly higher than *WTPbase*. This shows an overall interest of the respondents in the "greener" and multifunctional aspects of

NBS, which match very well to those of other studies (Derkzen et al., 2017; Hérivaux & Le Coent, 2021) and makes a case for encouraging a multidisciplinary and multi-benefits approach to NBS projects during a planning and other decision-making processes.

4.3.2 Results of the models

What is driving the different valuations across sites shown in the previous section? In order to find out, we analysed the results as specified in Table 4.1, and the outcomes are presented in Table 4.3.

Table 4.3 Results of all the models for the influence of variables on WTP. Only the significant variables are reported. Source: **Paper III**.

▲ = p<0.01
△ = p<0.1

		Frequency of visit	Sex (male)	People in household	Household income	Concern over risk	Direct risk experience	Importance of nature areas	Importance of biodiversity	Visiting the area to enjoy nature	Visiting the area to exercise	Passing by the area
WTP base	Lake Egå				▲			▲	△	▲		
	Hovmarksparken							▲				
	Seden Strand				▲	▲		▲				
	Elbe Estuary	▲			▲				▲			
	IJssel River			▽	△							
	Portofino Park				▲	▽	△					
WTP total	Lake Egå				▲			▲	▲	▲	△	
	Hovmarksparken							▲		△		△
	Seden Strand				▲	▲		▲			△	
	Elbe Estuary	▲		▽	▲				▲			
	IJssel River		△					△				
	Portofino Park		△		▲							

We can distinguish three main drivers of the valuation that are influential in different sites, in order from more to less influent:

- Income
- Personal preference/sensitivity towards nature
- Relationship with/usage of the area

These results fit quite well with the current understanding of the drivers of valuation of NBS. Income is usually highly correlated with a higher WTP since, unsurprisingly, those who have more resources are also most likely to be willing to use them (Andrews et al., 2017; Pepper et al., 2005; Saz-Salazar & Rausell-Köster, 2008). However, contrary to other studies, not many other socio-economic or spatial characteristics such as age or distance from the NBS appeared to significantly affect the WTP (Andrews et al., 2017; Tibesigwa et al., 2020). Instead, various variables connected to personal preferences and uses of the area are shown to be quite influential on the expressed bids, in particular the importance attributed to no-access nature areas, biodiversity enhancements and visiting the NBS to see/experience nature. Despite its limited presence in the literature, the impact of preferences is accounted for as a positive influence on the WTP (e.g. Bernath & Roschewitz, 2008).

Also, as expected, preferences and relationship to the area appear to play a larger role in the definition of *WTPtotal* rather than for *WTPbase*.

Preferences and attitudes of the public regarding NBS and their non-tangible benefits are complex to assess, but our results add to the evidence suggesting that they are a necessary step for a complete evaluation of these strategies. Knowing the drivers of the value associated by the respondents to the NBS is a great asset, as the public is taking on a bigger and bigger role in terms of co-design, implementation, and long-term monitoring and protection of NBS (Anderson et al., 2022).

5 Upscaling potential

In order to upscale the knowledge gathered through our surveys and the single-site valuation models, we looked into the development of value functions, i.e. functions that can be used to define the value of a good or service of interest (in this case a NBS area) starting from the available knowledge about it (Bockarjova et al., 2020) (**Paper III**). This way, we tried to determine whether the outcomes of our survey could also provide transferable value functions for sites where the distribution of questionnaires is challenging, if not impossible.

In this chapter our proposal of value functions for a possible upscaling approach is presented and compared to the results of existing meta-studies on similar strategies (i.e. NBS or NBS-like strategies). We conclude by discussing the feasibility of such an approach.

5.1 Determination of joint value functions

As a first step, we created an aggregated dataset by joining those of the single sites. However, during this joining process, it became clear that the respondents for Portofino Park were standing out from the rest by being mainly touristic visitors of the site. Given the respondents' different relationship with the site, it is likely that their WTP expressed the value of different aspects of the NBS in respect to the other sites, and therefore it was difficult to argue that their data could be meaningfully summarized into the model (**Paper III**). The Portofino dataset was therefore excluded from the following analyses. This left us with a dataset across 5 sites with very similar characteristics: implemented in peri-urban, residential areas, counteracting flooding risks (pluvial, riverine and coastal), and with the respondents living either close to or on the NBS area.

Once the dataset was determined, we proceeded with the definition of different models (see Table 4.1). First, we focused on creating a joint descriptive model that would effectively summarize the significant variables shown to influence the WTP in the single-site models (Table 4.3), and later we looked into the possibility of using our dataset for the determination of a predictive value function. Specifically for the latter, we tried to create an easily up-scalable (i.e. replicable to other sites) function, that would include only information easy to retrieve, e.g. through open-access data, like distance from the site, income, etc. The results of the two models are shown in Table 5.1.

Table 5.1 Outcomes of the descriptive and predictive joint regression models for *WTPbase* and *WTPtotal*. Standard errors are reported in the square brackets. Transformed variables were used here. USER is a dummy for the sites where the collected responses came from "users only" NBS sites. 'p<0.1 *p<0.05 **p<0.01 ***p<0.001 Source: adapted from **Paper III**.

	WTP base				**WTP total**			
	Predictive model		***Descriptive model***		***Predictive model***		***Descriptive model***	
		USER=1		USER=1		USER=1		USER=1
Intercept	-0.23 [0.05]***		-0.28 [0.06]***		-0.25 [0.05]***		-0.45 [0.07]***	
People in the house-hold	-0.05 [0.03]	-0.11 [0.06] '	-0.05 [0.04]	-0.09 [0.06]	-0.05 [0.04]	-0.10 [0.06]	-0.05 [0.03]	-0.08 [0.06]
Age	0.003 [0.03]	0.09 [0.07]	-	-	0.006 [0.03]	0.06 [0.07]	-	-
Sex (male)	0.04 [0.07]	-0.04 [0.13]	-	-	0.04 [0.06]	0.16 [0.12]	0.09 [0.06]	0.16 [0.12]
Household income	0.10 [0.03]**	0.35 [0.08]***	0.13 [0.04]***	0.30 [0.08]***	0.12 [0.03]***	0.23 [0.08]**	0.014 [0.03]***	0.17 [0.08]*
Direct risk experience	0.10 [0.07]	-0.05 [0.13]	0.01 [0.08)	-0.01 [0.13]	0.09 [0.07]	-0.12 [0.13]	-	-
Distance	-0.09 [0.02]**	0.02 [0.07]	-	-	-0.08 [0.03]**	0.04 [0.07]	-	-
Travel time	0.05 [0.03]	0.02 [0.07]	-	-	0.08 [0.03]*	-0.006 [0.07]	-	-
Frequency of visit			-0.01 [0.04]	0.15 [0.07]*			-0.06 [0.05]	0.22 [0.07]**
Concern over the risk			0.12 [0.04]**	0.02 [0.07]			0.11 [0.03]**	-0.08 [0.06]
Importance of "nature for nature" areas			0.15 [0.03]***	-0.001 [0.07]			0.18 [0.03]***	-0.03 [0.07]
Importance of biodi-versity			0.11 [0.04]**	-0.05 [0.06]			0.11 [0.04]**	0.005 [0.06]
Visiting to enjoy na-ture			0.20 [0.06]**	-0.36 [0.12]**			0.20 [0.07]**	-0.28 [0.13]*
Visiting to do sport			-	-			0.15 [0.07]*	-0.25 [0.13] '
Visiting just passing by			-	-			0.15 [0.08]*	0.03 [0.16]

To reflect in the models the two approaches used to collect responses (either randomized including both users and non-users of the site or on site including only users), we created a dummy variable (USER) for the “users-only” sites (Elbe Estuary and IJssel River). This allowed us to identify possible differences in outcomes based on the respondent sample.

The descriptive model appears to follow quite closely the results of the single-site models (Table 4.3): household income, concern over the hydro-meteorological risk, and personal preferences over nature benefits and reasons to visit the area have the strongest influence over *WTPbase*. Similarly to the site-specific outcomes of the Elbe Estuary and IJssel River (identified by the USER dummy), the income and the frequency of visit for the USER group appear to have a stronger influence than in the rest of the sites. On the other hand, visit preferences become insignificant for the USER group. Similar significances can be observed in the model for *WTPtotal*. In this case though, the significance of preferences and visit habits have a stronger influence in the reference group (i.e. the Danish sites) than in the model using *WTPbase*. The differences with the USER group however, stay comparable to the ones observed for the other model.

When observing the predictive model, only the income and the distance to the NBS appear to be influencing the *WTPbase* across NBS sites. Particularly in the USER group the income seems to have much more influence on the WTP. As for the *WTPtotal* model, the same variables are highlighted, with also the travel time to the area becoming significant. This latter development appears to be connected to a higher regard of the NBS from the respondent. In fact, if more time is used to reach the area, it is likely that the respondents will have a higher interest in the (natural) features of the site, and therefore be more willing to spend money on their improvement. Furthermore, in this second model on *WTPtotal*, the USER sites do not show significant differences from the reference group, except for the consolidated higher influence of income.

In comparison with similar functions determined by other studies using meta-analysis, our outcomes appear to confirm the effect of income on the WTP for NBS (Bockarjova et al., 2020; Czajkowski et al., 2017). Moreover, Bockarjova et al. (2020) also found a positive relation between the perceived provision of aesthetics and existence values of nature and a higher WTP. Other studies highlight that the specific type of nature employed in the NBS (e.g. park or nature area) is not a significant predictor for its value (Bockarjova et al., 2020; Skrydstrup et al., 2022). Theoretically, in our study we have assessed the same kind of strategies, as all of our case studies are NBS, but their characteristics vary widely. Therefore we could argue that this finding is reflected in our results as well. For example, the three Danish sites have quite different features, nevertheless, they have very similar values attributed to them (statistically the same, in the case of Lake Egå and Hovmarksparken (**Paper II**)). This seems to suggest that the valuation of a NBS is mostly connected to its, and the respondents', context. We cannot exclude however, that if we had examined sites with more different features we could have captured other nuances. Lastly, further investigation, or a potential integration, of other variables that are commonly included in meta-analyses (e.g. size of the NBS, population density, etc.) in our models could be an interesting development to further test the comparability of our dataset to those used in secondary analysis studies. Overall, the possibility of comparing our results with those of meta-analyses strengthens the argument of replicable SP methods being very versatile tools. On top of providing easily comparable datasets that can strengthen the knowledge base on NBS, secondary data analyses can be directly based on their outcomes.

However, in respect to the transferability of our produced value functions, specifically the predictive model, we have to address some limitations. First, we analysed a very specific type of NBS, namely peri-urban NBS mostly visited (or directly inhabited) by residents in the area. Thus, it is not clear whether they would reflect the valuation of sites with different characteristics. Moreover, excluding the preferences variables, even if necessary to allow for upscaling in sites where their collection is challenged, eliminates a large part of the drivers of valuation. Given the proven impact of the public's preferences on WTP, it is likely that in the future more primary assessments of NBS will include these values (or other proxies) for a more thorough evaluation. This will hopefully increase the chances to being able to create up-scalable valuation functions including these variables as well. Lastly, a sturdier model could have been obtained if the collection of our data had been randomized for all the involved sites. Because of these shortcomings, we do not claim to have determined a "ready to use" value transfer function, but rather we frame our outcomes as a proof of concept. In fact, the comparability with similar meta-analysis studies seems to suggest that some overarching patterns in NBS quantitative evaluation have indeed been captured by our approach.

6 Conclusions

The main goal of this project was to improve the economic assessment of NBS used for hydro-meteorological risk reduction to support their implementation. The approach chosen to do this was to develop and apply a new methodology to assess the non-tangible benefits of NBS in a holistic and easily replicable way. To reach our aim, we went through a sequence of steps: the assessment of the current state-of-the-art through a literature review, the creation and application of a new method, and finally the analysis of the obtained dataset with the creation of both single-site and joint value functions. Based on the findings from these steps, we list here the main outcomes of this PhD project.

- This thesis identified critical biases and limitations in existing methods currently used for assessing non-market benefits of NBS, which were found to be lagging behind and missing a holistic perspective. There does not appear to be a structured approach to the assessment of the multiple benefits of NBS, with the benefits for nature in particular risking to be relegated to a background position. These shortcomings not only negatively impact the valuation of the specifically assessed NBS, but they also bias the entire "reference toolbox" for future assessments of non-tangible benefits of NBS. As it is, the current approach risks slowing down the uptake and creation of truly multi-benefit strategies.
- In order to (at least partly) close the individuated knowledge gaps, we looked into the creation and application of a holistic and replicable assessment methodology for the non-tangible benefits of NBS. Our review had highlighted the unexploited potential of SP methods for the assessment of non-tangible benefits. We thus expanded these methods to create a replicable and holistic questionnaire, shaped through a co-design process with seven NBS study sites. The bottom-up approach and the sparring of this process greatly helped with the involvement and participation of the case study partners, which resulted in the distribution of seven surveys comparable across sites. The produced survey scheme can be applied to other sites, or used as a blueprint to develop new, more replicable assessments.
- The novel methodology developed was put in use to determine which variables influence the valuation and preference heterogeneity for NBS across different sites and contexts. A unique dataset gathered from almost 1900 respondents allowed us to connect the characteristics of the respondents, their relationship with the NBS area, and their preferences regarding non-

tangible benefits to a monetary value across different contexts. Through our analyses it was possible to determine that, across all the examined sites, the respondents had a generally positive attitude towards the NBS and that they especially associated more value to increased “multi-functionality” in the area, specifically to changes directed at benefitting nature. Moreover, personal preferences and attitudes were shown to greatly influence the value attributed to NBS. The similarity of outcomes suggest that understanding the multiple dimensions which influence these strategies' valuation can benefit the planning of more purposefully designed and efficient solutions across different contexts.

- Various joint value functions were defined starting from our collected dataset. Some of them were used to effectively summarize the results from our single-site models. They highlighted how the WTP from responses collected on-site is more strongly influenced by income and frequency of visit, and less by personal preferences, than that of responses collected randomly (i.e. both off- and on-site). Furthermore, upscaling-friendly valuation functions restricted to easily retrievable variables showed that income, distance from, and travel time to the site appear to be the significant variables to determine the WTP of the respondents. Despite room for improvement, our models still captured the most important variables influencing the valuation of the assessed NBS, in a way that can be compared to other studies in the literature. Overall, our results can be of use for decision-makers as well as for communication purposes.

This thesis summarized the outcomes of our effort to create a more balanced and replicable assessment of non-tangible benefits of NBS, which will hopefully allow for a more thorough evaluation of these strategies. However, it is important to highlight that the scope of our research is limited: we examined only the non-tangible benefits of NBS, which do not encompass the full array of NBS benefits, as much as they were proven to be a fundamental part of them (see Fig. 1.5). Other assessments, such as risk reduction assessments, are fundamental for the proper quantification of NBS benefits. Thus, our outcomes and methods have to be seen as complementary to these other, tangible quantifications. Only this way we can ensure the development and implementation of more holistic, well-balanced, multifunctional NBS across different sites.

7 Recommendations and suggestions for future research

7.1 On the future applications of the developed methodology

As highlighted in chapter 3, there were some challenges in the creation and implementation of our methodology, and therefore, we offer here some suggestions on how it could be better applied in future studies. First, co-design has been proven to be a powerful tool, both for the engagement of partners and to optimize the data collection process, but we recognize that its application could be improved from what we have done in our study. Larger co-design sessions involving more case study partners simultaneously could have contributed to a more truly transferable survey, by defining a general survey scheme with questions and answer options that were more fitting to all the sites, rather than allowing for limited adaptations on a scheme that had already been distributed in some sites. However, the most important step to get to a fully comparable set of data is an agreement on the distribution method across sites. Ideally, random samples should be collected in all examined sites, i.e. gathering responses from both users and non-users of the NBS (i.e. as in the Danish sites in our study). Such a dataset would have likely simplified our analyses, particularly when it came to determining a joint value function for the majority of the sites. Nevertheless, we recognize that a randomized collection such as the one allowed by the official email addresses in Denmark is not feasible everywhere (e.g. because of time or resource constraints). In that case, we suggest to choose the collection method which is the most replicable across locations (e.g. in-person surveying, etc.).

An interesting development for this method, once its design and distribution approach were to be perfected, would be to apply it to widely different case studies, i.e. outside of Western Europe, to provide a larger pool of contexts to analyse. The lack of representation of different contexts is one of the reasons why transferring values of NBS is so challenging (European Commission, 2021b), especially when taking into consideration the non-tangible benefits of NBS, which are heavily influenced by context and preferences that are likely to widely change across different backgrounds. Therefore, expanding our survey to a more varied selection of case studies could help shape a larger and more inclusive knowledge base of contexts and approaches to NBS, easing the up-scaling of these strategies.

Finally, it would be interesting to complement the quantification of NBS benefits with an assessment of their "disservices", i.e. negative effects for people (e.g. allergens, mobility issues, unsafety) (Lyytimäki et al., 2008; Shackleton et al., 2016). Although scarcely investigated in the literature, studies suggest that these negative effects may play a large role on people's perception and evaluation of NBS (Blanco et al., 2019; Hérivaux & Le Coent, 2021). Therefore, their inclusion in NBS assessments such as the one we defined could be valuable to more objectively frame NBS' contribution to human well-being and eventually adjust NBS development policies.

7.2 On the overall assessment of non-tangible benefits of NBS

We believe that our methodology is a step in the right direction towards a more holistic approach to the assessment of NBS, however, this goal can also be reached through the improvement and application of other methods. Ideally, the collection of any kind of quantitative primary data on the non-tangible benefits of NBS should increase (e.g. through the use of CE studies or structured interviews). Therefore, regardless of the use of our chosen approach, we support the call for more (and preferably standardized) data collections that has already been advocated by many studies (e.g. Faivre et al., 2017; Ruangpan et al., 2019; Venkataramanan et al., 2020). However, it would still be imperative for these methods to follow the general direction of being holistic and assessing the overlap between different benefits. Moreover, a more standardized approach to primary data collection would be fundamental for the development of more meta-analyses, which in turn would allow for a broader evaluation of benefits, also in sites where the collection of primary data is challenged.

Lastly, in this thesis we have discussed the limits and the critiques moved to quantitative approaches based on ESS and SP methods, and mentioned some frameworks suggested as alternatives, where the focus is shifted further away from an anthropocentric view (e.g. Díaz et al., 2018). Given their recent emergence, it is difficult to assess the results of the latter, but there is surely a push for a paradigm shift towards a different way to assess NBS benefits. Therefore, future research could benefit from examining the interconnections and the complementarities of these different approaches, as well as the differences between their outcomes. This process could help determine the best way to assess and promote sustainable solutions.

8 References

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., & Sanchez, A. (2019). Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management. *Journal of Environmental Management*, *239*(February), 244–254. https://doi.org/10.1016/j.jenvman.2019.03.036

Anderson, C. C., Renaud, F. G., Hanscomb, S., & Gonzalez-Ollauri, A. (2022). Green, hybrid, or grey disaster risk reduction measures: What shapes public preferences for nature-based solutions? *Journal of Environmental Management*, *310*(October 2021), 114727. https://doi.org/10.1016/j.jenvman.2022.114727

Andrews, B., Ferrini, S., & Bateman, I. (2017). Good parks – bad parks: the influence of perceptions of location on WTP and preference motives for urban parks. *Journal of Environmental Economics and Policy*, *6*(2), 204–224. https://doi.org/10.1080/21606544.2016.1268543

Arrow, K., Solow, R., Portney, P. R., Leamer, E. E., Radner, R., & Schuman, H. (1993). *Report of the NOAA panel on contingent valuation*.

Ayers, J., & Dodman, D. (2010). Climate change adaptation and development I. *Progress in Development Studies*, *10*(2), 161–168. https://doi.org/10.1177/146499340901000205

Bateman, I. J., Brouwer, R., Ferrini, S., Schaafsma, M., Barton, D. N., Dubgaard, A., Hasler, B., Hime, S., Liekens, I., Navrud, S., De Nocker, L., Ščeponavičiūtė, R., & Semėnienė, D. (2011). Making Benefit Transfers Work: Deriving and Testing Principles for Value Transfers for Similar and Dissimilar Sites Using a Case Study of the Non-Market Benefits of Water Quality Improvements Across Europe. *Environmental and Resource Economics*, *50*(3), 365–387. https://doi.org/10.1007/s10640-011-9476-8

Ben-Akiva, M., & Lerman, S. R. (1985). *Discrete choice analysis: theory and application to travel demand*. The MIT Press.

Bernath, K., & 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. https://doi.org/10.1016/j.jenvman.2007.01.059

Blanco, J., Dendoncker, N., Barnaud, C., & Sirami, C. (2019). Ecosystem disservices matter: Towards their systematic integration within ecosystem service research and policy. *Ecosystem Services*, *36*(January 2018), 100913. https://doi.org/10.1016/j.ecoser.2019.100913

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*(September 2019), 106480. https://doi.org/10.1016/j.ecolecon.2019.106480

Boyd, J., & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, *63*(2–3), 616–626. https://doi.org/10.1016/j.ecolecon.2007.01.002

Brander, L., Brouwer, R., & Wagtendonk, A. (2013). Economic valuation of regulating services provided by wetlands in agricultural landscapes: A meta-analysis. *Ecological Engineering*, *56*, 89–96. https://doi.org/10.1016/j.ecoleng.2012.12.104

Chenoweth, J., Anderson, A. R., Kumar, P., Hunt, W. F., Chimbwandira, S. J., & Moore, T.

L. C. (2018). The interrelationship of green infrastructure and natural capital. *Land Use Policy*, *75*(March), 137–144. https://doi.org/10.1016/j.landusepol.2018.03.021

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based solutions to address global societal challenges. In E. Cohen-Shacham, G. Walters, C. Janzen, & S. Maginnis (Eds.), *Nature-based solutions to address global societal challenges*. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., & Grasso, M. (2017). Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosystem Services*, *28*, 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008

Crawley, M. J. (2005). *Statistics. An introduction using R*. John Wiley & Sons, Ltd.

Czajkowski, M., Ahtiainen, H., Artell, J., & Meyerhoff, J. (2017). Choosing a Functional Form for an International Benefit Transfer: Evidence from a Nine-country Valuation Experiment. *Ecological Economics*, *134*, 104–113. https://doi.org/10.1016/j.ecolecon.2017.01.005

Dehnhardt, A. (2014). The Influence of Interests and Beliefs on the Use of Environmental Cost-Benefit Analysis in Water Policy: The case of German policy-makers. *Environmental Policy and Governance*, *24*(6), 391–404. https://doi.org/10.1002/eet.1656

del Saz Salazar, S., & García Menéndez, L. (2007). Estimating the non-market benefits of an urban park: Does proximity matter? *Land Use Policy*, *24*(1), 296–305. https://doi.org/10.1016/j.landusepol.2005.05.011

Derkzen, M. L., van Teeffelen, A. J. A., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences? *Landscape and Urban Planning*, *157*, 106–130. https://doi.org/10.1016/j.landurbplan.2016.05.027

Dessler, A. E. (2021). *Introduction to Modern Climate Change* (Third Edit). Cambridge University Press. https://doi.org/10.1017/9781108879125

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., Hill, R., Chan, K. M. A., Baste, I. A., Brauman, K. A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P. W., van Oudenhoven, A. P. E., van der Plaat, F., Schröter, M., Lavorel, S., … Shirayama, Y. (2018). Assessing nature's contributions to people. *Science*, *359*(6373), 270–272. https://doi.org/10.1126/science.aap8826

EEA. (2022). *Economic losses and fatalities from weather- and climate-related events in Europe*. https://www.eea.europa.eu/publications/economic-losses-and-fatalities-from

European Commission. (2015). *Towards an EU research and innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities: Final report of the Horizon 2020 expert group on "Nature-based solutions and re-naturing cities."*

European Commission. (2021a). Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change. *European Commission*, *6*(11), 951–952.

European Commission. (2021b). *SOLUTIONS A Handbook for Practitioners*. https://doi.org/10.2777/244577

Eurostat. (2022a). *EU's median age increased to 44.1 years in 2021*.

https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220228-1

Eurostat. (2022b). *Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates*. https://ec.europa.eu/eurostat/databrowser/view/prc_ppp_ind/default/table?lang=en

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., & Vandewoestijne, S. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*, *159*(September 2017), 509–518. https://doi.org/10.1016/j.envres.2017.08.032

Feuillette, S., Levrel, H., Boeuf, B., Blanquart, S., Gorin, O., Monaco, G., Penisson, B., & Robichon, S. (2016). The use of cost–benefit analysis in environmental policies: Some issues raised by the Water Framework Directive implementation in France. *Environmental Science & Policy*, *57*, 79–85. https://doi.org/10.1016/j.envsci.2015.12.002

Hansen, R., Olafsson, A. S., van der Jagt, A. P. N., Rall, E., & Pauleit, S. (2019). Planning multifunctional green infrastructure for compact cities: What is the state of practice? *Ecological Indicators*, *96*(November 2016), 99–110. https://doi.org/10.1016/j.ecolind.2017.09.042

Hanson, H. I., Wickenberg, B., & Alkan Olsson, J. (2020). Working on the boundaries—How do science use and interpret the nature-based solution concept? *Land Use Policy*, *90*(October 2019), 104302. https://doi.org/10.1016/j.landusepol.2019.104302

Hérivaux, C., & Le Coent, P. (2021). Introducing Nature into Cities or Preserving Existing Peri-Urban Ecosystems? Analysis of Preferences in a Rapidly Urbanizing Catchment. *Sustainability*, *13*(2), 587. https://doi.org/10.3390/su13020587

Hoff, J. V., Rasmussen, M. M. B., & Sørensen, P. B. (2021). Barriers and opportunities in developing and implementing a Green GDP. *Ecological Economics*, *181*(July 2020), 106905. https://doi.org/10.1016/j.ecolecon.2020.106905

IPCC. (2021a). Regional fact sheet - Europe. *Climate Change 2021: The Physical Science Basis: IPCC Working Group I Sixth Assessment Report: (AR6-WGI) 2*. https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Europe.pdf

IPCC. (2021b). *Summary for Policymakers In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan,* . https://doi.org/10.1017/9781009157896.001

IPCC. (2022). *Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of*. https://doi.org/10.1017/9781009325844.001

IUCN. (2012). *The IUCN Programme 2013 – 16. March 2012*, 184–210.

IUCN. (2020). IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition. In *IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition*. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2020.08.en

Johnston, R.J., Rofle, J., Rosenberger, R. S., & Brouwer, R. (2015). *Benefit Transfer of Environmental and Resource Values - A guide for Researchers and Practitioners, Volume 14. ed, Benefit Transfer of Environmental and Resource Values*. Springer, Dordrecht. https://doi.org/https://doi.org/10.1007/978-94-017-9930-0

Johnston, Robert J., Boyle, K. J., Adamowicz, W. (Vic), Bennett, J., Brouwer, R., Cameron, T. A., Hanemann, W. M., Hanley, N., Ryan, M., Scarpa, R., Tourangeau, R., & Vossler, C. A. (2017). Contemporary Guidance for Stated Preference Studies. *Journal of the Association of Environmental and Resource Economists*, *4*(2), 319–405. https://doi.org/10.1086/691697

Koetse, M., Brouwer, R., & van Beukering, P. J. H. (2015). Economic valuation methods for ecosystem services. In *Ecosystem Services: From Concepts to Practice* (pp. 108–131). https://doi.org/https://doi.org/10.1017/CBO9781107477612.010

Koetse, M. J., Verhoef, E. T., & Brander, L. M. (2017). A generic marginal value function for natural areas. *The Annals of Regional Science*, *58*(1), 159–179. https://doi.org/10.1007/s00168-016-0795-0

Lele, S., Springate-Baginski, O., Lakerveld, R., Deb, D., & Dash, P. (2013). Ecosystem services: Origins, contributions, pitfalls, and alternatives. *Conservation and Society*, *11*(4), 343–358. https://doi.org/10.4103/0972-4923.125752

Li, T., & Gao, X. (2016). Ecosystem Services Valuation of Lakeside Wetland Park beside Chaohu Lake in China. *Water*, *8*(7), 301. https://doi.org/10.3390/w8070301

Lyytimäki, J., Petersen, L. K., Normander, B., & Bezák, P. (2008). Nature as a nuisance? Ecosystem services and disservices to urban lifestyle. *Environmental Sciences*, *5*(3), 161–172. https://doi.org/10.1080/15693430802055524

Nelson, D. R., Bledsoe, B. P., Ferreira, S., & Nibbelink, N. P. (2020). Challenges to realizing the potential of nature-based solutions. *Current Opinion in Environmental Sustainability*, *45*(October), 49–55. https://doi.org/10.1016/j.cosust.2020.09.001

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Külvik, M., Rey, F., van Dijk, J., Vistad, O. I., Wilkinson, M. E., & Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment*, *579*, 1215–1227. https://doi.org/10.1016/j.scitotenv.2016.11.106

Nielsen, H. Ø., Frederiksen, P., Saarikoski, H., Rytkönen, A. M., & Pedersen, A. B. (2013). How different institutional arrangements promote integrated river basin management. Evidence from the Baltic Sea Region. *Land Use Policy*, *30*(1), 437–445. https://doi.org/10.1016/j.landusepol.2012.04.011

Pascual, U., Phelps, J., Garmendia, E., Brown, K., Corbera, E., Martin, A., Gomez-Baggethun, E., & Muradian, R. (2014). Social Equity Matters in Payments for Ecosystem Services. *BioScience*, *64*(11), 1027–1036. https://doi.org/10.1093/biosci/biu146

Pearce, D., Atkinson, G., & Mourato, S. (2006). *Cost-benefit analysis and the environment: Recent developments*. Organisation for Economic Cooperation and Development (OECD). https://doi.org/10.1787/9789264010055-en

Pepper, C., McCann, L., & Burton, M. (2005). Valuation study of urban bushland at Hartfield Park, Forrestfield, Western Australia. *Ecological Management and Restoration*, *6*(3), 190–196. https://doi.org/10.1111/j.1442-8903.2005.00236.x

Ranasinghe, R., Ruane, A. C., Vautard, R., Arnell, N., Coppola, E., Cruz, F. A., Dessai, S., Islam, A. S., Rahimi, M., Ruiz Carrascal, D., Sillmann, J., Sylla, M. B., Tebaldi, C., Wang, W., & Zaaboul, R. (2021). *Climate Change Information for Regional Impact and for Risk Assessment. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V.* https://doi.org/10.1017/9781009157896.014

Raworth, K. (2017). Why it's time for Doughnut Economics. *IPPR Progressive Review*, *24*(3), 216–222. https://doi.org/10.1111/newe.12058

Raymond, C. M., Pam, B., Breil, M., Nita, M. R., Kabisch, N., de Bel, M., Enzi, V., Frantzeskaki, 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. In *Horizon 2020*. https://doi.org/10.13140/RG.2.2.18682.08643

RECONECT. (2021). *About RECONECT*. http://www.reconect.eu/about-reconect/

Reynaud, A., Lanzanova, D., Liquete, C., & Grizzetti, B. (2017). Going green? Ex-post valuation of a multipurpose water infrastructure in Northern Italy. *Ecosystem Services*, *27*, 70–81. https://doi.org/10.1016/j.ecoser.2017.07.015

Richardson, L., Loomis, J., Kroeger, T., & Casey, F. (2015). The role of benefit transfer in ecosystem service valuation. *Ecological Economics*, *115*, 51–58. https://doi.org/10.1016/j.ecolecon.2014.02.018

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S. I., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society*, *14*(2), art32. https://doi.org/10.5751/ES-03180-140232

Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L. S., Capobianco, V., Oen, A. M. P., McClain, M. E., & Lopez-Gunn, E. (2019). Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. *Natural Hazards and Earth System Sciences*, *20*(1), 243–270. https://doi.org/10.5194/nhess-20-243-2020

Saz-Salazar, S. del, & Rausell-Köster, P. (2008). A Double-Hurdle model of urban green areas valuation: Dealing with zero responses. *Landscape and Urban Planning*, *84*(3–4), 241–251. https://doi.org/10.1016/j.landurbplan.2007.08.008

Schröter, M., van der Zanden, E. H., van Oudenhoven, A. P. E., Remme, R. P., Serna-Chavez, H. M., de Groot, R. S., & Opdam, P. (2014). Ecosystem Services as a Contested Concept: A Synthesis of Critique and Counter-Arguments. *Conservation Letters*, *7*(6), 514–523. https://doi.org/10.1111/conl.12091

Shackleton, C. M., Ruwanza, S., Sinasson Sanni, G. K., Bennett, S., De Lacy, P., Modipa, R., Mtati, N., Sachikonye, M., & Thondhlana, G. (2016). Unpacking Pandora's Box: Understanding and Categorising Ecosystem Disservices for Environmental Management and Human Wellbeing. *Ecosystems*, *19*(4), 587–600. https://doi.org/10.1007/s10021-015-9952-z

Skrydstrup, J., Löwe, R., Gregersen, I. B., Koetse, M., Aerts, J. C. J. H., de Ruiter, M., & Arnbjerg-Nielsen, K. (2022). Assessing the recreational value of small-scale Nature-Based Solutions when planning urban flood adaptation. *Journal of Environmental Management*.

Sowińska-Świerkosz, B., & García, J. (2022). What are Nature-based solutions (NBS)? Setting core ideas for concept clarification. *Nature-Based Solutions*, *2*(January), 100009. https://doi.org/10.1016/j.nbsj.2022.100009

Tibesigwa, B., Ntuli, H., & Lokina, R. (2020). Valuing recreational ecosystem services in developing cities: The case of urban parks in Dar es Salaam, Tanzania. *Cities*, *106*(July), 102853. https://doi.org/10.1016/j.cities.2020.102853

Turconi, L., Faccini, F., Marchese, A., Paliaga, G., Casazza, M., Vojinovic, Z., & Luino, F. (2020). Implementation of Nature-Based Solutions for Hydro-Meteorological Risk Reduction in Small Mediterranean Catchments: The Case of Portofino Natural Regional Park, Italy. *Sustainability*, *12*(3), 1240. https://doi.org/10.3390/su12031240

van Beukering, P. J. H., Brouwer, R., & Koetse, M. J. (2015). Economic values of ecosystem services. In J. A. Bouma & P. J. . van Beukering (Eds.), *Ecosystem Services: From Concepts to Practice* (pp. 89–107). Cambridge Univ. Press. https://doi.org/https://doi.org/10.1017/CBO9781107477612.010

Van Oijstaeijen, W., Van Passel, S., & Cools, J. (2020). Urban green infrastructure: A review on valuation toolkits from an urban planning perspective. *Journal of Environmental Management*, *267*(April), 110603. https://doi.org/10.1016/j.jenvman.2020.110603

Venkataramanan, V., Lopez, D., McCuskey, D. J., Kiefus, D., McDonald, R. I., Miller, W. M., Packman, A. I., & Young, S. L. (2020). Knowledge, attitudes, intentions, and behavior related to green infrastructure for flood management: A systematic literature review. *Science of The Total Environment*, *720*(February), 137606. https://doi.org/10.1016/j.scitotenv.2020.137606

Vollmer, D., Prescott, M. F., Padawangi, R., Girot, C., & Grêt-Regamey, A. (2015). Understanding the value of urban riparian corridors: Considerations in planning for cultural services along an Indonesian river. *Landscape and Urban Planning*, *138*, 144–154. https://doi.org/10.1016/j.landurbplan.2015.02.011

Voulvoulis, N., Arpon, K. D., & Giakoumis, T. (2017). The EU Water Framework Directive: From great expectations to problems with implementation. *Science of the Total Environment*, *575*, 358–366. https://doi.org/10.1016/j.scitotenv.2016.09.228

9 Papers

I **Viti, M.**, Löwe, R., Sørup, H. J. D., Rasmussen, M., Arnbjerg-Nielsen, K., & McKnight, U. S. (2022). Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies. *Science of the Total Environment*, 841(February), 156636. https://doi.org/10.1016/j.scitotenv.2022.156636

II **Viti, M.**, Löwe, R., Sørup, H. J. D., Iversen, S., Gebhardt, O., Ladenburg, J., McKnight, U. S., & Arnbjerg-Nielsen, K. (2023). Holistic valuation of Nature-Based Solutions accounting for human perceptions and nature benefits. *Journal of Environmental Management*, 334, 12 p., 117498 https://doi.org/10.1016/j.jenvman.2023.117498

III **Viti, M.**, Ladenburg, J., Löwe, R., Sørup, H. J. D., McKnight, U. S., & Arnbjerg-Nielsen, K. (2023). Beyond meta-studies: learnings from a large multi-site primary dataset on non-tangible benefits of Nature-Based Solutions. *Manuscript*.

I

Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies

Viti, M., Löwe, R., Sørup, H. J. D., Rasmussen, M., Arnbjerg-Nielsen, K., & McKnight, U. S.

Science of the Total Environment, 841(February), 156636.
https://doi.org/10.1016/j.scitotenv.2022.156636

Science of the Total Environment 841 (2022) 156636

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies

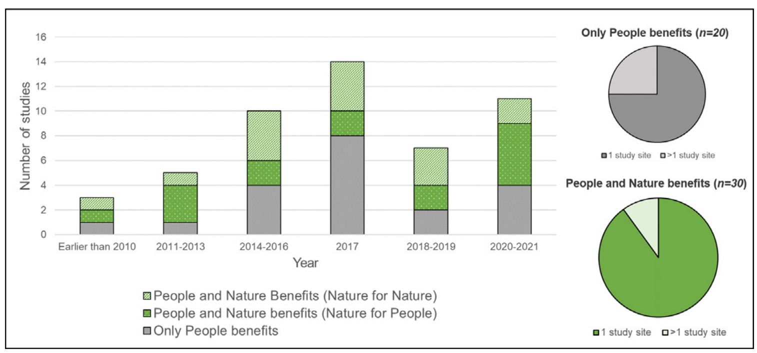
Martina Viti [a,*], Roland Löwe [a], Hjalte J.D. Sørup [a], Marzenna Rasmussen [b], Karsten Arnbjerg-Nielsen [a], Ursula S. McKnight [a,c]

[a] Department of Environmental Engineering, Technical University of Denmark, Bygningstorvet Bldg. 115, 2800 Kgs. Lyngby, Denmark
[b] Amphi International ApS, Forskerparken 10, DK-5230 Odense M, Denmark
[c] Swedish Meteorological and Hydrological Institute, Folkborgsvägen 17, SE-601 76 Norrköping, Sweden

HIGHLIGHTS

- Review of studies using stated preference to assess non-market people benefits.
- Current literature relates to "non-NBS-specific" assessment methods.
- Replicability and up-scaling of methods are not prioritized.
- Integration of benefits for nature is often not considered in the assessments.
- Future research should focus on holistic and replicable NBS benefit quantification.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Jay Gan

Keywords:
NBS
Stated preference
Benefits assessment
Ecosystem services
Biodiversity assessment

ABSTRACT

Nature-Based Solutions (NBS) can be defined as solutions based on natural processes that meet societal challenges and simultaneously provide human well-being and biodiversity benefits. These solutions are envisioned to contribute to operationalizing sustainable development strategies, especially in the context of adaptation to climate change (e.g. flood risk reduction). In order to quantify NBS performance, ease their uptake and advocate for them as alternatives to "business-as-usual" infrastructures, a comprehensive, holistic valuation of their multiple benefits (multiple advantages and disadvantages) is needed. This entails quantifying non-market benefits for people and nature in addition to determining the (direct) cost-benefit of the risk-reduction measure. Despite the importance given to the assessment of non-tangible benefits for people and nature in the literature, systematic data collection on these dimensions seems to be missing. This study reviews publications that used stated preference methods to assess non-market human benefits of NBS and NBS-like strategies. Its aim is to highlight any biases or knowledge gaps in this kind of evaluation. Our results show that the valuation of non-tangible benefits of NBS (e.g. increased recreation and well-being, enhanced biodiversity) still suffers from a lack of common framing. Despite some steps being taken on enabling interconnected benefit assessments, unexploited opportunities concerning the integrated assessment of non-market human and nature benefits predominate. Moreover, the research to-date appears based on a case-to-case approach, and thus a shared holistic method does not emerge from the present literature, potentially delaying the uptake of NBS. We argue that future research could minimize missed opportunities by focusing on and systematically applying holistic benefits assessments. Methods based on stated preference surveys may help to ensure holistic approaches are taken, as well as contributing to their replicability and application when upscaling NBS.

* Corresponding author at: Technical University of Denmark, Bygningstorvet Bldg. 115, 2800 Kgs. Lyngby, Denmark.
E-mail address: martvit@env.dtu.dk (M. Viti).

http://dx.doi.org/10.1016/j.scitotenv.2022.156636
Received 16 February 2022; Received in revised form 7 June 2022; Accepted 7 June 2022
Available online 11 June 2022

Contents

1. Introduction

In recent years, the concept of natural capital, defined as the world's stocks of natural resources, including geology, air, soils, water and all living organisms, has been emerging, reflecting the acknowledgement that environmental systems play a fundamental role in determining a country's economic state and social well-being (EEA, 2015). In Europe and worldwide, the natural capital is under an ever-increasing pressure, and as we struggle to solve environmental, social and economic challenges, the need for transitioning to a sustainable use of natural resources is now more evident than ever. One of the strategies believed to be key for the operationalization of sustainable development is Nature-Based Solutions (NBS) (IUCN, 2020).

NBS are defined as strategies based on natural processes, which meet societal challenges and simultaneously provide human well-being and biodiversity benefits (European Commission, 2015; IUCN, 2012). The European Commission and the IUCN describe NBS slightly differently, with the European Commission defining them as “actions inspired or supported by nature”, while the IUCN frames them as “actions to protect, sustainably manage, and restore natural or modified ecosystems”. However, they both agree that what makes NBS particularly attractive is their ability to deliver multiple benefits. In fact, NBS not only provide direct solutions to present challenges (like climate change adaptation), but also enhance the spatial quality of the surrounding area in many direct and indirect ways (e.g. increased green areas, cleaner air, more recreation possibilities). Since their concept was coined, NBS have been prioritized in international environmental policy agendas (Cohen-Shacham et al., 2016), disaster risk management (World Bank, 2017) and research programs such as the European Union's (EU) Horizon 2020 (European Commission, 2015).

Despite this, the widespread application of NBS still appears to be lacking, due in part to the perceived high costs associated with their operationalization and maintenance (Jia et al., 2017; Qiu et al., 2020). Thus, a fundamental step for the successful uptake and implementation of NBS as alternatives to gray infrastructure is the holistic valuation of their multiple advantages and disadvantages, i.e. not only traditional valuation of tangible assets, but also quantification of non-market, non-tangible benefits, such as the ones affecting human well-being or biodiversity status. Economic valuation of non-tangible benefits is a crucial tool to ensure that stakeholders are aware of the total value of NBS and take this into consideration during decision-making. Recent studies have shown that despite the challenges of monetization, the inclusion of non-market benefits in cost-benefit analyses improves the economic feasibility of NBS and increases policy makers' awareness of these solutions (Bayulken et al., 2021; Venkataramanan et al., 2020). A more comprehensive benefit valuation, focusing on including also non-market benefits, could thus contribute to speeding up NBS uptake (Alves et al., 2019; Hanson et al., 2020; Sharifi et al., 2021; Teotónio et al., 2021). Given the strategic importance of NBS uptake for the achievement of sustainable adaptation, the European Commission has funded a series of projects for planning, evaluating and implementing NBS, including their upscaling outside of cities, in which holistic assessments occupy a key role (European Commission, 2015).

The economic quantification of non-tangible benefits can be challenging. When it comes to quantitatively assessing benefits that do not fit any market, they are quantified indirectly using revealed preference (RP) methods (e.g. travel cost/time and house prices) (Koetse et al., 2015). However, for non-tangible benefits that do not have any related markets, stated preference (SP) methods are the most prominently used strategies in the literature. Multiple variations of SP methods exist, but the most common approaches are contingent valuation (CV), in which respondents are asked whether they would choose a proposed option at a specified price, and choice experiments (CE) methods, where respondents have to state their preference among two or more multi-attribute options (Arrow et al., 1993; Johnston et al., 2017).

While SP methods allow us to establish a monetary valuation of non-tangible benefits, how they are presented within the assessment (questions posed) is also fundamental for ensuring a successful and holistic benefit quantification. There have been a number of studies focused on describing the best approach for the assessment of non-tangible benefits of NBS (Díaz et al., 2018; Hanson et al., 2020; IUCN, 2020; Norgaard, 2010; Raymond et al., 2017). Ideally, the valuation of non-tangible benefits (e.g. increased recreation and well-being, enhanced biodiversity) should extend across the three impact domains of NBS: namely the economic, environmental and social domains, as well as their interconnections. Ensuring these assessments are truly integrated should contribute to a more favorable cost-benefit analysis of NBS, and also ultimately reduce the potential need (and related costs) for fixing lost opportunities in the long run, e.g. incorporating nature-enhancing aspects once the risk reduction strategy is already in place.

Despite numerous recommendations – and associated tools developed to aid such benefits quantification (e.g. Benefits of SuDS Tool, O'Donnell et al., 2018; Blue-Green Cities toolbox, Mant et al., 2013) – recent studies point out that biases and gaps still remain regarding the evaluation of non-tangible NBS benefits (Choi et al., 2021; Hanson et al., 2020). Included among the highlighted gaps, for example, is a lack of stakeholder participation in the assessment of multiple benefits of NBS, and the need for improving methods for assessing especially socio- and ecological benefits (Ruangpan et al., 2019). Moreover, systematic data collection on the human dimensions (e.g. increased physical and psychological well-being, preferences and perceptions) of NBS and NBS-like strategies seems to be missing, and SP methods have been suggested as useful tools to fill this gap (Venkataramanan et al., 2020).

SP methods already have a predominant role in the estimation of non-use values, and are increasingly used as a fundamental support for the systematic assessment of NBS benefits. However, previous reviews on this topic still lack a more comprehensive analysis focusing on the implementation of SP methods beyond their theoretical consideration. Previous reviews on the assessment of NBS benefits have mainly focused either on structured analyses of impacts (Castellanos et al., 2020; Choi et al., 2021; Din Dar et al., 2021; Sharifi et al., 2021), or on studying the implementation and monitoring of solutions in specific settings, such as large-scale NBS against hydro-meteorological risks (Ruangpan et al., 2019), urban NBS in policy-making (Dumitru et al., 2020) or in crisis contexts (Bayulken et al., 2021). With regards to reviews specifically examining methodologies for the quantification of non-tangible NBS benefits, studies were found on the perception of NBS (Venkataramanan et al., 2020), on the obstacles and progresses of NBS financing (Hagedoorn et al., 2021; Teotónio et al., 2021; Toxopeus and Polzin, 2021), and on the inclusion of environmental justice dimensions (Pineda-Pinto et al., 2021). However, no comprehensive assessment on the usage of SP methods across NBS typologies emerged. A comprehensive assessment may help establish how SP methods have been previously used to assess non-tangible benefits of NBS (and NBS-like strategies) and whether they align with recommendations in the literature.

A review of SP studies applied to NBS could be the starting point to investigate the state-of-the-art regarding the quantification of non-market NBS benefits for people, as well as their interlinkage with nature benefits. By using the term people benefits, we mean the collection of NBS impacts that have people as final, direct beneficiaries, i.e. increased recreation, increased psychological and physical well-being, greater economic opportunities. The widely investigated benefits known as Ecosystem Services (ESS) are here considered as a subgroup within people benefits, as they are used to define how ecosystem structure and function contributes to supporting human well-being (e.g. food provision, climate regulation), without encompassing all of the possible impacts on people's lives (Raymond et al., 2017). In addition to people benefits, there are nature benefits, which are the NBS impacts that directly benefit nature, assessed independently from whichever effect they may have on people, i.e. habitat restoration (habitat quantity), improved habitat quality (e.g. increase in number of species). Incorporation of nature enhancing elements (i.e. for nature, and not primarily as ESS for human benefit) is critical to ensure that the design of NBS will maximize its benefits for nature (Lemaire et al., 2021), which could be costly to adapt if not considered initially.

This study aims to deliver an overview on how intangible benefits provided by NBS, or NBS-like strategies, are quantified, with the following specific objectives: (i) review publications that used SP methods for assessing the non-market people benefits of NBS, in order to highlight any biases or knowledge gaps in this type of evaluation, and (ii) based on these findings, highlight improvements for future research. We include in our research both studies that focus on NBS as concrete assessments of a particular solution at a specific site, and studies that are aimed more at quantifying the benefits of implementing strategies that promote the concepts of NBS, denoted NBS-like strategies. We cover both these types of studies since both offer an insight into the mindset behind the current assessment of these solutions. Specifically, the research questions we are focusing on encompass: How are SP methods currently used for assessing non-market people benefits of NBS and NBS-like strategies? Can SP methods be used to also integrate the assessment of nature benefits? Is there a systematic SP approach that could form the basis of replicable benefit assessments? In answering these questions, we aim to shed light on the current state-of-the-art with respect to the assessment of non-tangible benefits for NBS, and indicate how future research should advance to fill the identified gaps required to optimize the holistic valuation of the multiple benefits of NBS.

2. Materials and methods

This study is based on a structured literature review on the assessment of non-market benefits for NBS. Our aim was to include a wide range of peer-reviewed scientific publications from all over the world, where it is worth mentioning that the term NBS is fairly recent, and mostly used in a European context; the same concept takes on different names in different geographical regions or research areas, e.g. Water Sensitive Urban Design (WSUD), Blue-Green Infrastructure (BGI) (Fletcher et al., 2015; Ruangpan et al., 2019). Consequently, when setting out to screen the literature, the inclusion of studies on other NBS-like concepts, which are not defined using the keyword NBS but are carrying out the same kind of strategy – namely solving societal challenges while providing human well-being and biodiversity benefits – was deemed reasonable. For this reason, the term “nature-inspired strategies” will be used in this paper when referring to both NBS and NBS-like strategies.

A paper search was conducted in November and December 2020 using the electronic journal database Web of Science. The search protocol implemented was:

- TOPIC:
  - ○ (“Nature-based solutions” OR “Nature based solutions” OR “nature-based” OR “nature based” OR “Green Infrastructure” OR “Blue-Green Infrastructure”)
  - ○ AND (“benefits” OR “ecosystem services”)
  - ○ AND (“valuation” OR “value” OR “stated preference” OR “contingent valuation” OR “dichotomous choice” OR “choice experiment” OR “stated choice”)
- OR TITLE:
  - ○ (“Nature-based solutions” OR “Nature based solutions” OR “nature-based” OR “nature based” OR “Green Infrastructure” OR “Blue-Green Infrastructure” OR “blue amenities” OR “terrestrial water” OR “watershed” OR “wetlands” OR “open space” OR “water assets” OR “water bodies” OR “canals” OR “lakes” OR “green” OR “greenbelt” OR “green roof” OR “garden” OR “park” OR “forest” OR “water” OR “water quality” OR “wetland”)
  - o AND (“benefits” OR “ecosystem services”)
  - o AND (“valuation” OR “value” OR “stated preference” OR “contingent valuation” OR “dichotomous choice” OR “choice experiment” OR “stated choice”).

The search resulted in 585 articles published in scientific journals. In a first step, duplicate and retracted articles were removed. In addition, studies performed before the year 2000 ($n = 10$) were excluded to ensure that the selection was up-to date.

The remaining studies were filtered based on the following criteria:

- Must be a primary study, i.e. a study collecting data directly from the respondents through questionnaires and/or interviews;
- The study had to be assessing an NBS or a nature-inspired adaptation strategy. For example, a choice experiment for the implementation of passive forest restoration in a Natural Park was selected for further analysis. On the other hand, a survey on the willingness-to-pay (WTP) for water quality improvement *not* based on a nature-based/green infrastructure approach was not included in the analysis.
- Use a SP method to assess the non-market people benefits for nature-inspired strategies.

The outcome of the last filtering was a final sample of 50 papers. The full text of these papers was read, and their content was analyzed through the use of a standardized data extraction sheet (see Supplementary Material). The extraction sheet was designed to answer the research questions; to ensure that the review process was consistent, various meetings between co-authors were held during the phase of data collection. The outcome of this process was data classified into standardized definitions that can be grouped into two main sections:

1) Descriptive characteristics (e.g. study year, number of study sites, SP method used, type of nature-based strategy). These data were registered to provide a context for the study and to examine the overall trends in the literature. In particular, the number of case studies was also used as a proxy to determine whether the SP method applied in the paper was deployed in a way that considered and/or allowed for its replication in different study sites.
2) Quantified non-market benefits (e.g. how people benefits are assessed, if and how nature benefits are assessed). As this study is based on

literature assessing non-tangible benefits for humans, all the selected papers quantified people benefits in some way. Specifically, as the examined studies carried out their assessment through SP methods, we focused on their valuation questions in order to find out which non-market benefits they were targeting for quantification. Both CV and CE studies were reviewed; in the case of CE methods, the valuation question to the respondents may not be direct, but rather implicit within the choice cards presented (e.g. select preference from option given). Note that, in order to present more clearly the classification process as applied in this study, choice card examples have been summarized as questions.

The quantified people benefits were sorted in the following groups: regulating ESS, provisioning ESS, supporting ESS, cultural ESS, integrated ESS, recreation, economic benefits, accessibility, human well-being, and nonspecific benefits (Table 1, Supplementary Material). For example, if the respondents were asked to value the NBS based on a provided ESS (e.g. provision of clean water, through the question "How much would you be willing to pay for the proposed strategy to improve water quality?"), the study was classified as assessing ESS benefits (e.g. regulating ESS) (Ramajo-Hernández and del Saz-Salazar, 2012). If respondents were asked to value the NBS based on the recreation potential they receive from the area (e.g. through answering the question "How much would you be willing to pay for a trip/ticket to the area?"), the study was classified as assessing recreation benefits (e.g. Mejía and Brandt, 2017; Mishra, 2017). If the study asked for the valuation of, as an example, both recreation and provisioning ESS benefits of the nature-inspired strategy, both labels were then applied to it during the classification. In the case of the examined study not directly stating the human benefit(s) to be valued by the respondents, the study was classified as assessing a "nonspecific benefit". Table 1 presents a more detailed overview for all people benefits quantified in the literature reviewed here, including a brief description of which specific benefits are included within each category.

Furthermore, we documented whether the selected studies assessed only people benefits, or if they took into consideration nature benefits as well. A study was classified as assessing also nature benefits if the respondents were asked to value the NBS based on at least one nature benefit generated by the strategy. In this case, the possible entries for benefit quantification were: habitat quality, habitat quantity, biodiversity, species abundance, extent of protected area, management of protected area and landscape structure. For example, if respondents were asked to value the strategy based on the increase in the number of species it will support (e.g. through the question "How much would you value this proposed strategy, if it increased the number of migratory bird species in the area?"), the study was classified as assessing a "biodiversity benefit" (e.g. Faccioli et al., 2015; Petcharat et al., 2020). If respondents were asked to give a value to the increase in the extent of protected land (e.g. through the question "Would you be willing to pay more taxes to allow for the protection of larger natural areas?"), the study was classified as assessing an "extent of protected area benefit" (e.g. Hynes et al., 2021; Valasiuk et al., 2018). Also in this case, if the study asked for the valuation of more than one identified nature benefit, more labels were applied to it during classification. An overview for the classification labels regarding nature benefits can be found in Table 2.

Table 1
Scheme used for the classification of people benefits that were assessed in the reviewed studies, and examples of assessed benefits grouped under each label.

Quantified People benefits	Examples
Regulating ESS	Flood prevention, climate regulation, clean air, etc.
Provisioning ESS	Energy, food, transportation, etc.
Cultural ESS	Aesthetic appreciation; inspiration; spiritual; sense of place
Supporting ESS	Biological diversity maintenance, nutrient recycling, etc.
Nonspecific ESS	Assessment scenario mentions ESS provided by the NBS, but does not specify which one(s) in particular are being valued
Recreation	Recreation facilities, tourist attractions, size of the area that can be visited, increasing the recreational potential of the area
Economic benefits	Increase in property values; Increase in business opportunities
Accessibility	Distribution of green infrastructure/NBS in a certain area; Presence of paths/gates
Human well-being	Satisfaction with the experience in the NBS, enjoyment of the area, stress and worry decrease
Nonspecific benefits	The valuation scenario doesn't specify which human benefits are being valued

Within this latter group of studies assessing both people and nature benefits, we classified how the examined publications investigated nature benefits, in terms of separation from people ("nature for nature" or "nature for people", i.e. ESS). This classification was once again based on the way the valuation questions were posed. If the studies were using questions taking an anthropocentric perspective on changes benefitting nature (e.g. "How much will you be willing to pay for a swimmable water quality?" or "Would you be willing to pay a ticket to visit a more diverse forest?") (Doherty et al., 2014; Liu et al., 2019), they were classified as quantifying "nature for people" benefits. On the other hand, studies asking the respondents for the value of a nature benefit independently from people's possible experience of these same benefits were classified as quantifying "nature for nature" benefits. Examples could be, "How much would you be willing to pay for conservation efforts on this marine area?" or "Would you be willing to donate for the enlargement of this no-entrance protected forest?" (De Valck et al., 2014; Gelcich et al., 2013). For a complete overview of the classification scheme and the full list of references for the literature review, see the Supplementary Material (Tables S1 to S4). Finally, for these studies assessing both people and nature benefits, we ran a last analysis to determine which of these benefits were quantified together, and how often these "pairings" were repeated.

3. Results and analyses

3.1. Existing approaches for valuation of nature-inspired strategies

The screening process resulted in the selection of 50 papers for the more detailed review. Most of the studies (66 %) were published after 2016, with 2017 being the year where most of the selected papers were published (28 %). European nature-inspired projects were the most represented, constituting almost half (48 %) of the analyzed papers. 22 % of the projects were conducted in Asia, followed by North America, South America, then Africa and Oceania.

All the selected papers aimed to quantify the non-tangible benefits of a nature-inspired strategy, but only a few explicitly used the term "Nature-Based Solutions" (Derkzen et al., 2017; Reynaud et al., 2017). This could be a result of the difference in terms used across the world (Ruangpan et al., 2019). Moreover, a share of these articles pre-date the appearance of the term NBS, which was first described explicitly in 2008 (Hanson et al., 2020) and then further promoted by the IUCN and the EU research and innovation program Horizon 2020 later (European Commission, 2015; IUCN, 2012). Nevertheless, the overall literature on NBS has been reported as continually growing (Hanson et al., 2020; Ruangpan et al., 2019), but this growth does not seem to be related to growth in terms of research on the holistic quantification of non-tangible benefits for NBS.

3.1.1. Study design

A variety of nature-inspired strategies were examined in the selected studies, with the majority involving blue and/or green non-urban open space (Table 3). The studies were conducted on a range of different scales, with most of the strategies discussed appearing to be developed on a large scale. For example, older nature-inspired strategies focused on larger areas (e.g. natural parks, peri-urban open spaces). Smaller scale strategies deployed within urban areas seem to come into the picture at a later point of time, following the interest expressed by the EU Research and Innovation

Table 2
Scheme used for the classification of nature benefits that were assessed in the reviewed studies, and examples of assessed benefits grouped under each label.

Quantified Nature benefits	Examples
Habitat quality	Assessment of habitat functions; assessment of habitat quality indicators
Habitat quantity	Area and distribution of a certain habitat
Biodiversity	Number of species (species richness); gene pool assessment (genetic diversity); species composition
Species abundance	Number of species' individuals
Extent of protected area	Amount of protected land (e.g. as part of a Natural Park)
Management of protected area	Establishment of no-visit zones; launching of breeding programs
Landscape structure	Broader overview of landscape patterns: degree of habitat fragmentation, presence of different habitats/ecosystems, habitat diversification

agenda to deploy NBS to enhance sustainable urbanization (European Commission, 2015). The diversity of scales and types of nature-inspired strategies involved in the examined studies shows that the quantification of non-tangible benefits can be and has been conducted in a variety of contexts. Moreover, the knowledge resulting from these variety of studies is fundamental to be able to apply lessons learned to other NBS.

Notably, the SP method chosen is almost equally distributed between CV (54 %) and CE (46 %). The SP method used was registered to check for possible preferences regarding the approach to quantify NBS benefits. Given the even distribution of the methods, we can assume that there is not one clearly preferred approach in the examined literature. This reflects the literature's claims that both SP methods are relevant for the quantification of non-tangible use values of nature-inspired strategies (Johnston et al., 2017; Ndebele and Forgie, 2017), and that the choice of one over the other is made based on site-specific situations (e.g. cognitive burden to place on respondents, assessment of the totality of the benefits vs. individual attributes, etc.). Notably, all 50 selected papers chose the general population as the target group for their studies. Some focused on visitors (e.g. Mäntymaa et al., 2018; Pérez-Urrestarazu et al., 2017), others on residents (e.g. Reynaud et al., 2017; Sabyrbekov et al., 2020), but no targeted distribution to specific groups of, for example, experts or decision-makers was registered.

In regards to the characteristics of the studies, the majority of the papers (84 %) focused on one single study site only (e.g. Balderas Torres et al., 2015; López-Mosquera and Sánchez, 2011; Tyrväinen, 2001) (Fig. 1). The number of study sites in each paper was documented in order to examine whether the authors had an interest in or tried to apply the same quantification methods in different areas, and explore the replicability of their valuation approach. In one case (Bateman et al., 2011), this was explicitly listed as one of the goals of the paper. However, for the bulk of the reviewed cases, the studies did not seem designed with this in mind, i.e. to additionally explore the replicability of their methods, and instead focused on the creation of site-specific assessments. Using meta-analyses in order to transfer the findings of studies based on one study site can be a suitable option to upscale results. However, meta-analyses are dependent on the outcomes and assessed variables of primary studies, therefore their implementation can be impaired by primary studies basing their assessments on site-specific and non-standardized methods. This can force meta-analyses to rely on crude assumptions that in turn can lead to less precise estimations (Bockarjova et al., 2020).

Finally, it is important to point out that the choice related to number of study site depends of course on many other factors than just the testing of replicability, e.g. on budget or time restraints. Nevertheless, our findings seem to highlight a tendency in the literature to date to approach benefit quantification on a project-to-project basis in primary studies. Moreover, there appears to be a gap in research that strives for the creation of tools to quantitatively assess non-tangible benefits across different study sites.

3.1.2. Assessment of benefits

3.1.2.1. Types of benefits assessed. In a first step, the different types of benefits assessed in the sampled studies were analyzed in more detail. While some studies only assessed human benefits, 30 of the papers (60 %) also included nature benefits in their evaluation (Fig. 1). For example, in the study by De Valck et al. (2014), nature benefits such as the increase in biodiversity and diversification of habitat composition were recognized from the start as fundamental characteristics of the solution that were expected to influence the respondents' valuation. Therefore, they were assessed at the same time as, and in connection with, the people benefit of recreation. Notably, the studies including nature benefits are spread out rather evenly across the timeline, and there doesn't appear to have been a shift in the assessments' focus after the spread of the NBS concept. Overall, research appears to be integrating human and nature benefits within benefits assessments, which is a fundamental step in order to reach a properly integrated benefit quantification of NBS. However, there still seems to be some challenges related to pursuing an integrated approach, as indicated by the fact that almost half of the studies focus only on people benefits. This could be an issue, as inconsistent inclusion of nature benefits within SP assessments of non-market benefits could impair the integration of these benefits as a common practice in NBS evaluation.

3.1.2.2. Framing non-tangible benefits. Focusing first on the way nature benefits are assessed in the examined studies, our results show that half were quantified as "nature for people" benefits, while the other half as "nature for nature" benefits (Fig. 1). It is encouraging that 30 % of the total sample was not only quantifying nature benefits, but also doing so through a valuation scenario that was actually including improvements for nature regardless of their impact on humans, as it is expected from the implementation of nature-inspired strategies. However, the other half of the sample was only

Table 3
Descriptive characteristics of the analyzed studies ($n = 50$) according to NBS strategy type, including scale, number of studies and publication range.

Categories	Scale [study scale]	No. of studies [% of total]	Publication range [years]
Strategy types			
Building integrated greening	Street/building	3 [6 %]	2017–2020
Small-scale urban green/blue areas	Street/building; District/neighborhood	4 [8 %]	2015–2020
Public green areas (parks/gardens)	District/neighborhood; Metropolitan/city	9 [18 %]	2001–2020
Peri-urban open spaces	Metropolitan/city	7 [14 %]	2011–2020
Rural areas	Regional landscape	15 [30 %]	2007–2021
Protected natural areas (parks/reserves)	Regional landscape	12 [24 %]	2008–2020
Stated preference method used			
Contingent valuation (CV)	All	27 [54 %]	2001–2020
Choice experiment (CE)	All	23 [46 %]	2007–2021

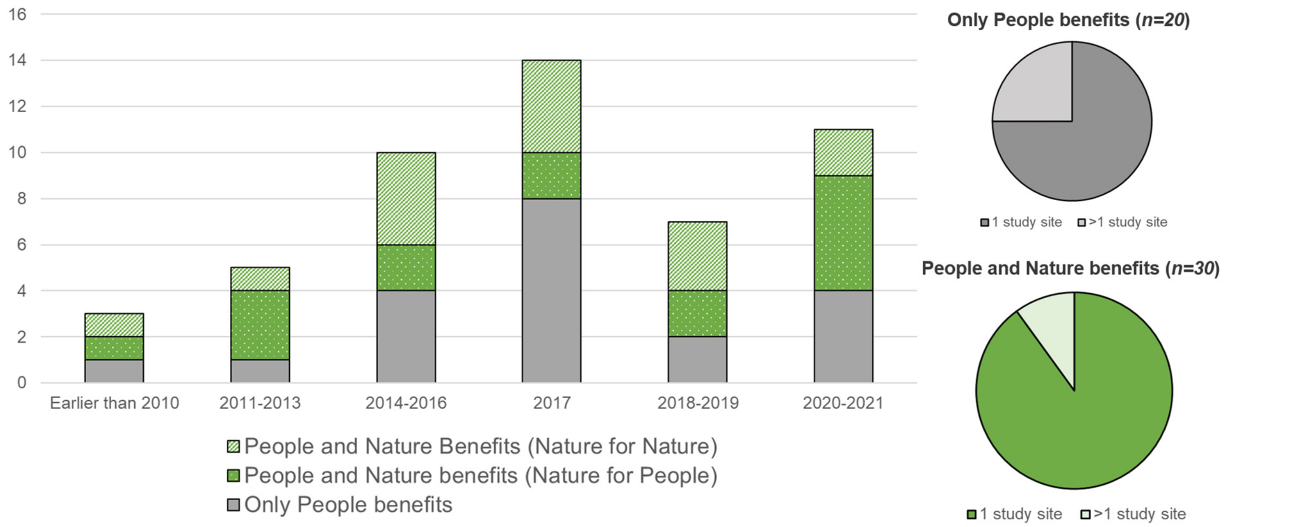


Fig. 1. Type of benefits assessed in the examined papers, grouped by publication year, including "only people" benefits (gray), and "people and nature" benefits. The latter are divided between "nature for people" (dotted) and "nature for nature" (striped) assessment of nature benefits. The pie charts additionally show how many papers had either one (darker gray and darker green) or more (lighter gray and lighter green) study sites.

looking at benefits from nature from an anthropocentric perspective. To a certain extent, this perspective can be useful for valuation, as benefits for people and for nature tend to overlap. For example, enhancing forest diversity can lead to an improvement of recreation activities and enjoyment of the area, and a consequent increase in the value associated to the changes by respondents. Yet, should the "nature for people" assessment become the predominant approach, it could normalize the misconception that the modifications created through NBS should ultimately prioritize human benefits. This could in turn lead to biased implementations, disproportionately favoring human activities (e.g. recreation) over improvements for nature. Therefore, assessment studies should attempt to include explicitly "nature for nature" quantification as independently as possible from human experience, in order to obtain a truly holistic valuation.

Fig. 2 shows more in detail how the assessed nature benefits were framed in the reviewed papers. The popularity of these two benefits well reflects the prominent position given to them in the guidelines for the robust assessment of NBS, such as the recent one by the European Commission (2021), given their centrality (specifically of biodiversity enhancement) in the NBS concept. Moreover, the presence of these benefits is possible in a wide range of NBS (e.g. from urban to rural contexts), while for example quantifying the benefits linked to the landscape structure requires a more specific type of NBS implementation. Finally, the quantification of benefits linked to a perceivable improvement of nature which may enhance the respondents' experience of the NBS is easier to determine through SP assessments.

Regarding the framing used for the assessment of people benefits, the quantification of recreation benefits seems to be the most widely applied throughout the sample. However, if considering all of the ESS sub-groups, ESS quantification appears to be the dominant way for assessing people benefits (Fig. 3). The ESS approach has various common points with the assessment of NBS benefits, e.g. both use indicators, monetary and non-monetary valuation techniques, and both link ecosystems to socio-economic systems, and can be a useful tool for people benefits quantification. Nevertheless, ESS-based quantifications are being criticized for relying on a framework that is only one of the many ways we understand ecosystems, being implemented on a project-by-project basis rather than at a greater scale, and failing to engage perspectives from social sciences and from stakeholders (Díaz et al., 2018; Norgaard, 2010; Raymond et al.,

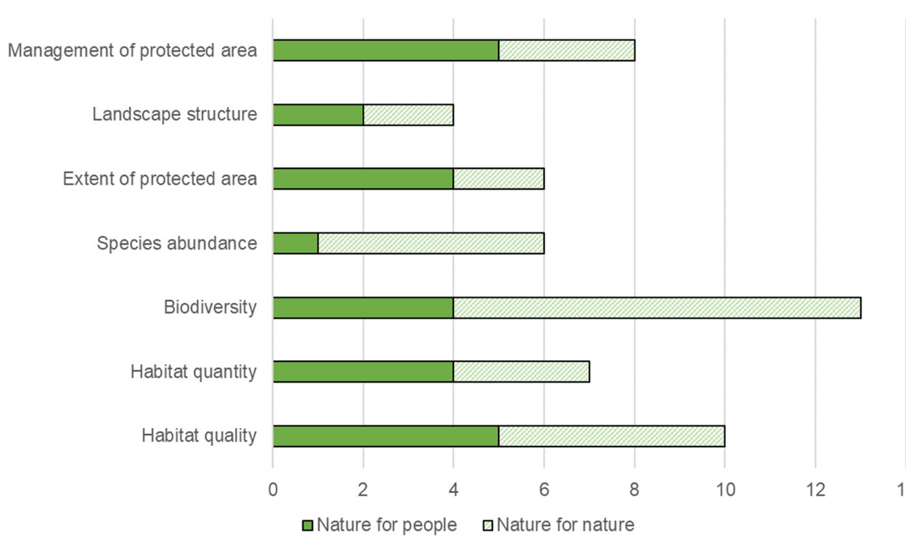


Fig. 2. Overview for the assessment of nature benefits across benefit types ($n = 30$), including benefits quantified as "nature for people" (darker green) and as "nature for nature" (striped lighter green).

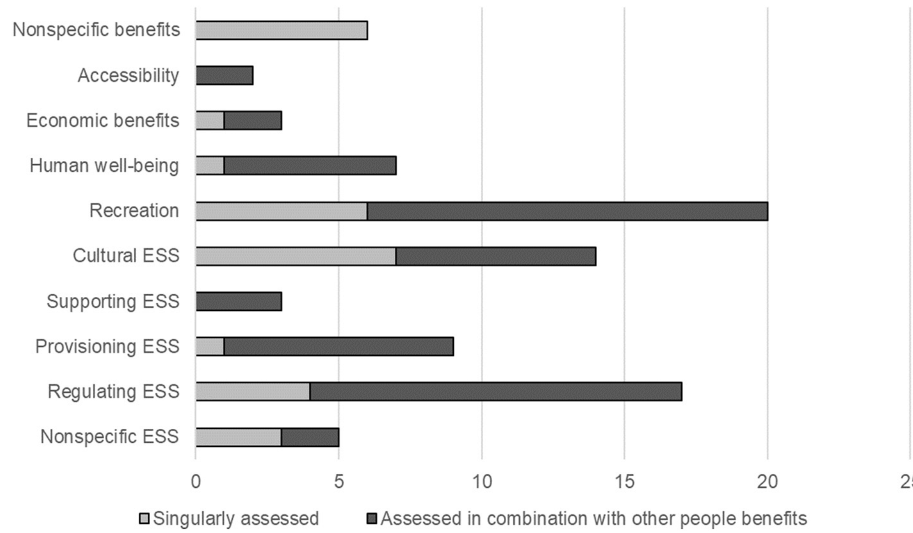


Fig. 3. Overview for people benefits that were assessed singularly (light gray) or in combination with other people benefits (dark gray), across benefit types ($n = 50$).

2017). Therefore, relying only on the assessment of ESS may result in an incomplete evaluation of the NBS benefits and a failure to identify potential for adverse impacts as a result of taking a fragmented approach to the valuation. For example, some studies were found focusing mostly on the benefits of enhanced ESS (mostly provisioning and regulating) of new green areas, without further exploring the possibility of the examined strategies benefitting nature as well. It is not surprising that regulating and provisioning ESS are extensively reported in the literature, as they include some of the services that are most directly linked to risk reduction and human livelihoods (e.g. flood risk reduction, wood provisioning, pollutants removal, food production, etc.). The quantification of these impacts is fundamental to support the use of NBS as alternatives to business-as-usual strategies. Nevertheless, downplaying the effects of NBS on nature may not only negatively affect the cost-benefit assessment of the strategy, but also miss the opportunity to consider different approaches to the solution. For example, by integrating more biodiversity enhancing areas or ensuring that the green area is planned in a way that is not only beneficial for people (i.e. ESS, recreation, and well-being) but also for nature (e.g. preventing degradation of nature at the expense of improving human benefits). Including such benefits and showing their potential value is thus an essential step to support holistic NBS implementation.

However, an ESS-valuation per se is not necessarily an option unsuited for the quantification of NBS benefits. For example, Reynaud et al. (2017) created a valuation scenario that included all of the aspects targeted by their examined NBS solution, i.e. risk reduction, and social and biodiversity benefits. The targeted people benefits were classified as ESS, but they were not treated as isolated impacts; on the contrary, the authors created a CV scenario that highlighted how the three components of the project fed off and interacted with each other to create integrated benefits. For example, they underline how having a green park would offer the same flood risk reduction (regulating ESS) as a gray infrastructure solution, but emphasize the additional benefits in terms of recreation and biodiversity benefits with the green solution. Further positive examples encompass studies that address various sub-groups of ESS and include other people benefits such as accessibility or human well-being (López-Mosquera and Sánchez, 2011; Sirina et al., 2017). Overall, if properly integrated with the evaluation of benefits from other perspectives (e.g. not only anthropocentric, but also focusing on benefits for nature), ESS assessments can be a valuable tool for the quantification of nature-inspired strategies' non-tangible benefits.

Aside from the valuation of ESS (with an emphasis on regulating ESS), our review also showed a tendency of the SP assessment for non-market benefits of NBS to rely heavily on the quantification of recreation benefits (Fig. 3). The reliance on recreation assessments could be partially explained by the fact SP assessments are particularly well suited for the quantification of these benefits (which are familiar, directly impacting the respondents and easy to create a valuation scenario for), as extensive coverage in the literature shows (Faccioli et al., 2015; Nielsen et al., 2007; Tyrväinen et al., 2014). Moreover, the assessment of these benefits is of great interest for the management of NBS implemented in touristic destinations, as it was the case in several of the reviewed publications, e.g. Ruka-Kuusamo winter sports area (Tyrväinen et al., 2014) or the Athalassa National Forest Park (Karanikola et al., 2017). Despite recreational benefits being a major component for enhancing the human well-being benefits of NBS, the quantification of nature-inspired strategies through valuation scenarios centering on human experience alone (e.g. "How much would you pay for experiencing this change/improvement?") can be limiting. In some cases, benefits for visitors and for biodiversity overlap, e.g. greater variety of ecosystems and species, larger green areas, etc. However, in other cases, if the NBS is assessed from a purely recreational perspective, some "nature for nature" improvements could be seen as negative changes (e.g. greater amount of deadwood or areas with limited access for people), contributing to lower valuations and a less positive cost-benefit assessment in total. Therefore, it is important for future valuations of NBS benefits to clearly articulate the aim and purpose of these strategies, in order to ensure the quantification of benefits integrates all of the impact areas of the solutions without any biases. A possible strategy to enable this is to supplement the evaluation method with the results of scientific assessment tools (e.g. ecological models, risk assessment analyses), which could show the respondents the most likely outcomes of the proposed strategies (as done in e.g. Derkzen et al., 2017). This procedure may be particularly effective in bringing to light the long-term effects of NBS, which often include "nature for nature" benefits (e.g. changes in the habitats, increase of a species' population numbers) and may be more difficult for the respondents to envision.

However, it should be noted that even with an unbiased presentation of NBS effects, trade-offs are inevitable among the different benefits of NBS (Alves et al., 2020). Moreover, the quantification of said trade-offs is especially challenging due to the varied perspectives of stakeholders, the multiple time scales of assessment and influence of other factors (European Commission, 2021). At the same time, their detection and analysis are key to achieve a holistic evaluation of NBS. Therefore, there is a need to reach a balance between establishing priorities among the benefits to evaluate and ensuring a holistic assessment of all possible benefits is undertaken (i.e. the risk reduction benefit should not be compromised, but the under prioritization of nature and people benefits should be avoided) (Alves et al., 2020). To achieve this complex balance, various studies suggest different approaches, from a thorough analysis of the trade-offs between costs, risk reduction and benefit enhancement (European Commission, 2021), to strengthening the involvement of citizens and private actors (Dushkova and Haase, 2020). Moreover, sufficient evidence to clearly define NBS trade-offs is still needed (Alves et al., 2020; Dushkova and Haase, 2020; European Commission, 2021), and SP assessments could offer a relevant contribution to an evidence base gathered through direct interaction with various stakeholders.

Overall, and in the words of Hanson et al. (2020), research on the quantification of NBS and their benefits seems to be stuck on using an "older concepts toolbox" (e.g. quantification of ESS), passed down from concepts developed earlier such as green infrastructure or valuation of recreational benefits. As much as these incremental steps (i.e. building upon already established concepts) has previously worked to facilitate and promote the NBS approach within the scientific sphere, this compartmentalized "toolbox" is in danger of becoming more of a barrier when trying to holistically assess the benefits of NBS and expand their uptake in other contexts. Nonetheless, we have also seen how new assessment approaches are starting to emerge by effectively combining the quantification of the three areas of impact of NBS (i.e. within the economic, social and environmental domains). On the one hand, several of the reviewed studies strived to integrate all of these impact areas in their assessments by presenting all the expected impacts to the respondents, as discussed previously for Reynaud et al. (2017). On the other hand, some publications have utilized a more general valuation question regarding the impacts of the strategy. The latter refers to the approach that was labeled as "nonspecific benefits" within the context of this study. The publications using it have presented the implemented solutions and their impacts, and then let the respondents value them, i.e. asking valuation questions such as "How much will you be willing to pay for the implementation of the presented solution?" (e.g. Collins et al., 2017; Derkzen et al., 2017; Nielsen et al., 2007; Wilker and Gruehn, 2017). This broader approach does not focus the respondent's valuation on specific impacts, thereby avoiding reducing the assessment of the entire nature-inspired strategy to the valuation of a single aspect, or a small selected group of its benefits (e.g. only water provisioning services). At the same time, this approach is more susceptible to the knowledge limits of the respondent, and therefore also in this case, the NBS's overarching goals and expected positive impacts need to be clearly stated and explained in the valuation scenario.

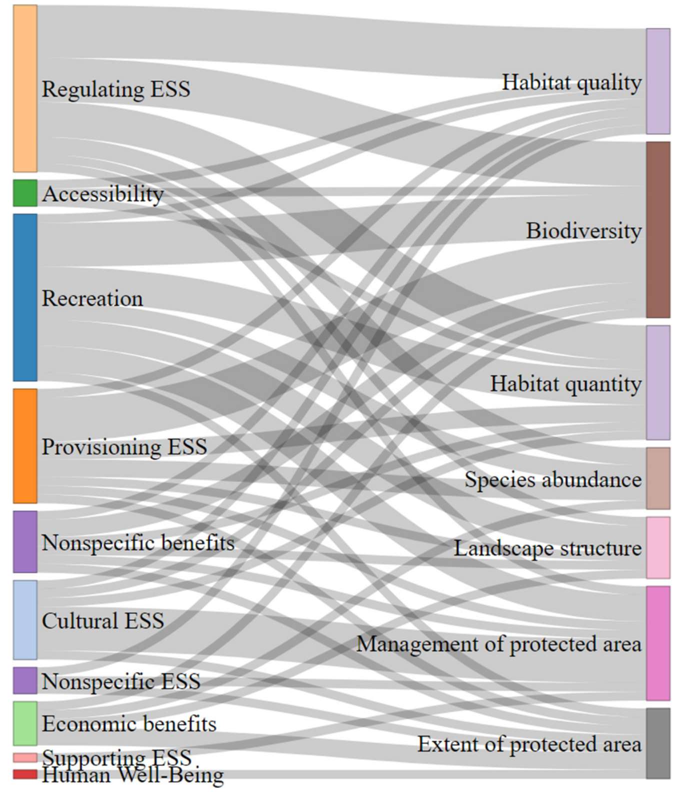


Fig. 4. Sankey diagram showing the relations between the assessed people (listed on the left-hand axis) and nature benefits (right-hand axis) for all of the analyzed benefit types. The higher the number of papers assessing two benefits together, the thicker the line connecting them. Note that the maximum line thickness symbolizes 6 papers.

3.1.2.3. Assessing interlinkages between people and nature benefits. Finally, for those publications where both people and nature benefits were valued together, we further examined which of these benefits were typically quantified together. Based on our initial analyses, the people indicators assessed most were recreation, followed by regulating, provisioning and cultural ESS (see Fig. 3). And for the nature indicators, these were biodiversity, habitat quality, and management of the protected area (Fig. 2). Fig. 4 schematizes the number of publications in which the chosen benefits were assessed together, where the thickness of the lines is proportional to the number of articles that quantify the connected benefits. This last analysis is based on a subset of the publications reviewed here ($n = 30$, i.e. the number of reviewed articles assessing both nature and people benefits); nevertheless, the highlighted connections offer some insights into how previous SP studies have paired up the assessment of people and nature benefits, in the absence of a predefined valuation framework.

Regulating and provisioning ESS appear to have a similarly strong connection to the valuation of biodiversity, but differ in their relationship to habitat quality assessment, which is for the most part quantified together with regulating ESS (Fig. 4). This latter connection appears to be particularly strong in nature-inspired solutions focusing on water-related risk reduction (e.g. solutions to contrast hydro-meteorological risks, such as cloudbursts or floods). When quantifying regulating ESS such as flood risk reduction and improvement of water quality, extending the valuation scenario to include the benefit of improved habitat quality appeared to be a sensible choice for various studies (e.g. Ando et al., 2020; Bateman et al., 2011; Ramajo-Hernández and del Saz-Salazar, 2012). As for the recreation benefits, they appear to be most often quantified together with biodiversity benefits, followed by habitat quantity (Fig. 4). The strong relation between cultural ESS and management of protected area benefits is most likely linked to the fact that cultural ESS were mainly assessed in study sites of particular relevance for visitors, i.e. natural parks and/or touristic destinations. In these contexts, the most common objective for the nature benefit quantification was to ascertain the positive impacts of managing (including actions such as maintaining, protecting and restoring) the NBS area and its characteristics (Liu et al., 2019; Sato et al., 2017; Thapa et al., 2020).

Benefits that can be intuitively paired can act as a solid starting point for the creation of a framework for the comprehensive assessment of NBS benefits. However, we believe that an assessment framework is needed that strives for a more objective and thus complete valuation, which permits the connection of all possible benefits, even those that may not be automatically linked. This way, even "unexpected" applications and impacts of nature-inspired strategies would be assessed, if qualitatively-based as a start (Pagano et al., 2019; Perrone et al., 2020), and not excluded a priori.

3.2. Path to implementation for a holistic quantification of NBS benefits

The results of our review disclose a number of gaps within the research on the assessment of non-market benefits of NBS and NBS-like strategies. First, the literature on this subject has been, until now, only partially integrating the spheres of human and nature benefits and has focused predominantly on single-case studies (Fig. 1). Moreover, despite offering a good insight into the use of the method, the past literature on the use of SP for the assessment of non-tangible benefits of nature-inspired strategies does not seem to offer a robust holistic framework that could be systematically applied to new NBS projects. In fact, most of the analyzed studies appeared to have different focuses and prioritization of benefits (compare Figs. 2, 3, 4).

These highlighted gaps in the current research can be particularly harmful in a planning context, where being able to obtain a holistic overview of a strategy's benefits is fundamental for designing and implementing a NBS fulfilling the desired impacts. Studies on the barriers for the implementation of NBS in such contexts name economic factors, together with a lack of knowledge and legal issues, as one of the main obstacles to NBS uptake (Wihlborg et al., 2019). Initiatives such as the COST Action Circularity City (Langergraber et al., 2021) aim at creating frameworks for the classification of NBS interventions and to achieve a better understanding of their concept in decision-making environments. However, as long as the benefits of nature-inspired solutions will be classified and valued as "separated silos", application of NBS will be challenged to comprehensively meet the various (and sometimes competing) goals within key international legislation and agendas (e.g. UN Sustainable Development Goals). Another key aspect of NBS valuation highlighted in the recent literature is the need for distancing from purely anthropocentric perspectives and advancing towards an approach that is as holistic as possible, from the planning to the evaluation phase (Bayulken et al., 2021; Pineda-Pinto et al., 2021). As we have also touched upon in our analyses, there seems to be an underlying tendency for treating the "nature for nature" benefits of NBS as an afterthought, i.e. after "solving" and implementing solutions beneficial for controlling water-related risks and working to ensure benefits to people are maximized (in terms of reducing water-related hazards). This trend risks compromising the actual impact of the solution, and at the same time can contribute to downplay the value of NBS, which would then again reinforce the perception of these solutions as economically infeasible or inconvenient. Here it is important to point out that our research does not mean to hold up the examined literature, which in various instances precedes the term "NBS" itself, against the newly emerged ideals. Instead, it strives to highlight how future primary data collection approaches, regarding the non-tangible benefits of nature-inspired strategies, need a change of pace that matches our growing knowledge on the said benefits.

We thus believe that research going forwards should focus on filling the identified gaps when conducting valuation studies in order to transition from a compartmentalized quantification to one that maximizes both the recognition for and the valuation of the multiple impacts stemming from nature-inspired strategies. If the array of NBS benefits is left unrecognized for long enough, it will be difficult in the future to advocate for these solutions in decision-making environments and justify their higher costs in respect to "business-as-usual", gray strategies (Jia et al., 2017; Qiu et al., 2020). It also risks a negative economic backlash, if implemented solutions must be adjusted once again, for example in what could become costly "restoration" activities, to undo unforeseen damage to local ecosystems.

Hence, we envision the path to implementation for a holistic quantification of NBS benefits to rely on an "enhanced" SP approach. SP methods have already been identified as a central tool for the assessment of non-tangible benefits of NBS by the literature. Moreover, they are widespread, supported by a large body of literature, and are the base on which broader meta-analyses are built upon (Arrow et al., 1993; Bockarjova et al., 2020; Johnston et al., 2017). All of these characteristics make a case for their continued use in the future. In particular, meta-studies would benefit from the application of an assessment framework that would produce comparable results from different locations.

Specifically, we envision any new methodological developments to focus on better transferability in addition to being holistic, as our study has highlighted a lack of studies carried out across different sites in the literature. A more transferable approach that can be applied across different sites could possibly uncover broader, perhaps regionalized, trends such as inclusion of e.g. aesthetic factors or cultural characteristics in the economic appraisal. On the other hand, a too high reliance on site-specific assessments could harm the idea of NBS as effective and competitive alternatives for climate adaptation, as they could come to be seen as extremely specific strategies creating very locally-bound (and complex to quantify) benefits. A new balance between local characteristics and more regional trends would allow us to reach, if not a seamlessly transferable quantification method, at least a common starting point for assessing NBS non-market benefits that could contribute to the uptake and upscaling of NBS.

3.3. Appraising limitations of SP methods

Despite the advantages offered by the SP approach in creating a replicable assessment of non-tangible benefits, limitations need to be addressed when considering the further application of this method. In the literature, a number of criticisms have been mentioned regarding SP methods. Probably one of the most cited is the possibility to run into hypothetical bias, due to the fact that the respondents' bids on an imaginary scenario can lead to unreliable estimates (e.g. due to free-riding, pressure to give the "correct answer", not fully understanding the scenario, etc.) (Schläpfer et al., 2004). However, it has been shown that hypothetical bias can be addressed through the comparison with results from other methods; for example, revealed preference approaches such as hedonic pricing or travel cost method (Bateman et al., 2006).

Further limitations include in-sample selection bias, non-response bias (Bateman et al., 2006), placing a heavy cognitive burden on the respondents (Ndebele and Forgie, 2017), and the risk of WTP responses to quantify the "moral satisfaction of contributing to public goods" rather than the actual economic values for these goods (Kahneman and Knetsch, 1992). Nevertheless, suggestions have been made to overcome all of these obstacles and can be applied to improve any adaptation or methodological development. Overall, when their limitations are properly addressed, SP approaches still remain the most reliable methods when endeavoring to value the non-market benefits of a specific good (Carson et al., 2014; Champ, 2017; Johnston et al., 2017).

4. Conclusions

This paper delivers an overview of how SP methods are currently used to assess intangible people benefits provided by NBS and NBS-like strategies, as well as how well they quantify the links between people and nature benefits. The study analyzes relevant non-market valuation studies from around the world and strives to highlight any biases or knowledge gaps of the current evaluation, and identify further research needs.

We show that there are still many challenges and unexploited opportunities in existing research concerning the integrated assessment of non-market human and nature benefits for nature-inspired strategies. The valuation of non-tangible benefits is still not so widespread, especially in projects explicitly labeled as NBS. Furthermore, most of the research is based on a case-to-case approach, and this study has struggled to find papers suggesting and opening paths for replication of their methodology. Steps are being taken, however, towards a more interconnected assessment of benefits (i.e. the majority of the studies include both people and nature benefits, and nature benefits are assessed in a way that takes into consideration "nature for nature" benefits). Nonetheless, for the most part, the current assessment approaches have applied pre-existing methods (e.g. valuation of ESS and recreation) and a predominantly anthropocentric perspective to benefit quantification. Overall, a shared holistic approach does not appear to emerge from the present literature.

Considering the emphasis placed on the need for a holistic assessment of NBS impacts, and the particularly relevant position that non-market benefits hold with regards to advocating for NBS during decision-making, there seems to be a mismatch between the actions that are needed for supporting NBS uptake and the methods available so far. Therefore, a new understanding and framing of the benefits of NBS and NBS-like strategies needs to come forward, advocating for more comprehensive and interconnected approaches. We argue that we need to actively ensure a paradigm shift occurs, away from the application of older methods towards a more holistic assessment, for the purpose of (i) not missing opportunities for the creation of multiple benefits across NBS domains, and (ii) assuring a thorough valuation of non-tangible benefits. Both these aspects will positively influence the cost-benefit analysis of both NBS and NBS-like strategies, and increase their chance to increasingly be considered as feasible alternatives to "business-as-usual" climate adaptation strategies.

Thus, we suggest that further research could include the creation of a novel SP tool that should be: (i) easily tailorable to maximize its potential application across a wide variety of NBS, (ii) focused on people and nature non-market benefits, and their interconnections, and, where possible (iii) designed to ensure its potential for replicability and upscaling.

CRediT authorship contribution statement

Martina Viti: Writing - Original Draft, Investigation, Methodology, Data Curation, Visualization. **Roland Löwe**: Conceptualization, Writing - Review & Editing, Methodology. **Hjalte J.D. Sørup**: Writing - Review & Editing, Methodology. **Marzenna Rasmussen**: Writing - Review & Editing, Validation. **Karsten Arnbjerg-Nielsen**: Supervision, Writing - Review & Editing, Project Management, Funding acquisition. **Ursula S. McKnight**: Conceptualization, Supervision, Writing - Review & Editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was funded by the European Union's Horizon 2020 Research and Innovation program under grant agreement No. 776866 for the RECONECT (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion) project.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.156636.

References

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., Sanchez, A., 2019. Assessing the co-benefits of green-blue-grey infrastructure for sustainable urban flood risk management. J. Environ. Manag. 239 (February), 244–254. https://doi.org/10.1016/j.jenvman.2019.03.036.

Alves, A., Vojinovic, Z., Kapelan, Z., Sanchez, A., Gersonius, B., 2020. Exploring trade-offs among the multiple benefits of green-blue-grey infrastructure for urban flood mitigation. Sci. Total Environ. 703, 134980. https://doi.org/10.1016/j.scitotenv.2019.134980.

Ando, A.W., Cadavid, C.L., Netusil, N.R., Parthum, B., 2020. Willingness-to-volunteer and stability of preferences between cities: estimating the benefits of stormwater management. J. Environ. Econ. Manag. 99, 102274. https://doi.org/10.1016/j.jeem.2019.102274.

Arrow, K., Solow, R., Portney, P.R., Leamer, E.E., Radner, R., Schuman, H., 1993. Report of the NOAA Panel on Contingent Valuation.

Balderas Torres, A., MacMillan, D.C., Skutsch, M., Lovett, J.C., 2015. 'Yes-in-my-backyard': spatial differences in the valuation of forest services and local co-benefits for carbon markets in México. Ecol. Econ. 109, 130–141. https://doi.org/10.1016/j.ecolecon.2014.11.008.

Bateman, Ian J., Day, B.H., Georgiou, S., Lake, I., 2006. The aggregation of environmental benefit values: welfare measures, distance decay and total WTP. Ecol. Econ. 60 (2), 450–460. https://doi.org/10.1016/j.ecolecon.2006.04.003.

Bateman, I.J., Brouwer, R., Ferrini, S., Schaafsma, M., Barton, D.N., Dubgaard, A., Hasler, B., Hime, S., Liekens, I., Navrud, S., De Nocker, L., Ščeponavičiūtė, R., Semėnienė, D., 2011. Making benefit transfers work: deriving and testing principles for value transfers for similar and dissimilar sites using a case study of the non-market benefits of water quality improvements across Europe. Environ. Resour. Econ. 50 (3), 365–387. https://doi.org/10.1007/s10640-011-9476-8.

Bayulken, B., Huisingh, D., Fisher, P.M.J., 2021. How are nature based solutions helping in the greening of cities in the context of crises such as climate change and pandemics? A comprehensive review. J. Clean. Prod. 288, 125569. https://doi.org/10.1016/j.jclepro.2020.125569.

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 (September 2019), 106480. https://doi.org/10.1016/j.ecolecon.2019.106480.

Carson, R.T., Groves, T., List, J.A., 2014. Consequentiality: a theoretical and experimental exploration of a single binary choice. J. Assoc. Environ. Resour. Econ. 1 (1/2), 171–207. https://doi.org/10.1086/676450.

Castellanos, L.A., Versini, P., Bonin, O., 2020. A Text-mining Approach to Compare Impacts and Benefits of Nature-based Solutions in Europe, pp. 1–19.

Champ, P.A., 2017. Collecting Nonmarket Valuation Data, pp. 55–82 https://doi.org/10.1007/978-94-007-7104-8_3.

Choi, C., Berry, P., Smith, A., 2021. The climate benefits, co-benefits, and trade-offs of green infrastructure: a systematic literature review. J. Environ. Manag. 291 (April), 112583. https://doi.org/10.1016/j.jenvman.2021.112583.

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based solutions to address global societal challenges. In: Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S. (Eds.), Nature-based Solutions to Address Global Societal Challenges. IUCN International Union for Conservation of Nature https://doi.org/10.2305/IUCN.CH.2016.13.en.

Collins, R., Schaafsma, M., Hudson, M.D., 2017. The value of green walls to urban biodiversity. Land Use Policy 64, 114–123. https://doi.org/10.1016/j.landusepol.2017.02.025.

De Valck, J., Vlaeminck, P., Broekx, S., Liekens, I., Aertsens, J., Chen, W., Vranken, L., 2014. Benefits of clearing forest plantations to restore nature? Evidence from a discrete choice experiment in Flanders, Belgium. Landsc. Urban Plan. 125, 65–75. https://doi.org/10.1016/j.landurbplan.2014.02.006.

Derkzen, M.L., van Teeffelen, A.J.A., Verburg, P.H., 2017. Green infrastructure for urban climate adaptation: how do residents' views on climate impacts and green infrastructure shape adaptation preferences? Landsc. Urban Plan. 157, 106–130. https://doi.org/10.1016/j.landurbplan.2016.05.027.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Shirayama, Y., 2018. Assessing nature's contributions to people. Science 359 (6373), 270–272. https://doi.org/10.1126/science.aap8826.

Din Dar, M.U., Shah, A.I., Bhat, S.A., Kumar, R., Huisingh, D., Kaur, R., 2021. Blue green infrastructure as a tool for sustainable urban development. J. Clean. Prod. 318 (June), 128474. https://doi.org/10.1016/j.jclepro.2021.128474.

Doherty, E., Murphy, G., Hynes, S., Buckley, C., 2014. Valuing ecosystem services across water bodies: results from a discrete choice experiment. Ecosyst. Serv. 7, 89–97. https://doi.org/10.1016/j.ecoser.2013.09.003.

Dumitru, A., Frantzeskaki, N., Collier, M., 2020. Identifying principles for the design of robust impact evaluation frameworks for nature-based solutions in cities. Environmental Science & Policy 112 (April 2019), 107–116. https://doi.org/10.1016/j.envsci.2020.05.024.

Dushkova, D., Haase, D., 2020. Not simply green: nature-based solutions as a concept and practical approach for sustainability studies and planning agendas in cities. Land 9 (1), 19. https://doi.org/10.3390/land9010019.

EEA, 2015. Natural Capital and Ecosystem Services.

European Commission, 2015. Towards an EU Research and Innovation Policy Agenda for Nature-based Solutions & Re-naturing Cities: Final Report of the Horizon 2020 Expert Group on "Nature-based Solutions and Re-naturing Cities".

European Commission, 2021. Evaluating the Impact of Nature-based Solutions: A Summary for Policy Makers. https://doi.org/10.2777/2219.

Faccioli, M., Riera Font, A., Torres Figuerola, C.M., 2015. Valuing the recreational benefits of wetland adaptation to climate change: a trade-off between species' abundance and diversity. Environ. Manag. 55 (3), 550–563. https://doi.org/10.1007/s00267-014-0407-7.

Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P.S., Rivard, G., Uhl, M., Dagenais, D., Viklander, M., 2015. SUDS, LID, BMPs, WSUD and more – the evolution and application of terminology surrounding urban drainage. Urban Water J. 12 (7), 525–542. https://doi.org/10.1080/1573062X.2014.916314.

Gelcich, S., Amar, F., Valdebenito, A., Castilla, J.C., Fernandez, M., Godoy, C., Biggs, D., 2013. Financing marine protected areas through visitor fees: insights from tourists willingness to pay in Chile. Ambio 42 (8), 975–984. https://doi.org/10.1007/s13280-013-0453-z.

Hagedoorn, L.C., Koetse, M.J., van Beukering, P.J.H., Brander, L.M., 2021. Reducing the finance gap for nature-based solutions with time contributions. Ecosyst. Serv. 52 (March), 101371. https://doi.org/10.1016/j.ecoser.2021.101371.

Hanson, H.I., Wickenberg, B., Alkan Olsson, J., 2020. Working on the boundaries—how do science use and interpret the nature-based solution concept? Land Use Policy 90 (October 2019), 104302. https://doi.org/10.1016/j.landusepol.2019.104302.

Hynes, S., Chen, W., Vondolia, K., Armstrong, C., O'Connor, E., 2021. Valuing the ecosystem service benefits from kelp forest restoration: A choice experiment from Norway. Ecological Economics 179 (September 2020), 106833. https://doi.org/10.1016/j.ecolecon.2020.106833.

IUCN, 2012. The IUCN Programme 2013 – 16. March 2012, pp. 184–210.

IUCN, 2020. IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition. IUCN Global Standard for Nature-based Solutions: A User-friendly Framework for the Verification, Design and Scaling up of NbS: First Edition. IUCN, International Union for Conservation of Nature https://doi.org/10.2305/IUCN.CH.2020.08.en.

Jia, H., Wang, Z., Zhen, X., Clar, M., Yu, S.L., 2017. China's sponge city construction: a discussion on technical approaches. Front. Environ. Sci. Eng. 11 (4), 18. https://doi.org/10.1007/s11783-017-0984-9.

Johnston, R.J., Boyle, K.J., Adamowicz, W.(Vic), Bennett, J., Brouwer, R., Cameron, T.A., Hanemann, W.M., Hanley, N., Ryan, M., Scarpa, R., Tourangeau, R., Vossler, C.A., 2017. Contemporary guidance for stated preference studies. J. Assoc. Environ. Resour. Econ. 4 (2), 319–405. https://doi.org/10.1086/691697.

Kahneman, D., Knetsch, J.L., 1992. Valuing public goods: the purchase of moral satisfaction. J. Environ. Econ. Manag. 22 (1), 57–70. https://doi.org/10.1016/0095-0696(92)90019-S.

Karanikola, P., Panagopoulos, T., Tampakis, S., 2017. Weekend visitors' views and perceptions at an urban national forest park of Cyprus during summertime. J. Outdoor Recreat. Tour. 17 (December 2015), 112–121. https://doi.org/10.1016/j.jort.2016.10.002.

Koetse, M., Brouwer, R., van Beukering, P.J.H., 2015. Economic valuation methods for ecosystem services. Ecosystem Services: From Concepts to Practice, pp. 108–131 https://doi.org/10.1017/CBO9781107477612.010.

Langergraber, G., Castellar, J.A.C., Pucher, B., Baganz, G.F.M., Milosevic, D., Andreucci, M.-B., Kearney, K., Pineda-Martos, R., Atanasova, N., 2021. A framework for addressing circularity challenges in cities with nature-based solutions. Water 13 (17), 2355. https://doi.org/10.3390/w13172355.

Lemaire, G., Carnohan, S., Grand, S., Mazel, V., Bjerg, P., McKnight, U., 2021. Data-driven system dynamics model for simulating water quantity and quality in peri-urban streams. Water 13 (21), 3002. https://doi.org/10.3390/w13213002.

Liu, W.-Y., Lin, Y.-Y., Chen, H.-S., Hsieh, C.-M., 2019. Assessing the amenity value of Forest ecosystem services: perspectives from the use of sustainable green spaces. Sustainability 11 (16), 4500. https://doi.org/10.3390/su11164500.

López-Mosquera, N., Sánchez, M., 2011. Emotional and satisfaction benefits to visitors as explanatory factors in the monetary valuation of environmental goods. An application to periurban green spaces. Land Use Policy 28 (1), 151–166. https://doi.org/10.1016/j.landusepol.2010.05.008.

Mant, J., Holman, I., Janes, V., Arthur, S., Haynes, H., Allen, D., Fenner, D., Hoang, L., Morgan, M., 2013. Delivering and Evaluating Multiple Flood Risk Benefits in Blue-Green Cities Key Project Outputs February.

Mäntymaa, E., Ovaskainen, V., Juutinen, A., Tyrväinen, L., 2018. Integrating nature-based tourism and forestry in private lands under heterogeneous visitor preferences for forest attributes. J. Environ. Plan. Manag. 61 (4), 724–746. https://doi.org/10.1080/09640568.2017.1333408.

Mejía, C.V., Brandt, S., 2017. Utilizing environmental information and pricing strategies to reduce externalities of tourism: the case of invasive species in the Galapagos. J. Sustain. Tour. 25 (6), 763–778. https://doi.org/10.1080/09669582.2016.1247847.

Mishra, P.P., 2017. The benefits of improving urban lakes in mega cities: a revealed and stated preference approach applied to the Hussain Sagar in Hyderabad, India. Environ. Dev. Econ. 22 (4), 447–469. https://doi.org/10.1017/S1355770X17000183.

Ndebele, T., Forgie, V., 2017. Estimating the economic benefits of a wetland restoration programme in New Zealand: a contingent valuation approach. Econ. Anal. Policy 55, 75–89. https://doi.org/10.1016/j.eap.2017.05.002.

Nielsen, A.B., Olsen, S.B., Lundhede, T., 2007. An economic valuation of the recreational benefits associated with nature-based forest management practices. Landsc. Urban Plan. 80 (1–2), 63–71. https://doi.org/10.1016/j.landurbplan.2006.06.003.

Norgaard, R.B., 2010. Ecosystem services: from eye-opening metaphor to complexity blinder. Ecol. Econ. 69 (6), 1219–1227. https://doi.org/10.1016/j.ecolecon.2009.11.009.

O'Donnell, E.C., Woodhouse, R., Thorne, C.R., 2018. Evaluating the multiple benefits of a sustainable drainage scheme in Newcastle, UK. Proc. Inst. Civ. Eng. Water Manage. 171 (4), 191–202. https://doi.org/10.1680/jwama.16.00103.

Pagano, A., Pluchinotta, I., Pengal, P., Cokan, B., Giordano, R., 2019. Engaging stakeholders in the assessment of NBS effectiveness in flood risk reduction: a participatory system dynamics model for benefits and co-benefits evaluation. Sci. Total Environ. 690, 543–555. https://doi.org/10.1016/j.scitotenv.2019.07.059.

Pérez-Urrestarazu, L., Blasco-Romero, A., Fernández-Cañero, R., 2017. Media and social impact valuation of a living wall: the case study of the Sagrado Corazon hospital in Seville (Spain). Urban For. Urban Green. 24, 141–148. https://doi.org/10.1016/j.ufug.2017.04.002 (November 2016).

Perrone, A., Inam, A., Albano, R., Adamowski, J., Sole, A., 2020. A participatory system dynamics modeling approach to facilitate collaborative flood risk management: a case study in the Bradano River (Italy). Journal of Hydrology 580 (November 2019), 124354. https://doi.org/10.1016/j.jhydrol.2019.124354.

Petcharat, A., Lee, Y., Chang, J.B., 2020. Choice experiments for estimating the non-market value of ecosystem services in the Bang Kachao Green Area, Thailand. Sustainability 12 (18), 7637. https://doi.org/10.3390/su12187637.

Pineda-Pinto, M., Frantzeskaki, N., Nygaard, C.A., 2021. The potential of nature-based solutions to deliver ecologically just cities: lessons for research and urban planning from a systematic literature review. Ambio https://doi.org/10.1007/s13280-021-01553-7.

Qiu, S., Yin, H., Deng, J., Li, M., 2020. Cost-effectiveness analysis of green-gray stormwater control measures for non-point source pollution. Int. J. Environ. Res. Public Health 17 (3), 998. https://doi.org/10.3390/ijerph17030998.

Ramajo-Hernández, J., del Saz-Salazar, S., 2012. Estimating the non-market benefits of water quality improvement for a case study in Spain: a contingent valuation approach. Environ. Sci. Pol. 22, 47–59. https://doi.org/10.1016/j.envsci.2012.05.006.

Raymond, C.M., Pam, B., Breil, M., Nita, M.R., Kabisch, N., de Bel, M., Enzi, V., Frantzeskaki, 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. Horizon. 2020. https://doi.org/10.13140/RG.2.2.18682.08643.

Reynaud, A., Lanzanova, D., Liquete, C., Grizzetti, B., 2017. Going green? Ex-post valuation of a multipurpose water infrastructure in northern Italy. Ecosystem Services 27, 70–81. https://doi.org/10.1016/j.ecoser.2017.07.015.

Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L.S., Capobianco, V., Oen, A.M.P., McClain, M.E., Lopez-Gunn, E., 2019. Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. Nat. Hazards Earth Syst. Sci. 20 (1), 243–270. https://doi.org/10.5194/nhess-20-243-2020.

Sabyrbekov, R., Dallimer, M., Navrud, S., 2020. Nature affinity and willingness to pay for urban green spaces in a developing country. Landsc. Urban Plan. 194, 103700. https://doi.org/10.1016/j.landurbplan.2019.103700 (December 2018).

Sato, M., Ushimaru, A., Minamoto, T., 2017. Effect of different personal histories on valuation for forest ecosystem services in urban areas: a case study of Mt. Rokko, Kobe, Japan. Urban For. Urban Green. 28 (October), 110–117. https://doi.org/10.1016/j.ufug.2017.09.016.

Schläpfer, F., Roschewitz, A., Hanley, N., 2004. Validation of stated preferences for public goods: a comparison of contingent valuation survey response and voting behaviour. Ecol. Econ. 51 (1–2), 1–16. https://doi.org/10.1016/j.ecolecon.2004.04.006.

Sharifi, A., Pathak, M., Joshi, C., He, B., 2021. A systematic review of the health co-benefits of urban climate change adaptation. Sustain. Cities Soc. 74 (June), 103190. https://doi.org/10.1016/j.scs.2021.103190.

Sirina, N., Hua, A., Gobert, J., 2017. What factors influence the value of an urban park within a medium-sized French conurbation? Urban For. Urban Green. 24 (August 2016), 45–54. https://doi.org/10.1016/j.ufug.2017.03.021.

Teotónio, I., Silva, C.M., Cruz, C.O., 2021. Economics of green roofs and green walls: a literature review. Sustain. Cities Soc. 69 (February), 102781. https://doi.org/10.1016/j.scs.2021.102781.

Thapa, S., Wang, L., Koirala, A., Shrestha, S., Bhattarai, S., Aye, W.N., 2020. Valuation of ecosystem services from an important wetland of Nepal: a study from Begnas watershed system. Wetlands 40 (5), 1071–1083. https://doi.org/10.1007/s13157-020-01303-7.

Toxopeus, H., Polzin, F., 2021. Reviewing financing barriers and strategies for urban nature-based solutions. J. Environ. Manag. 289 (August 2020), 112371. https://doi.org/10.1016/j.jenvman.2021.112371.

Tyrväinen, L., 2001. Economic valuation of urban forest benefits in Finland. J. Environ. Manag. 62 (1), 75–92. https://doi.org/10.1006/jema.2001.0421.

Tyrväinen, Liisa, Mäntymaa, E., Ovaskainen, V., 2014. Demand for enhanced forest amenities in private lands: the case of the Ruka-Kuusamo tourism area, Finland. Forest Policy Econ. 47, 4–13. https://doi.org/10.1016/j.forpol.2013.05.007.

Valasiuk, S., Czajkowski, M., Giergiczny, M., Żylicz, T., Veisten, K., Landa Mata, I., Halse, A.H., Elbakidze, M., Angelstam, P., 2018. Is forest landscape restoration socially desirable? A discrete choice experiment applied to the Scandinavian transboundary Fulufjället National Park Area. Restor. Ecol. 26 (2), 370–380. https://doi.org/10.1111/rec.12563.

Venkataramanan, V., Lopez, D., McCuskey, D.J., Kiefus, D., McDonald, R.I., Miller, W.M., Packman, A.I., Young, S.L., 2020. Knowledge, attitudes, intentions, and behavior related to green infrastructure for flood management: a systematic literature review. Sci. Total Environ. 720 (February), 137606. https://doi.org/10.1016/j.scitotenv.2020.137606.

Wihlborg, M., Sörensen, J., Alkan Olsson, J., 2019. Assessment of barriers and drivers for implementation of blue-green solutions in Swedish municipalities. J. Environ. Manag. 233 (July 2018), 706–718. https://doi.org/10.1016/j.jenvman.2018.12.018.

Wilker, J., Gruehn, D., 2017. The potential of contingent valuation for planning practice. The example of Dortmund westpark. Raumforsch. Raumordn. 75 (2), 171–185. https://doi.org/10.1007/s13147-016-0468-6.

World Bank, 2017. Implementing nature based flood protection. Implementing Nature Based Flood Protection. World Bank, Washington, DC https://doi.org/10.1596/28837.

II

Holistic valuation of Nature-Based Solutions accounting for human perceptions and nature benefits

Viti, M., Löwe, R., Sørup, H. J. D., Iversen, S., Gebhardt, O., Ladenburg, J., McKnight, U. S., & Arnbjerg-Nielsen, K.

Journal of Environmental Management, 334, 12 p., 117498
https://doi.org/10.1016/j.jenvman.2023.117498

Journal of Environmental Management 334 (2023) 117498

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Holistic valuation of Nature-Based Solutions accounting for human perceptions and nature benefits

Martina Viti [a,*], Roland Löwe [a], Hjalte J.D. Sørup [a], Jacob Ladenburg [c], Oliver Gebhardt [d], Signe Iversen [e], Ursula S. McKnight [b], Karsten Arnbjerg-Nielsen [a]

[a] Department of Environmental and Resource Engineering, Technical University of Denmark, Bygningstorvet Bldg. 115, 2800, Kgs. Lyngby, Denmark
[b] Swedish Meteorological and Hydrological Institute, Folkborgsvägen 17, SE-601 76, Norrköping, Sweden
[c] Department of Technology, Management and Economics, Technical University of Denmark, Akademivej Bldg. 358, 2800, Kgs. Lyngby, Denmark
[d] Department of Economics, Helmholtz Centre for Environmental Research, Permoserstraße 15, D-04318, Leipzig, Germany
[e] Department of Technology and Environment, Aarhus Municipality, Karen Blixens Boulevard 7, 8220, Brabrand, Denmark

A R T I C L E I N F O

Keywords:
Nature-based solutions
Willingness to pay
Climate change adaptation
Hydrometeorological risk
Holistic assessment

A B S T R A C T

When assessing strategies for implementing Nature-Based Solutions (NBS), it is paramount to identify and quantify all benefits for securing better, informed decisionmaking. Nevertheless, there appears to be a lack of primary data for linking the valuation of NBS sites with the preferences and attitudes of people interacting with them and their connection to supporting efforts to reduce biodiversity loss. This is a critical gap, as the socio-cultural context of NBS has been proven to play a big role in NBS valuation, especially for their non-tangible benefits (e.g. physical and psychological well-being, habitat enhancements, etc.). Consequently, through coccreation with the local government, we co-designed a contingent valuation (CV) survey to explore how the valuation of NBS sites may be shaped by their relationship with the users and the specific respondent and site characteristics. We applied this method to a case study of two distinct areas located in Aarhus, Denmark, with notable differences related to their attributes (e.g. size, location, time passed since construction). The esults obtained from 607 households in Aarhus Municipality show that the personal preferences of the respondent are the most relevant driver of value, surpassing both the perceptions linked to the physical features of the NBS and the socio-economic characteristics of the respondents. Specifically, the respondents attributing most importance to nature benefits were the ones assigning a higher value to the NBS and being willing to pay more for an improvement of the nature quality in the area. These findings highlight the relevance of applying a method assessing the interconnections between human perceptions and nature benefits to ensure a holistic valuation and purposeful design of NBS.

1. Introduction

It is widely acknowledged that climate change will have a major role in shaping our future, and many predictions are being made regarding the impacts and adaptations that society will face. In the case of Northern Europe, changes in rainfall regimes and an increase in mean sea level, coupled with expanding urbanization, are expected to result in increased direct damages (e.g. lost infrastructure, displacements, damage costs) and negative impacts on human well-being (e.g. mental health impacts) (European Commission, 2021a; IPCC, 2021).

The concept of Nature-Based Solutions (NBS) has emerged to tackle these challenges. NBS are defined as strategies inspired and supported by nature, which not only provide direct solutions to challenges but also enhance the spatial quality of the surrounding area in many direct and indirect ways, from biodiversity integrity to human well-being (physical, psychological and socio-economic) (Cohen-Shacham et al., 2016; European Commission, 2015; IUCN, 2012). Key to implementing and maximizing the value of NBS is quantifying their non-tangible benefits (Díaz et al., 2018; IUCN, 2020). However, the multi-dimensional nature of NBS and the trade-offs between their functions (European Commission, 2021b) make quantification very complex.

Considering the current non-tangible benefits of NBS assessment literature, the majority of studies rarely target the multiple dimensions of the socio-cultural context of NBS (e.g. people's knowledge,

* Corresponding author.
E-mail address: martvit@dtu.dk (M. Viti).

https://doi.org/10.1016/j.jenvman.2023.117498
Received 14 November 2022; Received in revised form 3 February 2023; Accepted 10 February 2023
Available online 16 February 2023

preferences and relationships to NBS sites) (Demuzere et al., 2014; Derkzen et al., 2017; Han and Kuhlicke, 2019; Madureira et al., 2015). Some studies assess people's characteristics but not their uses of the area (e.g. Ando et al., 2020), while others assess people's preferences and uses but not their knowledge or concerns regarding the risks counteracted by the proposed projects (e.g. Tibesigwa et al., 2020). Still fewer recognize the implicit interconnection between people and nature benefits and the (lost) potential for opportunities when considered separately (Viti et al., 2022). Knowledge, preferences, uses and values are all influential in determining the value attributed to the NBS, which may be an important reason for the substantial uncertainties reported by several meta-studies (Bockarjova et al., 2020; Skrydstrup et al., 2022). Moreover, all of these components are influenced by "external factors", namely the demographic, socio-economic and personal characteristics of the respondents, as well as the physical (e.g. distance from urban areas; size; biodiversity; etc.) and spatial (e.g. distance to the NBS, distance to substitute sites, quality of sites) characteristics of the NBS, as described within the vast urban green area and water body preference literature (Jørgensen et al., 2013; Sutherland and Walsh, 1985; Venkataramanan et al., 2020). Therefore, NBS assessments should consider all these factors to create both a holistic quantification of the NBS benefits and, at the same time, reduce the overall uncertainty associated with the sources and heterogeneity of NBS values.

Specifically, an expansion of the knowledge base on the factors with the greatest impact on non-tangible benefits assessments would be extremely useful to determine the attributes influencing people's evaluation (whether it is e.g. personal preferences or the physical characteristics of the NBS). Moreover, a clear assessment of the underlying reasons for the value attributed to NBS is expected to help with the prioritization and uptake of NBS projects by managing expectations and providing the basis for a more transparent decision-making process (Derkzen et al., 2017; Hérivaux and Le Coent, 2021; Venkataramanan et al., 2020).

Therefore, novel approaches are urgently required to enable a more comprehensive assessment of NBS benefits in a way that integrates the socio-cultural context and is not excessively restricted by local characteristics to enhance (method) transferability and initiate much needed cross-NBS site learnings. The outputs from such assessments are expected to help decision-makers prioritize the implementation of holistic strategies like NBS over "business as usual" (Alves et al., 2019; Sharifi et al., 2021; Viti et al., 2022).

In many cases, Stated Preference (SP) method is the only source to provide a solid base for the assessment of non-tangible NBS benefits in the absence of a market price (Johnston et al., 2017; Mitchell and Carson, 1989). This is particularly the case if the NBS is expected to entail significant non-use values and/or if the valuation of the NBS is ex post their creation. SP approaches usually rely on carefully worded questionnaires to directly seek individual preferences (in the form of monetary amounts, choices, ratings, etc.). Various SP methods exist, but Contingent Valuation (CV) is recommended when trying to quantify the total value attributed to an environmental good or service (Bateman et al., 2002).[1]

This study aims to begin filling the gap related to holistic assessment studies for the non-tangible benefits of NBS through the co-development and application of a quantitative assessment of the non-tangible benefits of NBS, which.

(i) Considers the influences of uses, preferences and values of the respondents on the NBS assessment and how they vary depending on external factors (i.e. socio-economic characteristics, physical environment); and
(ii) Can be easily compared across sites.

The developed approach is applied to a case study comprised of two distinct NBS sites located in Aarhus, Denmark. Both NBS areas have as primary aims to: (i) prevent flooding from cloudbursts or water bodies, (ii) improve the local biodiversity and (iii) benefit the local population, but they differ in various characteristics, such as size and time passed since implementation. The latter dissimilarities are fundamental to highlight the different impacts of diverse NBS features on the value attributed to a NBS site.

2. Materials and methods

2.1. Study areas

Aarhus is the second largest urban area in Denmark with approximately 300,000 inhabitants. Since 2007, Aarhus Municipality has been working with climate change adaptation, focusing primarily on the pressure from the water, i.e. rising sea levels, flooding from cloudbursts and waterbodies, and areas swamped by increasing groundwater levels (Aarhus Kommune, 2014). Recently, a cloudburst storm in 2012 heavily impacted the Aarhus area, causing widespread flooding. Various projects aiming at limiting the chances and damages of flooding have therefore been carried out in the area, and particular attention has been given to NBS, pinpointed as holistic strategies with multidimensional benefits (e.g., the reduction of coastal eutrophication and the enhancement of biodiversity in the area).

This paper focuses on testing the developed approach on two of the NBS project areas; specifically, the Lake Egå and Hovmarksparken sites. Both are found in the river catchment area of River Egå in the northern part of the city (Fig. 1). Lake Egå is placed in a low-lying area especially vulnerable to flooding, while Hovmarksparken is situated on a hillslope.

Lake Egå is an artificial waterbody established in 2006 as a large water reservoir (155 ha). Initially, Lake Egå's main task is to retain nutrients (e.g. nitrogen loss from upstream farmland) before the water flows into the Bay of Aarhus. However, its usefulness in reducing floods to residential areas was demonstrated, specifically concerning the 2012 cloudburst event. Moreover, the area adjacent to the lake has been reconstituted into natural riparian areas, including wetlands and meadows with different humidity levels. The adjacent area is now a protected natural area and provides both habitat to many species (especially birds, mostly waterfowl, both migratory and resident, but also rare birds of prey, have been observed repopulating the grounds) and increased recreational opportunities for visitors. Regarding the latter, 5.2 km of walking and cycling paths have been established around the lake, together with a birdwatching tower and an "activities area", including shelters, playgrounds and information signs. Using the total economic terminology (Pearce, 1993), Lake Egå has both large use-values (e.g. recreation opportunities) and potentially non-use values (e.g. habitat enhancements).

Hovmarksparken, adjacent to Lake Egå, contains one of 11 local rainwater management sites in the suburb of Lystrup, and is part of a larger urban cloudburst adaptation strategy. The 11 local climate adaptation sites have been implemented between 2015 and 2017. They are all interconnected, and all have in common that they either delay or retain the rainwater or direct it to areas where any ensuing damage should be reduced, e.g. fields and ponds. Given its recent establishment, the Lystrup adaptation sites have not yet been exposed to the hazard it was built to combat (i.e. a 100-year event), despite successfully counteracting severe rain episodes. Hovmarksparken is the largest of the adaptation sites, covering 6 ha and including a rainwater pond and rainwater dikes, as well as fields and green areas. The latter are mostly open to recreational activities, and some facilities are present as well (e.g. jetties on the pond, football goals). In order to support biodiversity

[1] If the goal is to estimate the value of the specific NBS attributes, such water body qualities, access levels and types etc. the method Discrete Choice Experiments is recommended (Adamowicz and Louviere, 1998; Louviere and Woodworth, 1983).

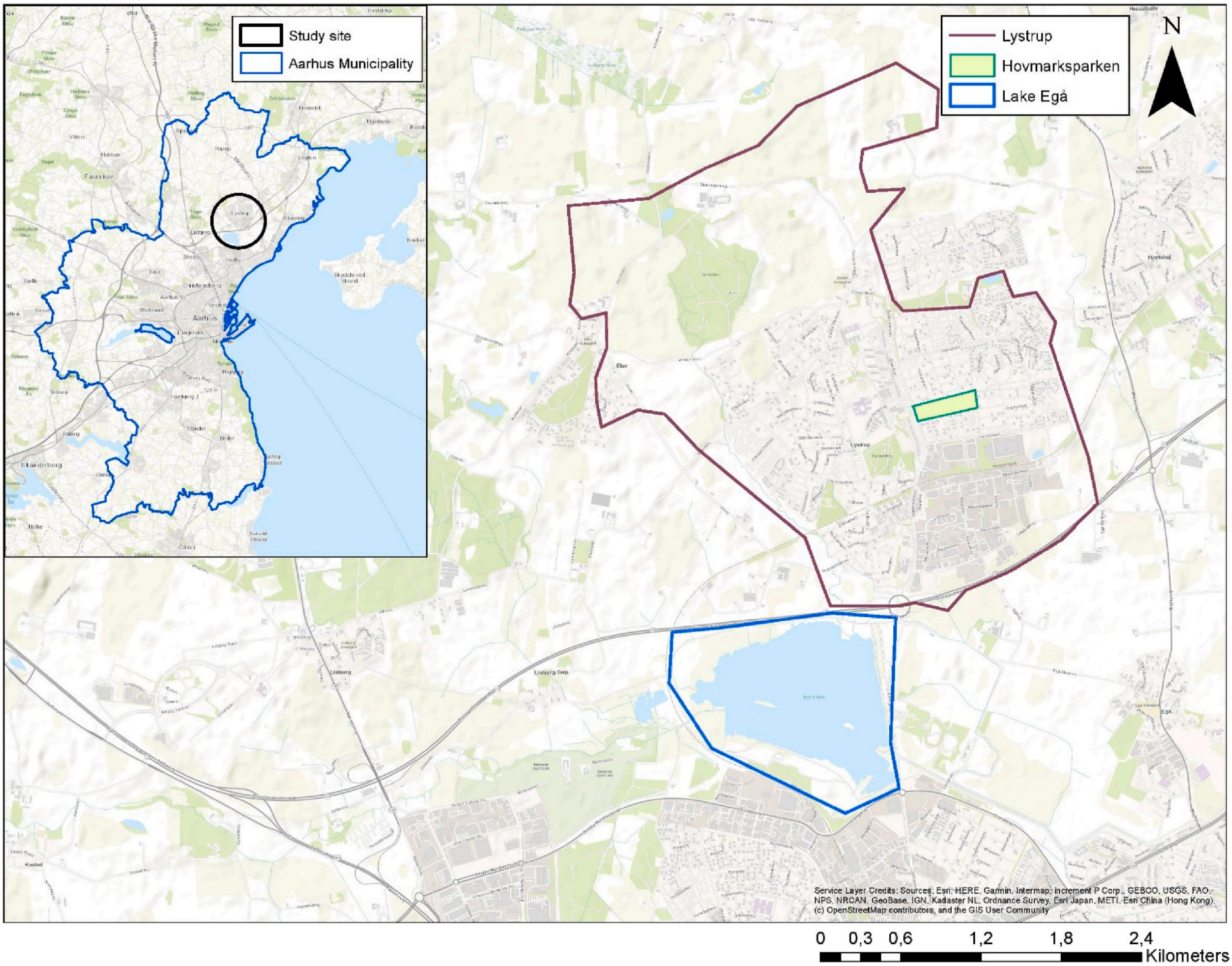


Fig. 1. *Location of the two study sites in Aarhus Municipality, Denmark (DMS Coordinates: 56°09′24.26″ N 10°12′38.74″ E).*

within the park, several biodiversity-enhancing elements were implemented as well, including planting rare native vegetation using nutrient-poor soils, leaving deadwood in situ, creating small habitats, converting a green lawn to grazed meadows, etc. These elements were partly determined and implemented through the local population's participatory processes (Knudsen et al., 2019). Pictures of the two sites can be found in the SI (Figs. S1–S4).

The two NBS sites are geographically quite close, approximately 2.5 km from each other, see Fig. 1. Despite their proximity and common goal, their physical characteristics place them in two different recreational and nature categories. Hovmarksparken is an urban NBS, while Lake Egå can be classified as a peri-urban, large-scale NBS. This makes the two substitute areas very interesting case studies, where two NBS sites can be evaluated by residents who are likely to be familiar with both.

2.2. Survey design

For the design of our survey, we worked to integrate the steps needed for a proper assessment of NBS (e.g. assessing both the social and environmental benefits) with the CV methods' characteristics to create a holistic framework specifically targeting the quantification of non-market benefits of NBS. Once the basic structure was defined, the survey was subjected to a co-design process. Testing surveys with relevant target groups and adjusting them according to feedback is a staple of Stated Preference (SP) methods (Presser et al., 2004). However, in our study, we went a step further, inviting local decision-making stakeholders to be actively involved in the co-creation of the survey. Specifically, we worked with Aarhus Municipality to ensure that the survey was tailored correctly to the study sites and adjusted so that planners and decision-makers could maximize the use of the results for better understanding and communicating the outcomes of the projects. The resulting survey was structured into four sections, listed below, and the collected variables are summarized in Table 1.

1. **Relationship between respondents and the study sites.** Descriptive texts for the NBS areas were developed together with Aarhus Municipality. Here we included a map of the sites and a short description of the NBS projects, summarizing their characteristics and ability to reduce the targeted problem. After reading the descriptions, the respondents could choose if they wanted to complete the questionnaire only with regards to Lake Egå or Hovmarksparken, or both. Once they chose one of the three options, they were asked about their (travel) distance to the area(s), frequency and reasons to visit, travel time and travel method to the site(s).
2. **People's preferences.** This section enquired about the respondents' concern concerning flood risk, the importance of recreation in green areas, and the presence of nature-enhancing elements. Respondents

Table 1
Summary of all the quantitative variables collected through the survey, divided by section.

Section	Variable name	Description	Answer method
Relationship between people and the study sit			
	Site	Choosing for which site to complete the survey (i.e. Lake Egå, Hovmarksparken, or both)	Multiple options
	Distance	Distance from the study site chosen	Multiple options
	Frequency	Frequency of visit to the study site	Multiple options
	Travel time	Length of travel time to the study site	Multiple options
	Visit time	Time spent visiting the study site	Multiple options
	Visit nature	Visiting the area to enjoy nature	Dichotomous
	Visit social	Visiting the area to spend time with family/friends	Dichotomous
	Visit sport	Visiting the area to practice sport	Dichotomous
	Visit pass	Visiting the area just passing by (e.g. on the way to work)	Dichotomous
	Flood worry	Respondent's concern regarding flooding	Likert scale (1–7)*
	Flood direct	Direct experience with flooding	Dichotomous
	Flood indirect	Knowing someone with flooding experience	Dichotomous
People's preference			
	Flood private	How important it is for the respondent to avoid flooding in their private property	Likert scale (1–7)
	Flood public	How important it is for the respondent to avoid flooding on public property	Likert scale (1–7)
	Green areas	How important it is for the respondent to access green areas	Likert scale (1–7)
	Recreation	How important it is for the respondent to have access to recreation facilities	Likert scale (1–7)
	Biodiversity	How important it is for the respondent that biodiversity enhancement features are in place	Likert scale (1–7)
	Nature only	How important it is for the respondent that areas set aside for nature (i.e. without access for people) are present	Likert scale (1–7)
Valuation questions			
	WTP base	Respondent's WTP for the maintenance of the area	Multiple options
	WTP nature	Respondent's WTP for the enhancement of nature benefitting features (additive)	Multiple options
	Protest	Respondent's reason for expressing 0 WTP in both valuations	Multiple options
Socio-demographic information			
	Post	Postal code	Open ended
	Age	Age	Multiple options
	Sex	Sex	Dichotomous
	Residence time	Time living in Aarhus Municipality	Open ended
	People household	Number of people in the household	Open ended
	Children	Presence of people younger than 18 in the household	Dichotomous
	Income	Household income	Multiple options

*1 being the lowest score and 7 being the highest.

were asked to rate how important each of these benefits was for them on a Likert scale from 1 to 7. This was followed up by questions in which the respondents elaborated on the response given through a series of pre-set sentences.

3. **Valuation questions.** This section included the description of a hypothetical scenario leading to the assessment of the Willingness-To-Pay (WTP) for having the NBS area in question (for those chosen by the respondent in section one). The WTP assessment was a two-step process using the payment card approach (Bateman et al., 2002). First we proposed that the maintenance of the NBS area would have to be paid for through a monthly fee per household, and we asked the respondents to state a WTP (referred in this paper as WTP base). Then, a second valuation question was asked, asking how much the respondents would be willing to increase their initial bid if further actions to improve the quality of nature were to be implemented in the NBS area(s) (WTP nature. The sum of WTP base and WTP nature is referred to as WTP total). In both questions, the respondents were supplied with a payment card with the possibility to also state a different amount. If the respondents stated a null WTP for both steps, they were asked a debriefing question to identify protest voters, i.e. those respondents who do not accept the hypothetical valuation scenario and therefore refuse to state a WTP (Bernath and Roschewitz, 2008; Meyerhoff and Liebe, 2008).
4. **Socio-demographic information.** The final section included questions for the collection of the demographic and socio-economic data of the respondents, e.g. residence postal codes, age, gender, income, and so on.

The complete survey can be found in the Supplementary Information (SI).

2.3. Distribution

We used a randomized electronic distribution of the survey, which, aside from being faster and more practical on larger scales, allowed us to avoid sample selection bias, i.e. over-representing frequent visitors of the areas. The final survey was transferred to the online survey platform SurveyXact and set to be completely anonymous (in compliance with EU GDPR requirements).

The respondents were contacted through an email to their digital online mailbox containing a cover letter explaining the scope and aim of the research and a link to the survey. The respondents were randomly selected from the municipal population register based on the numbers present in their birthdates. The program used by the Municipality to distribute the mails was used to operate the random selection. The only limits imposed were that the respondents had to be older than 18 and that half of the sample had to be residents of Lystrup (Fig. 1). The latter would ensure variation in distance to the study sites in the collected data. The collection started at the beginning of June 2021 and closed approximately one month later (at the beginning of July 2021), with reminders to participate sent after two weeks. After discarding the incomplete questionnaires, a total of 607 complete surveys were registered. This corresponds to a response rate of 15%, which is quite low if compared to other Danish survey using the same distribution methods, e.g. a Covid-19 study (Ladenburg and Christensen, 2021) and one on musculoskeletal disease (Boyle et al., 2021) obtained response rates of 34% and 36% respectively.

2.4. Identifying protest votes

Before proceeding to the statistical analyses, we separated the registered responses into protest and non-protest votes. The protest votes were identified by examining the answers to the debriefing question presented only to those respondents who chose a WTP of 0 DKK in both valuation scenarios (see section 2.2). These respondents were asked to justify why they would not spend any money on the study sites by choosing their main reason from five given options. If the respondents chose the options "I do not have the possibility to pay extra money each month", or "I do not think that it is important to maintain this site and its functions", they were classified as genuine zero bids. Those answering "I think that exclusively public funds should be used to finance the maintenance of the areas and their functions", or "I don't have enough information to choose a fee" were classified as protest voters. Finally, the last option let the respondents state other reasons. Depending on the reason, these 20 responses were manually classified as either protest or

Table 2
Summary of the methods used as part of the statistical analyses. The analyses have been carried out in R using the car and ggplot 2 packages.

Aim	Methods
Step 1 – Assess sample properties	
Is the sample biased compared to the general population in Aarhus?	Descriptive statistics of the respondents' socio-demographic characteristics relative to the general population, and of their direct responses to sections 2 and 3 of the survey.
Are protest votes associated with particular groups and would their exclusion thus bias the results in any direction?	Logistic regression model, with the binary protest variable as response variable. The entire dataset was used, and the final model was obtained through backwards selection. $$\log\left(\frac{p}{1-p}\right) = a + bX + cY + dZ + \varepsilon \quad (1)$$ p = stating a protest vote; X, Y, Z = vectors of explanatory variables regarding preferences, uses and socio-demographic characteristics of the respondents, respectively; a, b, c, d = vectors of parameters to be estimated in the logistic regression model; ε = error term.
Have we correctly identified protest voters?	Definition of two different datasets to be used for the analyses in step 2. Dataset 1: excluding all protest voters identified through the debriefing question (n = 387); Dataset 2: including plausible "false" protest votes (n = 517).
Step 2 – Analyze willingness to pay values	
Do respondents increase their original WTP bid (WTP_{base}) after "pointing out" the biodiversity benefits of the NBS measures (WTP_{total})?	Compare sample means using t-tests and bootstrapping (SI Table S2) $$H_0 : WTP_{base} = WTP_{total} \text{ for Lake Egå} \quad (2)$$ $$H_0 : WTP_{base} = WTP_{total} \text{ for Hovmarksparken} \quad (3)$$
Is WTP statistically different across the two sites?	Same as above, but only the bids of respondents who chose to answer for both sites were included. The bootstrapping tests were used to test whether the means of the WTP bids were statistically different across sites $$H_0 : WTP_{base} \text{Egå} = WTP_{base} \text{ Hovmarksparken} \quad (4)$$ $$H_0 : WTP_{total} \text{Egå} = WTP_{total} \text{ Hovmarksparken} \quad (5)$$
Which explanatory variables influence the WTP bid levels?	Multiple linear regression models, three for Lake Egå and three for Hovmarksparken, each pair separately using the three WTP bids (WTP base, WTP nature and WTP total) expressed for each site as dependent variables. WTP values were log-transformed due to the skewed data distribution. Both datasets 1 and 2 were used, and the final models were obtained through backwards selection Lake Egå $$\log(WTP_{base} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon \quad (6)$$ $$\log(WTP_{nature} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon \quad (7)$$ $$\log(WTP_{total} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon \quad (8)$$ Hovmarksparken $$\log(WTP_{base} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon \quad (9)$$ $$\log(WTP_{nature} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon \quad (10)$$ $$\log(WTP_{total} + y_0) = \alpha + \beta X + \gamma Y + \delta Z + \varepsilon \quad (11)$$ where y0 = 1 is introduced to allow WTP bids of zero value, X, Y, Z = vectors of explanatory variables regarding preferences, uses and socio-demographic characteristics of the respondents; α, β, γ, δ = vectors of parameters to be estimated in the linear regression models; ε = error term.
Is the quality of our models satisfactory?	Sensitivity analyses including model diagnostics (SI Fig. S13-S24) and F-tests (SI Table S6) were conducted for all the models.

non-protest votes during the analysis. This debriefing question was inspired particularly by the studies of Bernath and Roschewitz (2008) and Ramajo-Hernández & del Saz-Salazar (2012).

Despite their seemingly very high number (36% of the total responses in our study), protest bids are an expected outcome when eliciting WTP through a payment scenario, and our rate of protest votes fits the range expected in a CV study, i.e. from 20% to 40% (Carson, 1991). Once the two groups of respondents (protest and non-protest) were defined, we proceeded with the creation of different statistical models to explore the relationship between the registered variables and the valuation of the NBS. In hindsight, we could have used a Protest Reduction Entreaty (i.e. a statement presented in the survey before the WTP questions highlighting that the payment is included to allow the respondent to convey the value of the good in focus, and not to collect money from them) to reduce the number of protest respondents, as done by Bonnichsen and Ladenburg (2009). Using such an entreaty might also have improved the systematic relations between WTP and the perceived qualities of the two NBS (Bonnichsen and Ladenburg, 2015).

2.5. Statistical analyses

We divided our analysis into 2 steps. First, we analyzed the socio-demographic properties of the full sample and those of the protest voters. Second, we assessed the variation of WTP values and which variables explained these variations. These latter assessments were performed on two different datasets: dataset 1 excludes all protest votes, and dataset 2 includes part of the protest votes as zero values. This was done to account for an ambiguity in the interpretation of the protest votes and derive a sensitivity range for the results. Table 2 summarizes all the methods used, inspired by different sources (Bernath and Roschewitz, 2008; Crawley, 2005).

3. Results

3.1. Socio-demographic characteristics of the respondents

Table 3 compares the socio-demographic characteristics of our respondent sample with those of the general population living in Aarhus Municipality. Our sample appears to be representative based on gender, family size and income. However, there is a slight overrepresentation of elderly citizens and an underrepresentation of people under 35 in our sample. Moreover, there appears to be an overrepresentation of households with higher incomes.

In addition to the characteristics, we were able to determine both the respondents' average cost per square meter of property and their distance to the coast (approximated to the postal code area) due to the

Table 3
Comparison of the sample and census demographics of Aarhus (2021 census data from Statistics Denmark).

Demographics	Categories	Percentage of sample	Percentage in Aarhus Municipality
Gender	**Male**	**51%**	**49%**
	Female	**49%**	**51%**
	Other	**0.2%**	**N/A**
	Prefer not to say	**0.3%**	**N/A**
Age	**18–25**	**8%**	**22%**
	26–35	**10%**	**22%**
	36–45	**13%**	**13%**
	46–55	**18%**	**13%**
	56–65	**20%**	**12%**
	66–75	**23%**	**10%**
	Older than 75	**8%**	**7%**
Income (household/year)	**Under 200.000 DKK**	**13%**	**24%**
	200.000–299.999 DKK	**8%**	**19%**
	300.000–449.999 DKK	**16%**	**19%**
	450.000–699.999 DKK	**25%**	**17%**
	700.000–849.999 DKK	**20%**	**6%**
	850.000–999.999 DKK	**9%**	**5%**
	Over 1 million DKK	**9%**	**10%**
Household	**Single**	**17%**	**24%**
	Without children	**56%**	**44%**
	With children	**27%**	**27%**

available statistical information in Denmark. These variables were used in the analyses to give a more complete picture of the respondents' socio-economic characterization.

3.2. Use of the case studies

The first part of the survey was dedicated to collecting data regarding the respondents' use of Lake Egå and Hovmarksparken. Fig. 2 offers an overview of the most relevant people-place relationship variables.

Most respondents answered the survey for Lake Egå, followed by people who answered for both sites. The most often cited reason to visit Lake Egå is to enjoy the nature in the area (57% of the respondents), while in the case of Hovmarksparken it appears to be "passing through" (40%), an option that included e.g. crossing the park to go to work. On average, the respondents spend a longer time at Lake Egå but visit Hovmarksparken slightly more often. Most of the respondents reside no further than 5 km from both sites, with the vast majority of the people answering for Hovmarksparken living less than 1 km from the park (see Supplementary Information, Figs. S1 and S2). For both sites, the most common travel time is less than 30 min (Figs. S1 and S2), but the respondents tend to travel by car to Lake Egå, and by foot to Hovmarksparken.

Overall, Lake Egå was the preferred choice of the population outside of Lystrup. It is seen as a natural area worth visiting specifically for spending time in it and enjoying the nature there. On the other hand, Hovmarksparken is depicted as an area mostly known to people living in its' immediate proximity and visited quickly, often only passing by.

3.3. Background preferences

In the survey, we registered the respondents' preferences towards three impact spheres targeted explicitly by the examined NBS sites: flood risk reduction, recreation enhancements (incl. the presence of green areas) and improvements to nature (Fig. 3).

The respondents appear to be highly concerned about flooding in private and public settings, with more than 70% expressing the highest concern (Likert value 7) regarding avoiding private flooding and more than 50% for public flooding. The presence of green areas is also deemed very important for more than 70% of the respondents, while the presence of recreation facilities is slightly less. The presence of features enhancing biodiversity is perceived overall as very important by more than 50% of the respondents. However, it received slightly lower scores from the group of respondents who chose to answer only for Hovmarksparken compared to the respondents who chose Lake Egå or both sites (Fig. S7). "Nature for nature" zones with no entry for visitors are the characteristics that got the lowest scores out of all the features, despite still being indicated as overall important.

3.4. Evaluating protest votes

Table 4 shows which variables significantly affected the occurrence of protest votes. A full model with all variables is in the SI (Table S1).

Four variables significantly influenced the probability of stating a protest vote. Regarding socio-demographic characteristics, protest voters appear to be older and living in an area associated with lower property value. Notably, our sample had an overrepresentation of older people, which may have influenced the number of protest votes registered. In addition, protest voters attribute less importance to the presence of characteristics enhancing biodiversity or areas set aside for nature.

We proceeded to visualize the outcomes of the logistic regression, as shown in Fig. 4, by clustering the respondents according to the four relevant variables (Table 4). The first division is driven by the most significant variables, namely the importance attributed to areas set aside for nature and to the presence of biodiversity. We then further divided this group according to the less relevant variables influencing the probability of stating a protest vote, i.e. property cost and age of the respondent. Note that the limits indicated in the graph were subjectively chosen based on the distribution of the responses (e.g. the mean value for "importance of space for nature areas" was 5, therefore a value of 6 or higher corresponds to respondents very interested in nature areas). There is a disproportional representation of protest votes among the respondents valuing the nature benefits of the NBS less (lower left quadrant in the larger graph). In contrast, there is an overrepresentation, although less extreme, of protest votes among the older and less wealthy respondents (lower right quadrant in the smaller graph).

The overrepresentation of protest votes among people who associate less value to nature benefits challenged the idea of proceeding by simply eliminating all protest votes from the dataset. People less interested in nature are also less likely to highly (if at all) value a NBS, regardless of their disagreement on the hypothetical valuation scenario. In other words, they could be representing "false protest votes", and the exclusion of these zero bids would translate into a biased assessment of the WTP, which would be higher than in reality. To avoid this, we created two datasets that we have used for the following analyses. In the first set, all the respondents being classified as protest votes are excluded (dataset 1, n = 387). In the second data set, only the protest voters that stated an interest of 6 or higher for "nature for nature" areas were excluded (dataset 2, n = 517).

3.5. Distribution of WTP responses

The freedom to choose one or both NBS when answering the survey might have caused the respondents to select only the NBS they gained the highest utility from. In that case, we would expect that the WTP for Egå would be higher among respondents who only stated a WTP for Egå, when compared to the respondents who stated WTPs for both NBS. However, the WTPs of the single-site respondents were observed to be generally lower than the WTPs of both sites' respondents, though not significantly (SI Tables S2a&b). This denotes that potential sorting into stating a WTP for only one of the sites or both sites is not significantly

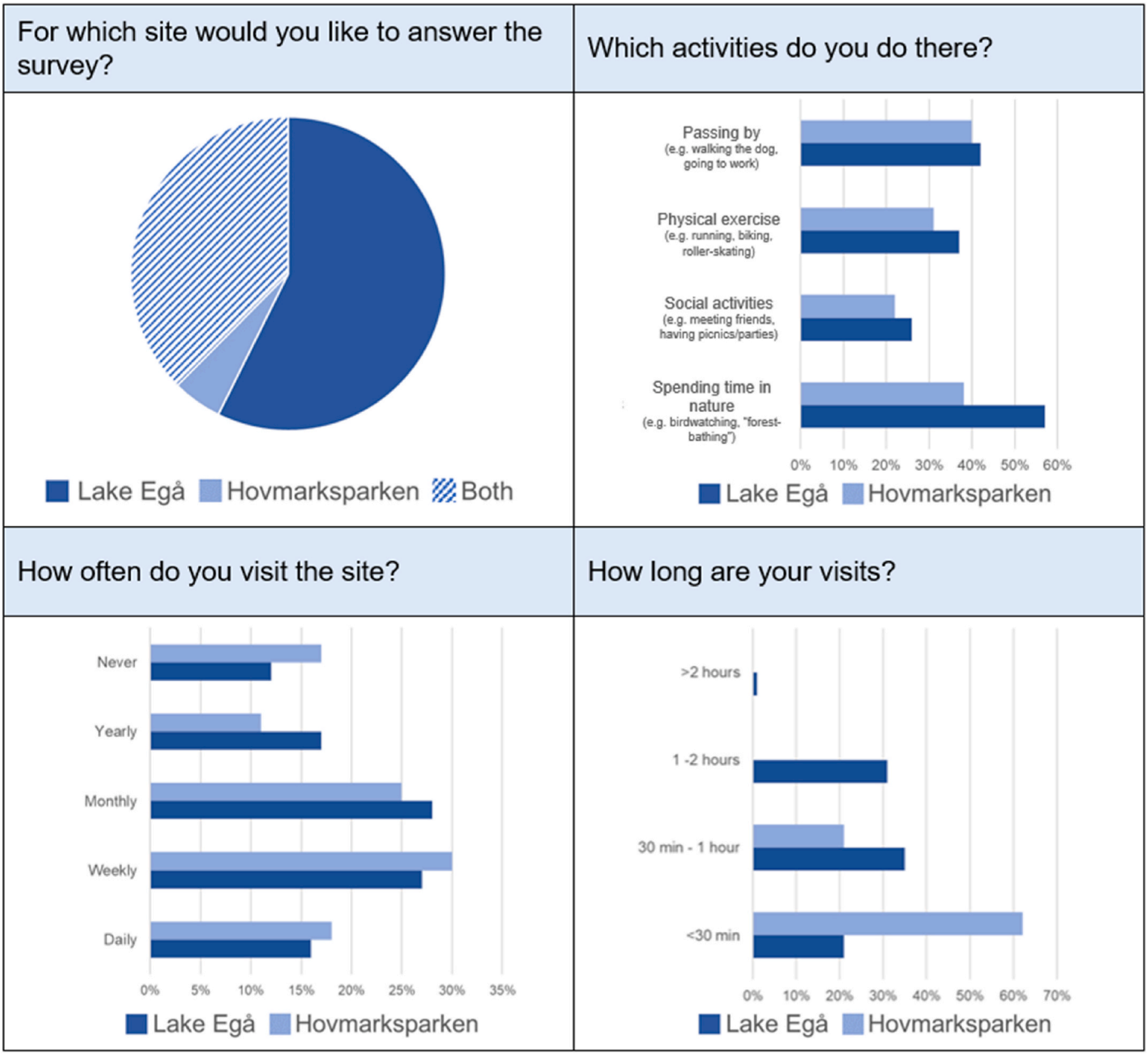


Fig. 2. Percentages showing the respondents' answers to 4 of the survey's questions (indicated above the graphs) on the relationship between people and the NBS area, divided by site.

related to the level of the stated WTPs. Therefore, we joined the three groups in the analysis of WTP for the two NBS sites.

The respondents generally appear to increase their bid when asked about considering the benefits for nature for both sites. This tendency can be observed in the graphical representation of the WTP means in Fig. 5 (compare the distribution of the blue and the green boxes). The "base WTP" bids for the two areas follow the same pattern for both datasets (see the blue and light blue boxes), in the same way, the "total WTP" (i.e. WTP base + WTP nature) values do (see the green and light green boxes). The data also showed a strong correlation between WTP base and WTP nature (Pearson's correlation index higher than 0.85 in both sites and in both datasets), showing that the same people who attribute a high value to the NBS area as it is, are also the ones that would pay more for an improvement of the nature quality.

Overall, the respondents were willing to pay between 30 and 40 DKK/month/household (corresponding to app. 4 and 5.50 EUR) for the maintenance of Lake Egå as it is, while their bids increased to between 50 and 66 DKK/month/household (app. 6.70 and 9 EUR) if further nature enhancements were to be implemented. As for Hovmarksparken, the bids were between 25 and 35 DKK/month/household (app. 3.50 and 4.70 EUR) for the NBS maintenance and between 40 and 58 DKK/month/household (app. 5.50 and 7.80 EUR) with the inclusion of nature benefits enhancements (SI Table S2a&b). Bootstrapping tests (SI Table S3) confirmed a statistically significant difference between the two WTP values for both areas and considering both datasets, substantiating that the respondents are willing to pay on average a greater amount of money for enhancing the nature benefits in addition to maintaining the NBS areas.

Fig. 5 shows slight differences between the expressed WTP for Lake Egå and the one for Hovmarksparken, with the latter being slightly lower (compare the light blue boxes with the blue ones and the light green with the dark green). We investigated if this difference was

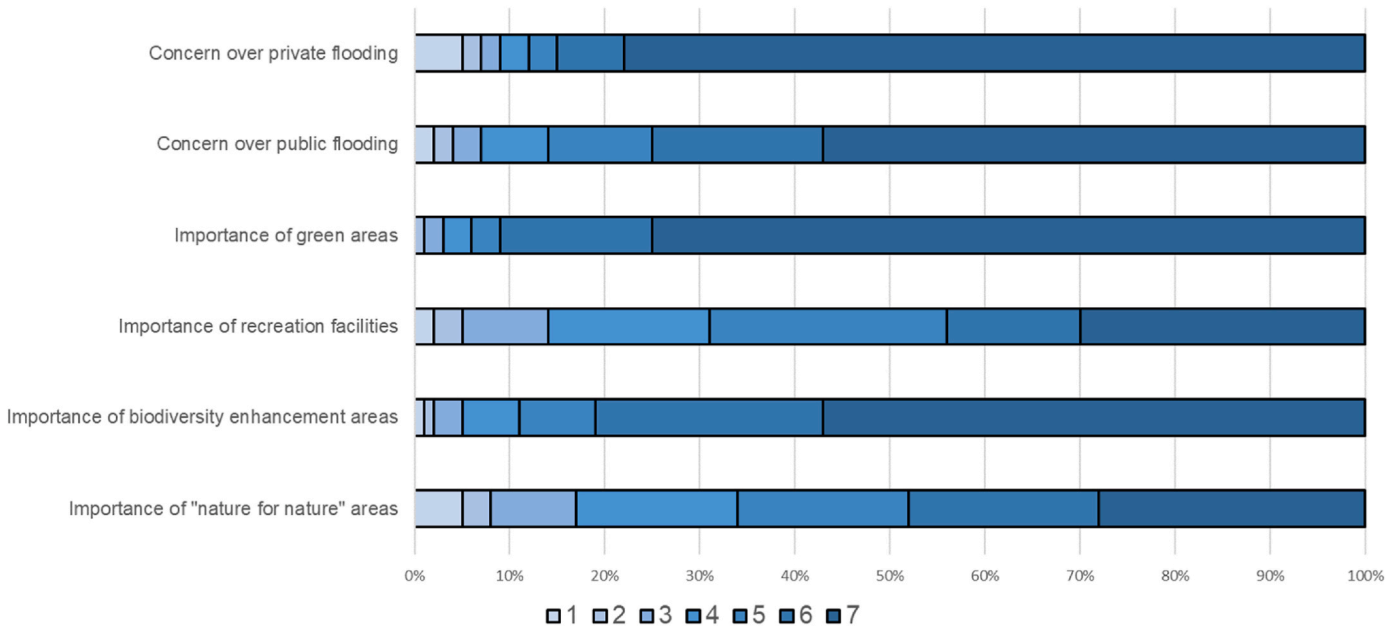


Fig. 3. Importance (1 being not important and 7 being very important) of the different functions of NBS, as expressed by the respondents. The results divided by site can be seen in the SI (Figs. S7–S12).

Table 4
Estimated logistic regression model using the binary variable indicating protest votes as dependent variable (only the significant results are shown). The full sample of respondents was used in this analysis.

Logistic regression model (dependent variable = expressing a protest vote)	Estimates
Importance attributed to the presence of biodiversity	− 0.205**
Importance attributed to areas set aside for nature	−0.155**
Property cost	− 3.048e-05*
Age of the respondent	0.014*

*p < 0.05.
**p < 0.01.
***p < 0.001.

statistically significant and if the respondents were willing to pay the same amount on average for the two sites. Once again, we applied both a *t*-test and a bootstrapping test using a subset of the data. We used only the bids of the respondents that expressed a WTP for both NBS (n = 139 for dataset 1 and n = 196 for dataset 2). The outcome (SI Table S4) shows no statistically significant difference between the bids stated for Lake Egå and those stated for Hovmarksparken.

3.6. Variables affecting WTP

Table 5 shows the significant variables in the different multiple linear regression models. As reported in Table 2, the dependent variable WTP was log-transformed. We have tested that the resulting models are robust towards variations of y_0. The independent variables were used without transforming them. We used the same method for model building for both datasets 1 and 2.

The importance given to "nature for nature" areas non-accessible for visitors appears to be the most relevant variable linked to the WTP expressed by the respondents, as it is the only variable appearing across all 12 models. Also, the importance attributed to biodiversity enhancements remains relevant throughout sites and datasets, specifically for the models concerning Lake Egå. These properties denote substantial none-use values associated with the two NBS.

Variables indicating recreation uses (e.g. reasons for visiting the area) appear to fill a more marginal role but generally seem to confirm that people doing activities in the area tend to attribute a higher WTP to the site. Moreover, passing through Hovmarksparken is associated with higher WTPs. In contrast, increasing distance to Egå is associated with lower WTP. The latter result nicely illustrates the spatial properties of NBS WTP, which are found in the spatial preferences literature.

The socio-economic variables are largely insignificant, and they appear to have some relevancy only in the context of Lake Egå. As expected, higher income levels are associated with higher WTPs. Finally, our models do not seem to distinguish a defined influence of the flooding concerns on the WTP. Despite a clear result, the variables on flooding perception become relevant in both datasets when eliciting the additive bid on nature enhancements. It seems that a greater concern for private flooding corresponds to a higher WTP for nature benefits, while the concern over flooding in public property negatively influences the WTP. It is interesting to observe how the concern over flooding in different areas determines whether the respondent sees the improvement of benefits for nature as a useful addition to the risk reduction capacities of the NBS.

Overall, the models created for the WTP total appear to summarize the ones created for WTP base and WTP nature of the respective site, as expected. Notably, most of the collected variables were irrelevant in any models. Tests excluding the "interest for nature" variables (i.e. importance of no access "nature for nature" areas and importance of biodiversity enhancements) from the models did not lead to the expression of new significant variables.

4. Discussion

4.1. Effect of NBS characteristics and relationship with the area on WTP

We find a quite distinct preference of the respondents for choosing Lake Egå instead of Hovmarksparken, also for those people living close to the park, namely in Lystrup (Fig. 1). Analyzing more in-depth the relationships between the respondents and the two areas (SI Fig. S5 & S6), it appears that Lake Egå is considered more of a "destination" worth visiting for the people of Aarhus (e.g. longer visits, visiting to enjoy the nature). In comparison, Hovmarksparken is seen as a part of the urban context that is, for the most part, passively experienced by close

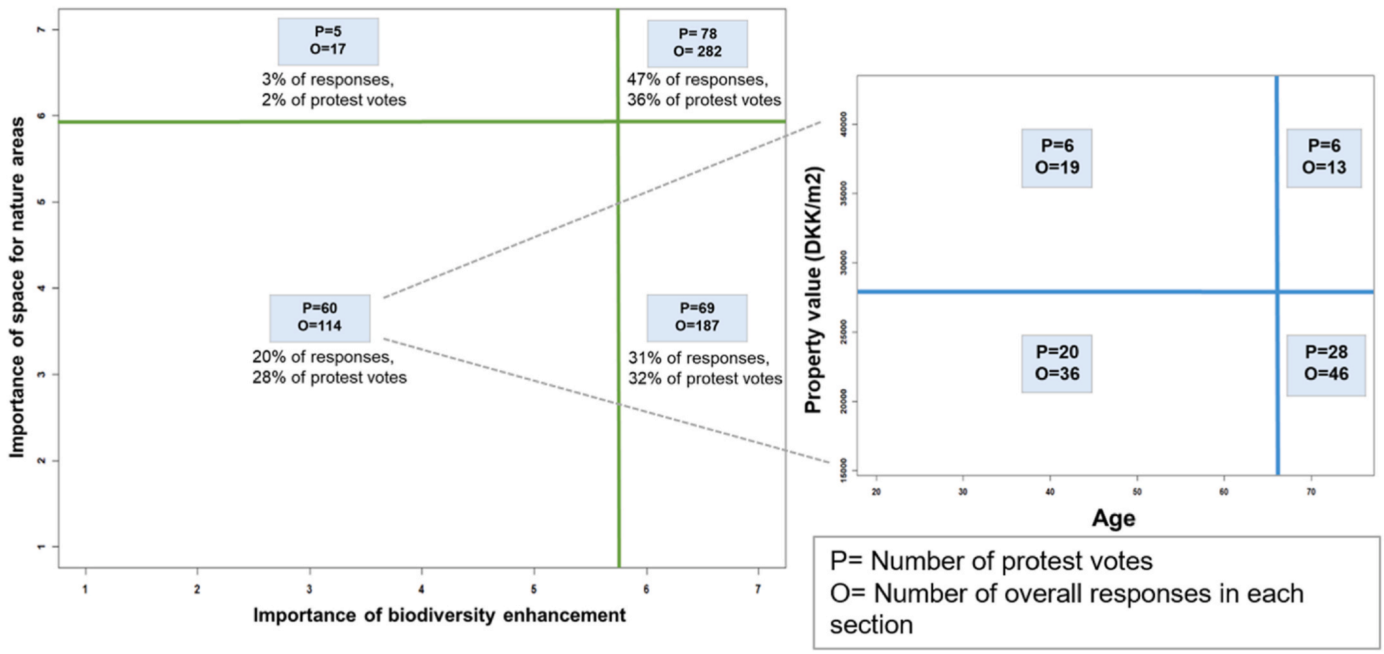


Fig. 4. Visual representation of the respondents' protest vote data divided according to the relevant variables from the logistic regression model (see Table 4). Within each area of the graph it is shown the number of protest votes and the overall responses (i.e. protest and non-protest votes) for the respondents with those characteristics (i.e. older than 60 years old and living in an area with property value below average).

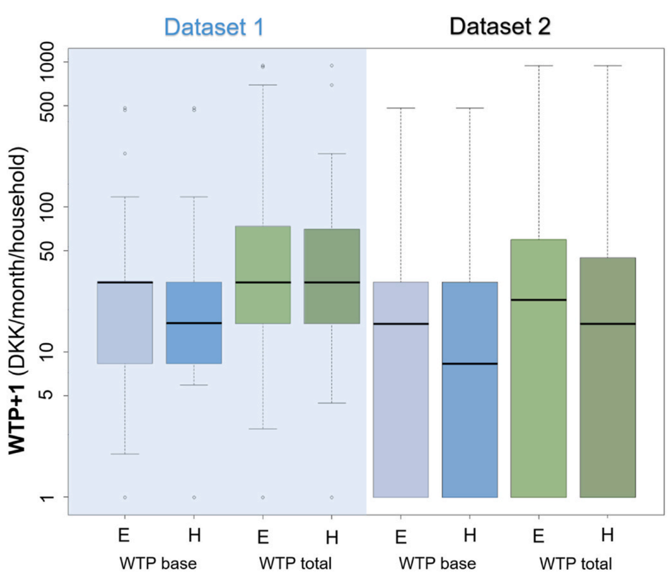


Fig. 5. Representation of the different WTP in datasets 1 (excluding all protest votes) and 2 (re-introducing some protest votes), classified by area (E for Lake Egå or H for Hovmarksparken) and by first and final bids (base and total).

residents (e.g. shorter visits, just passing by). Therefore, our results seem to uncover how the area's physical characteristics appear to influence what the respondents identify as an area worth valuing. Specifically, in the case of the Aarhus NBS sites, the larger, peri-urban site appears to be more likely to be identified as an area of particular interest for recreation or nature enhancement. On the other hand, the smaller site seems to struggle to be recognized as relevant infrastructure for contributing to the same benefits. The influence of size on the value attribute to NBS has also been observed in other studies (e.g. Liebelt et al., 2018; Skrydstrup et al., 2022). Nevertheless, such perceptions do not appear to be reflected in the quantitative valuation of our study sites, as the difference between WTP bids for the two sites was not deemed statistically significant (Fig. 5, SI Table S4).

4.2. Effect of personal preferences on WTP

The "raw" outcomes on background preferences were relatively homogeneous (Fig. 3, SI Fig. S7-12), but the queries on the nature benefits of NBS were the most divisive. Specifically, respondents that attributed a higher importance to nature were answering (i.e. were willing to express a value) for both sites, whereas those who did not value nature as highly were more likely to choose to answer only for the urban NBS site. This seems to suggest that Hovmarksparken is not perceived as an area particularly relevant for the improvement of nature quality.

In terms of quantitative valuation, the mean WTP values in the two datasets appeared to follow the same patterns, despite the lower average of dataset 2, due to a higher number of zero bids. WTP bids significantly increased across sites when the elements enhancing biodiversity were introduced into the hypothetical valuation scenario (Fig. 5, SI Table S2). This finding suggests that the improvement of nature is seen as a positive addition worth paying more for, independently from which site is considered. The relevance of people's preferences regarding the benefits of NBS for nature is also reflected in the results of our models (Table 5), where the importance given to areas set aside for nature is the only variable influencing the WTP present across all 12 models. Despite the unclear influence of some variables, the models seem to paint a quite cohesive picture: people's preferences are the drivers of valuation, followed by variables describing the recreational uses of the respondents, and finally, socio-demographic characteristics, which have a more marginal effect.

4.3. Evaluating method applicability

The proposed holistic assessment proved useful in solidifying the importance of using multi-dimensional approaches when assessing NBS. In relation to our first research objective, our method was able to capture a wide range of uses and perceptions of the areas, and our results support the claim that economic valuations alone are insufficient to clearly represent all the non-market benefits of NBS. Our results thus match the outcomes of other preference studies conducted in similar contexts

Table 5
Linear regression model results for the expressed WTP base, WTP nature and WTP total for Lake Egå (E) and for Hovmarksparken (H) using both datasets 1 and 2 (only the variables that were significant in at least one model were reported. For the results including the complete list of variables, see Table S5 in the SI). $*p < 0.05$ $**p < 0.01$ $***p < 0.001$.

Independent variables	Dataset 1 (excluding all protest votes)						Dataset 2 (partly re-integrating protest votes)					
	WTP base		WTP nature		WTP total		WTP base		WTP nature		WTP total	
	E	H	E	H	E	H	E	H	E	H	E	H
Intercept	1.057***	1.565***	−0.306	2.086***	1.232*	1.609***	−0.936**	−0.462	−0.799	0.330	−1.095**	−0.825*
Importance of no access “nature for nature” areas	0.179***	0.236***	0.150**	0.292***	0.139**	0.254***	0.373***	0.511***	0.303***	0.462***	0.419***	0.598***
Importance of biodiversity enhancements	–	–	0.241**	–	0.192**	–	0.196**	–	0.198**	–	0.235***	–
Visiting the area to enjoy nature	0.581***	–	–	0.443*	0.441**	0.406*	–	–	–	0.381*	–	–
Visiting the area to practice sport	–	–	0.493**	–	–	–	0.455**	–	0.572***	–	0.554***	–
Passing by the area	–	–	–	–	–	0.443*	–	–	–	–	–	–
Distance to the area	–	–	–	–	−0.011*	–	–	–	–	–	–	–
Household income	1.146e-06***	–	9.418e-07***	–	1.258e-06***	–	–	–	–	–	–	–
Importance of avoiding flood in private property	–	–	0.114*	–	–	–	–	–	0.088*	–	–	–
Importance of avoiding flood in public property	–	–	−0.191***	−0.272***	−0.096*	–	–	–	−0.149**	−0.145*	–	–
Indirect experience with flooding	–	–	–	–	–	–	–	–	–	–	–	0.461*

(Anderson et al., 2022; Ando et al., 2020; Bernath and Roschewitz, 2008; Derkzen et al., 2017; Hérivaux and Le Coent, 2021; Reynaud et al., 2017; Schaich, 2009), with the additional novelty of having conducted a comprehensive ex-post assessment taking into consideration all the factors influencing valuation.

What clearly emerges from our study is that non-tangible benefits of NBS are positively valued by the users of these areas, regardless of their use. For example, the option of an increase in benefits for nature was preferred, and a high interest in biodiversity enhancements and “space for nature” areas was registered. Therefore, in order to ensure continuous support in NBS uptake, it is fundamental that the multiple benefits of NBS are not only produced, but also highlighted and shared with the population, at least in a Danish context. These are crucial assessments for decision-makers and stakeholders (e.g. municipalities) striving for the creation of NBS, and therefore worth pursuing for more effective and successful implementations.

We were able to show a strong link between personal preferences and the value attributed to the NBS; however, a clear connection between the latter and the physical characteristics and uses of the NBS could not be found. This may be due to a number of reasons, both methodological (e.g. most of the respondents live very close to the two sites, and many of them completed the survey for both NBS), and contextual (e.g. Danish welfare state, widespread awareness of the population to climate adaptations). Therefore, a suggestion for future research on this approach could be to replicate it on other NBS sites (of different sizes, completion ages and cultural contexts) to further test and evaluate these findings. Through such a replication, it will be possible to obtain a wider array of data on uses, preferences and benefits of NBS, which the literature calls for (e.g. Venkataramanan et al., 2020) to achieve more genuinely comprehensive and holistic NBS implementation frameworks. Our questionnaire was successfully adapted to register responses for two different sites, and the co-design procedure used with Aarhus Municipality could be replicated with stakeholders from different NBS, obtaining a series of similar datasets allowing for quick and accurate comparisons across NBS.

4.4. *Limitations of the methods*

CV methods have their shortcomings. Collecting data through a questionnaire makes it easy to incur in-sample selection bias. Our distribution was random, but our collected sample shows, for example, a bias towards older people. This could be because retired people can allocate more to answering surveys. Nevertheless, the over-representation was not deemed so critical that it needed a sample correction. However, given the tendency of older people to protest against the valuation scenario (Fig. 4), it is essential to keep in mind that the obtained WTP values could be slightly lower than in reality.

Another possible bias in our sample could be the hypothetical bias, i.e. running into unreliable estimates due to the respondents’ having to evaluate an imaginary scenario (Schläpfer et al., 2004). Another source of hypothetical bias is the protest answers. The scenarios we proposed (i.e. having to pay a fee to maintain the study sites) could be why people stated protest bids, rather than not approving the NBS project. However, we tried to reduce the protest bias by clearly stating the imaginary nature of the queries and eliciting a WTP for two projects that have already been implemented. Moreover, it is fair to point out that the additive, two-step valuation approach could be partly responsible for the difference seen in the bids “for nature”. However, the fact that not all respondents initially stating a WTP >0 also did so for the second question seems to indicate that the second valuation question provided enough of a distinction to stimulate truthful additive bids.

Regarding the analysis of the WTP values, the non-significant difference between the WTP of Lake Egå and Hovmarksparken could be because this specific analysis had to rely on the respondents that answered for both sites (which led to smaller subsamples in both datasets 1 & 2). Overall, at least this subset expressed approximately the same value for both areas.

It is also necessary to address how the data collection nature could have influenced the analyses. The data was collected through multiple choice questions, with the options often presented as intervals. It may be that the chosen intervals were not entirely fitting for this specific case. As an example, the vast majority of the respondents indicated to be living between 1 and 5 km from Lake Egå. Therefore, a more fitting set of intervals, i.e. with smaller increments, could have made a difference in the outcome of our analyses. Nevertheless, the overlap between relevant variables across models confirms their influence on the respondents' WTP regarding Aarhus's study sites.

5. Conclusions

We co-created a novel CV method for assessing the interconnections between the characteristics, perception and valuation of NBS, which was applied to two study sites. Based on our analyses of the results, we conclude the following.

- The physical characteristics of NBS sites influence people's perceptions and uses of the site. In our study site, the larger, peri-urban NBS is visited for longer periods of time, and more often, the purpose of the visits is to enjoy its nature. Moreover, it appears to be perceived as a better site for the improvement of the quality nature. However, these differences in perception did not lead to a statistically higher WTP for the larger area, suggesting that variables other than size and placement come into play to influence valuation.
- In the context of this study, people's expressed valuation of the NBS closely reflected their interest in improvements benefitting mostly nature (i.e. no-access "space for nature" areas). This suggests that our respondents' valuation links to their personal preferences rather than, e.g. their socio-demographic characteristics or the physical features of the NBS. Thus, highlighting the multiple benefits of NBS and actively involving citizens in their creation seem plausible approaches to support their prioritization and increase their uptake.

Our findings underline the importance of including benefits for nature both in the planning and the assessment phases as a key to successfully implementing NBS projects. The connection to nature benefits appears to increase the valuation, making these projects more appealing, also in comparison with traditional gray solutions. Moreover, publicizing the nature benefits that a particular NBS could introduce to an area appears to be a desirable choice, as the public seems to show a positive attitude towards "greener" solutions. Overall, this research demonstrates the importance of adopting a multi-dimensional approach in the economic valuation of the non-tangible benefits of NBS. Understanding the different dimensions that influence these strategies' valuation can further support the planning of more purposefully designed and efficient solutions.

Credit author statement

Martina Viti: Conceptualization, Writing – original draft, Investigation, Methodology, Data curation, Visualization. **Roland Löwe**: Conceptualization, Writing – review & editing, Methodology. **Hjalte J. D. Sørup**: Writing – review & editing, Methodology, Visualization. **Jacob Ladenburg**: Writing – review & editing, Visualization, Validation. **Oliver Gebhardt**: Conceptualization, Writing – review & editing. **Signe Iversen**: Writing – review & editing, Validation. **Ursula S. McKnight**: Conceptualization, Supervision, Writing – review & editing, Validation. **Karsten Arnbjerg-Nielsen**: Conceptualization, Supervision, Writing – review & editing, Methodology, Project Management, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We thank several colleagues for valuable comments on preliminary versions of the survey. Special thanks are due to Aarhus Municipality for great advice concerning the development and testing of the survey, and support for the mail distribution.

This research was funded by the European Union's Horizon 2020 Research and Innovation program under grant agreement No. 776866 for the RECONECT (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion) project.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.117498.

References

Aarhus Kommune, 2014. Klimatilpasningsplan 2014 - tilpasning til mere vand, pp. 1–39.

Adamowicz, W., Louviere, J., 1998. Introduction to attribute-based stated choice methods introduction to attribute-based stated choice methods. Alternatives 105 (1), 1339–1342.

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., Sanchez, A., 2019. Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management. J. Environ. Manag. 239 (February), 244–254. https://doi.org/10.1016/j.jenvman.2019.03.036.

Anderson, C.C., Renaud, F.G., Hanscomb, S., Gonzalez-Ollauri, A., 2022. Green, hybrid, or grey disaster risk reduction measures: what shapes public preferences for nature-based solutions? J. Environ. Manag. 310 (October 2021), 114727 https://doi.org/10.1016/j.jenvman.2022.114727.

Ando, A.W., Cadavid, C.L., Netusil, N.R., Parthum, B., 2020. Willingness-to-volunteer and stability of preferences between cities: estimating the benefits of stormwater management. J. Environ. Econ. Manag. 99, 102274 https://doi.org/10.1016/j.jeem.2019.102274.

Bateman, I., Carson, R., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Moruato, S., Özdemiroglu, E., Pearce, D., Sudgen, R., Swanson, J., 2002. Economic Valuation with Stated Preference Techniques. Edward Elgar Publishing. https://doi.org/10.4337/9781781009727.

Bernath, K., Roschewitz, A., 2008. Recreational benefits of urban forests: explaining visitors' willingness to pay in the context of the theory of planned behavior. J. Environ. Manag. 89 (3), 155–166. https://doi.org/10.1016/j.jenvman.2007.01.059.

Bockarjova, M., Botzen, W.J.W., Koetse, M.J., 2020. Economic valuation of green and blue nature in cities: a meta-analysis. Ecol. Econ. 169 (September 2019), 106480 https://doi.org/10.1016/j.ecolecon.2019.106480.

Bonnichsen, O., Ladenburg, J., 2009. Using an ex-ante entreaty to reduce protest zero bias in stated preference surveys - a health economic case. J. Choice Model. 2 (2), 200–215. https://doi.org/10.1016/S1755-5345(13)70010-1.

Bonnichsen, O., Ladenburg, J., 2015. Reducing status quo bias in choice experiments. Nordic J. Health Eco. 3 (1), 283–303. https://doi.org/10.5617/njhe.645.

Boyle, E., Folkestad, L., Frafjord, E., Koes, B.W., Skou, S.T., Hartvigsen, J., 2021. The Danish diabetes musculoskeletal cohort: non-responder analysis of an electronic survey using registry data. Clin. Epidemiol. 13, 397–405. https://doi.org/10.2147/CLEP.S293186.

Carson, R.T., 1991. Constructed markets. In: Braden, J.B., Kolstad, C.D. (Eds.), Measuring the Demand for Environmental Quality. North-Holland Elsevier, Amsterdam.

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based solutions to address global societal challenges. In: Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S. (Eds.), Nature-based Solutions to Address Global Societal Challenges. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13 (en).

Crawley, M.J., 2005. Statistics. An Introduction Using R. John Wiley & Sons, Ltd.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A.G., Mittal, N., Feliu, E., Faehnle, M., 2014. Mitigating and adapting to climate change:

multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manag. 146, 107–115. https://doi.org/10.1016/j.jenvman.2014.07.025.

Derkzen, M.L., van Teeffelen, A.J.A., Verburg, P.H., 2017. Green infrastructure for urban climate adaptation: how do residents' views on climate impacts and green infrastructure shape adaptation preferences? Landsc. Urban Plann. 157, 106–130. https://doi.org/10.1016/j.landurbplan.2016.05.027.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Shirayama, Y., 2018. Assessing nature's contributions to people. Science 359 (6373), 270–272. https://doi.org/10.1126/science.aap8826.

European Commission, 2015. Towards An EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-naturing Cities: Final Report of the Horizon 2020 Expert Group on "Nature-Based Solutions and Re-naturing Cities.

European Commission, 2021a. Forging a climate-resilient Europe - the new EU strategy on adaptation to climate change. European Comm. 6 (11), 951–952.

European Commission, 2021b. SOLUTIONS A Handbook for Practitioners. https://doi.org/10.2777/244577.

Han, S., Kuhlicke, C., 2019. Reducing hydro-meteorological risk by nature-based solutions: what do we know about people's perceptions? Water (Switzerland) 11 (12). https://doi.org/10.3390/w11122599.

Hérivaux, C., Le Coent, P., 2021. Introducing nature into cities or preserving existing peri-urban ecosystems? Analysis of preferences in a rapidly urbanizing catchment. Sustainability 13 (2), 587. https://doi.org/10.3390/su13020587.

IPCC, 2021. Summary for Policymakers in: Climate Change 2021: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://doi.org/10.1017/9781009157896.001. Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan.

IUCN, 2012. The IUCN programme 2013 – 16, pp. 184–210, 2012.

IUCN, 2020. IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS. In: IUCN Global Standard for Nature-Based Solutions: a User-Friendly Framework for the Verification, Design and Scaling up of NbS: First Edition, first ed. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2020.08 (en).

Johnston, R.J., Boyle, K.J., Adamowicz, W., Vic), Bennett, J., Brouwer, R., Cameron, T. A., Hanemann, W.M., Hanley, N., Ryan, M., Scarpa, R., Tourangeau, R., Vossler, C. A., 2017. Contemporary guidance for stated preference studies. J. Assoc. Environ. Res. Eco. 4 (2), 319–405. https://doi.org/10.1086/691697.

Jørgensen, S.L., Olsen, S.B., Ladenburg, J., Martinsen, L., Svenningsen, S.R., Hasler, B., 2013. Spatially induced disparities in users' and non-users' WTP for water quality improvements-Testing the effect of multiple substitutes and distance decay. Ecol. Econ. 92 https://doi.org/10.1016/j.ecolecon.2012.07.015.

Knudsen, B.T., Stage, C., Zandersen, M., 2019. Interspecies park life: participatory experiments and micro-utopian landscaping to increase urban biodiverse entanglement. Space Cult. 120633121986331 https://doi.org/10.1177/1206331219863312.

Ladenburg, J., Christensen, A.E.W., 2021. Hvordan arbejdede vi, da Danmark blev lukket ned af Corona? https://www.rockwoolfonden.dk/app/uploads/2021/02/RFF-Arbejdspapir-58_Hvordan-arbejdede-vi-da-Danmark-blev-lukket-ned-af-corona.pdf.

Liebelt, V., Bartke, S., Schwarz, N., 2018. Revealing preferences for urban green spaces: a scale-sensitive hedonic pricing analysis for the city of leipzig. Ecol. Econ. 146 (November 2017), 536–548. https://doi.org/10.1016/j.ecolecon.2017.12.006.

Louviere, J.J., Woodworth, G., 1983. Design and analysis of simulated consumer choice or allocation experiments: an approach based on aggregate data. J. Market. Res. 20 (4), 350–367. https://doi.org/10.1177/002224378302000403.

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 For. Urban Green. 14 (1), 56–64. https://doi.org/10.1016/j.ufug.2014.11.008.

Meyerhoff, J., Liebe, U., 2008. Do protest responses to a contingent valuation question and a choice experiment differ? Environ. Resour. Econ. 39 (4), 433–446. https://doi.org/10.1007/s10640-007-9134-3.

Mitchell, R.C., Carson, R.T., 1989. Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington, DC.

Pearce, D., 1993. Economic Values and the Natural World. MIT Press.

Presser, S., Couper, M.P., Lessler, J.T., Martin, E., Martin, J., Rothgeb, J.M., Singer, E., 2004. Methods for testing and evaluating survey questions. Publ. Opin. Q. 68 (1), 109–130. https://doi.org/10.1093/poq/nfh008.

Ramajo-Hernández, J., del Saz-Salazar, S., 2012. Estimating the non-market benefits of water quality improvement for a case study in Spain: a contingent valuation approach. Environ. Sci. Pol. 22, 47–59. https://doi.org/10.1016/j.envsci.2012.05.006.

Reynaud, A., Lanzanova, D., Liquete, C., Grizzetti, B., 2017. Going green? Ex-post valuation of a multipurpose water infrastructure in Northern Italy. Ecosyst. Serv. 27, 70–81. https://doi.org/10.1016/j.ecoser.2017.07.015.

Schaich, H., 2009. Local residents' perceptions of floodplain restoration measures in Luxembourg's Syr Valley. Landsc. Urban Plann. 93 (1), 20–30. https://doi.org/10.1016/j.landurbplan.2009.05.020.

Schläpfer, F., Roschewitz, A., Hanley, N., 2004. Validation of stated preferences for public goods: a comparison of contingent valuation survey response and voting behaviour. Ecol. Econ. 51 (1–2), 1–16. https://doi.org/10.1016/j.ecolecon.2004.04.006.

Sharifi, A., Pathak, M., Joshi, C., He, B., 2021. A systematic review of the health co-benefits of urban climate change adaptation. Sustain. Cities Soc. 74 (June), 103190 https://doi.org/10.1016/j.scs.2021.103190.

Skrydstrup, J., Löwe, R., Gregersen, I.B., Koetse, M., Aerts, J.C.J.H., de Ruiter, M., Arnbjerg-Nielsen, K., 2022. Assessing the recreational value of small-scale Nature-Based Solutions when planning urban flood adaptation. J. Environ. Manag. 320 (2022) 115724. doi:10.1016/j.jenvman.2022.115724.

Sutherland, R.J., Walsh, R.G., 1985. Effect of distance on the preservation value of water quality (coal mining). Land Econ. 61 (3) https://doi.org/10.2307/3145843.

Tibesigwa, B., Ntuli, H., Lokina, R., 2020. Valuing recreational ecosystem services in developing cities: the case of urban parks in Dar es Salaam, Tanzania. Cities 106 (July), 102853. https://doi.org/10.1016/j.cities.2020.102853.

Venkataramanan, V., Lopez, D., McCuskey, D.J., Kiefus, D., McDonald, R.I., Miller, W.M., Packman, A.I., Young, S.L., 2020. Knowledge, attitudes, intentions, and behavior related to green infrastructure for flood management: a systematic literature review. Sci. Total Environ. 720 (February), 137606 https://doi.org/10.1016/j.scitotenv.2020.137606.

Viti, M., Löwe, R., Sørup, H.J.D., Rasmussen, M., Arnbjerg-Nielsen, K., McKnight, U.S., 2022. Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies. Sci. Total Environ. 841 (February), 156636 https://doi.org/10.1016/j.scitotenv.2022.156636.

III

Beyond meta-studies: learnings from a large multi-site primary dataset on non-tangible benefits of Nature-Based Solutions

Viti, M., Ladenburg, J., Löwe, R., Sørup, H. J. D., McKnight, U. S., Arnbjerg-Nielsen, K.

Manuscript

Beyond meta-studies: learnings from a large multi-site primary dataset on non-tangible benefits of Nature-Based Solutions

Martina Viti[1*], Jacob Ladenburg[2], Roland Löwe[1], Hjalte J.D. Sørup[1], Ursula S. Mcknigh[3], Karsten Arnbjerg-Nielsen[1]

[1] *Department of Environmental and Resource Engineering, Technical University of Denmark, Bygningstorvet Bldg. 115, 2800 Kgs. Lyngby, Denmark*

[2] *Department of Technology, Management and Economics, Technical University of Denmark, Akademivej Bldg. 358, 2800 Kgs. Lyngby, Denmark*

[3] *Swedish Meteorological and Hydrological Institute, Folkborgsvägen 17, SE-601 76 Norrköping, Sweden*

***Corresponding author:** martvit@dtu.dk

Potential journals for publication: Science of the Total Environment, Journal of Environmental Management.

Keywords: NBS; Contingent Valuation; Benefits Assessment; Value Functions

Abstract

Despite the growing popularity of Nature-Based Solutions (NBS) as strategies for, among others, the reduction of hydro-meteorological risks, their uptake is slow. Uncertainties regarding the valuation and consequent economic feasibility of NBS are deemed to be a substantial barrier to their uptake. The monetary valuation of non-tangible benefits of NBS (e.g., increased recreation and enhanced biodiversity) is seen as a plausible strategy to get closer to a holistic assessment. However, the quantification of non-tangible benefits is often not integrated into the assessment of NBS. This situation may risk leading to an inconsistent and biased valuation, which can, in turn, negatively influence the prioritization of these strategies. Thus, our study aims at collecting holistic data on the non-tangible benefits of NBS across different study sites and determining if there are any patterns in how the different types and contexts of NBS influence people's valuation. We applied a Contingent Valuation survey to six different peri-urban NBS study sites for the reduction of hydro-meteorological risks. The target of the survey was the general public, and we used willingness-to-pay questions to quantify the value given by the respondents to the NBS. Our results show that people appear to value the multiple benefits of NBS, and positively react to implementations improving nature across all sites. Moreover, similar variables seem to influence the value attributed to NBS across sites, with income and personal preferences ranking highly among them. However, the degree of significance of these variables changes according to the different contexts. Nevertheless, the similarity of the outcomes across sites allowed for the creation of joint valuation models, suggesting that the use of replicable primary collection methods could possibly be considered as an alternative and/or complementary approach to meta-analyses.

Highlights

- Application of a new transferable approach to assess non-market benefits of NBS.
- Respondents positively react to the multiple benefits of NBS.
- Similar variables influence the value attributed to NBS across EU sites.
- Definition of joint value functions comparable with meta-analyses' results.

1. Introduction

Nature-Based Solutions (NBS) are defined as strategies based on natural processes to address societal challenges and, at the same time, increase people's welfare and benefit biodiversity (Cohen-Shacham et al., 2016). What sets NBS apart from other ecosystem-based initiatives is their integrated perspective for tackling societal challenges (i.e. including biodiversity conservation, climate change adaptation, disaster risk reduction, human health and well-being), as well as their role in promoting a transition from a resource-intensive growth model towards a more sustainable and inclusive one (Faivre et al., 2017). In 2015, the EU Horizon 2020 Research and Innovation program launched the NBS concept as one of its major research areas (European Commission, 2015), which greatly increased the interest on the subject and the level of scientific activity around it. Moreover, in its most recent strategy for adaptation to climate change, the EU has committed to promoting NBS as essential strategies to reach a climate-resilient EU in 2050 (European Commission, 2021a).

Despite this popularity, the implementation of NBS appears to be lagging behind (European Commission, 2021b; Wihlborg et al., 2019). Uncertainties regarding the valuation, and consequent economic feasibility, of NBS are deemed to be a significant obstacle to their uptake (Nelson et al., 2020). Therefore, the monetary valuation of non-tangible benefits of NBS (including e.g. increased recreation and well-being, enhanced biodiversity) is seen as a plausible strategy to get closer to a holistic assessment and support the prioritization of these solutions as alternatives to "business-as-usual" approaches (Alves et al., 2019). However, the quantification of non-tangible benefits is often not integrated into the valuation of these strategies, or it is relegated to a secondary position in respect to more easily quantified benefits, e.g. risk reduction benefits (Alves et al., 2019; Venkataramanan et al., 2020; Viti et al., 2022).

Within this overall missing evaluation of NBS non-tangible benefits, specifically the assessment of large-scale NBS appears to be lacking. In the current literature, the evaluation of small-scale, urban NBS appear to be prioritized (Ruangpan et al., 2019; Turconi et al., 2020). Despite the higher level of complexity, large-scale strategies are fundamental for successfully adapting to climate change impacts. Therefore, large-scale NBS assessments are still very necessary.

The highlighted gaps risk leading to an inconsistent and biased valuation of NBS benefits, which can in turn negatively influence the prioritization of these strategies, both directly and indirectly (i.e. through the impossibility of conducting value transfers). In order to avoid this, both science-based organizations and the scientific literature are calling for more data and base evidence to better quantify the benefits (and particularly non-tangible benefits) of NBS (Cohen-Shacham et al., 2019; IUCN, 2020; Lafortezza et al., 2018). Guidelines and frameworks have been produced to streamline the data collection process for non-tangible benefits of NBS and to identify possible approaches to their quantification. Regarding the latter, Stated Preference (SP) methods have been highlighted as suitable approaches, as they are used to quantify non-market benefits of goods (Johnston et al., 2017; Mitchell & Carson, 1989).

Various studies have used SP methods for assessing non-tangible benefits of NBS (e.g. Derkzen et al., 2017; Reynaud et al., 2017). However, they tend to be very site-specific and produce nontransferable assessments, which do not optimally address the need of easily collectable and comparable data to fill the lack of base evidence on non-tangible benefits of NBS (Skrydstrup et al., 2022; Viti et al., 2022). Therefore, with this study we aim at enhancing the application of primary data collection by using a transferable SP method to assess of non-tangible NBS benefits in six different European sites.

This approach will allow us to obtain a unique dataset linking the characteristics of the respondents, their relationship with the NBS area, and their preferences regarding non-tangible benefits to a monetary value across different contexts. Moreover, all these data will be completely comparable across sites, having originated from the same survey scheme applied to various NBS. In this paper, we want to test the value of our approach by examining its results to determine the drivers of NBS valuation heterogeneity across several European contexts. Furthermore, we aim at summarizing these drivers into a joint, up-scalable value function. This way, we believe that we can take a first step in defining new up-scalable assessment methods for the valuation of non-tangible benefits of NBS.

2. Materials and Methods

2.1 Case studies

Our primary data was collected in six different case studies, all part of the EU Horizon 2020 project RECONECT. All case studies are large-scale NBS, aiming at reducing different kinds of hydro-meteorological risks. The case studies' locations are shown in Figure 1, and their case-specific characteristics are presented below, in Table 1. The two NBS sites of the Greater Aarhus site (see Viti et al. (2023) and Supplementary Information) are examined separately as two "sub-cases": Lake Egå and Hovmarksparken.

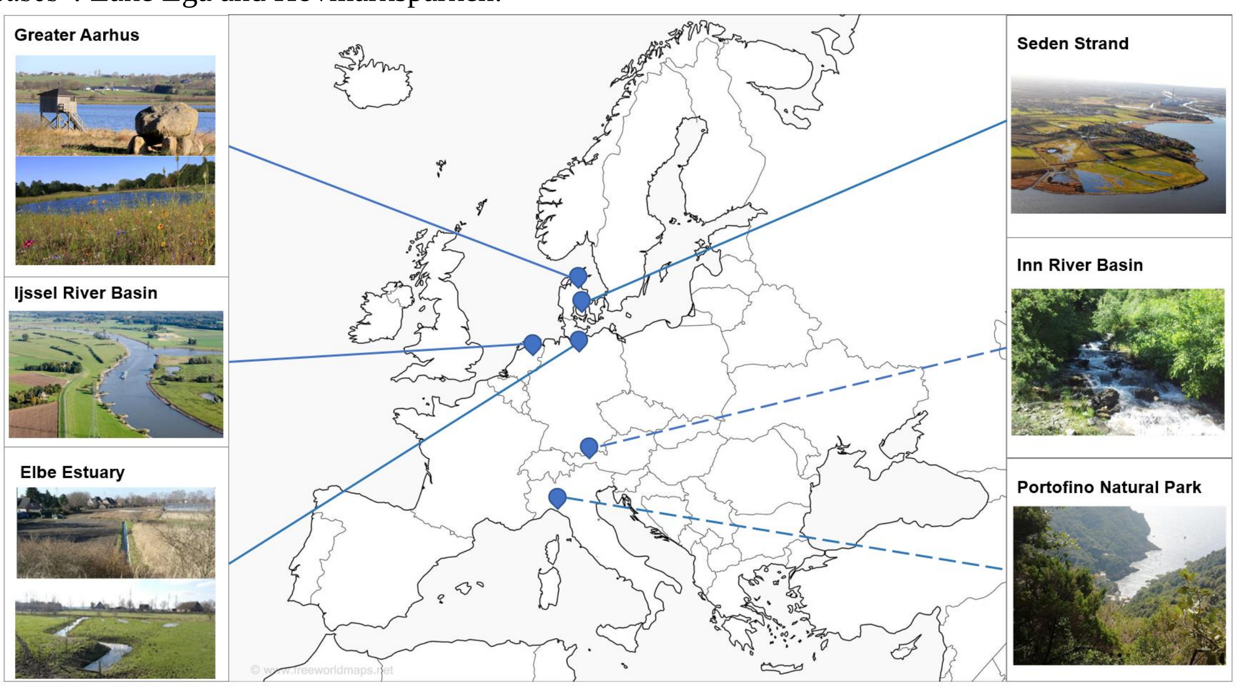


Figure 1 – Map of all study sites. The dashed lines indicate touristic sites.

Table 1 – Summary of the characteristics of the study sites

Study sites	Main type of respondent	Recreation facilities	Counteracted risks	Year of completion
Greater Aarhus – Lake Egå	Residents	Paths, benches, birdwatching towers, shelters	Pluvial floods	2006
Greater Aarhus - Hovmarksparken	Residents	Paths, benches, sport facilities	Pluvial floods	2017
Seden Strand, Odense	Residents	Paths, birdwatching tower	Coastal floods	2021/2022
IJssel River Basin	Residents	(Biking) paths, benches, sport facilities	Pluvial floods, riverine floods	2016
Elbe River Delta	Residents	N/A	Pluvial floods	Ongoing
Inn River Basin	Residents	Hiking trails, mountain-biking trails, ski slopes	Flash floods, landslides	1950
Portofino Natural Park	Visitors	Hiking trails, historical monuments, information signs	Flash floods, landslides	Ongoing

More details and the maps of the sites can be found in the SI (Figures S1 to S6).

2.2 Survey creation, distribution and responses

Given the focus on transferability and comparability of results, a common approach was used in all study sites. A modular Contingent Valuation (CV) survey previously developed (see Viti et al. (2023) for details, including the full text of the survey and all the collected variables). The survey was comprised of four sections assessing, respectively: the relationship between the NBS and the respondent (e.g. frequency, length, and reason of visits), the attitudes of the respondents regarding the benefits of NBS (e.g. interest in the increase of recreational opportunities or enhancement of biodiversity), the value attributed to the NBS as it is and with an increase in the benefits for nature via two Willingness-To-Pay (WTP) questions, and finally the socio-demographic characteristics of the respondents (e.g. age, gender, income). The two WTP questions offered a list of options presented in local currency units, but represented identical amounts in all sites when converted into Euros. This set-up produced two variables: WTP*base*, representing the WTP for maintaining the NBS (project) as it is; and WTP*total*, the sum of

WTP*base* and the extra bid expressed by the respondents for including further actions to improve the quality of the nature in the area.

The survey's sections have been co-designed with the "coordinators" of each study site (e.g. municipalities, Park direction). This approach was used to reach a satisfactory level of site-specificity that would allow for a proper valuation of each site.

The collection process was anonymous (in compliance with EU GDPR requirements) in all study sites. The distribution was carried out differently for each study site according to the responsible partners' preferences and availabilities. Due to the COVID-19 pandemic, in-person survey distribution was greatly challenged, and the collection of responses had to run almost exclusively online. The two exceptions were the IJssel and Elbe Estuary sites, where the responses were partly collected in-person. The sites whose data collection suffered the most from the pandemic's impact were the touristic sites (i.e. Inn River Basin and Portofino Natural Park), as the challenge of reaching visiting respondents was acerbated by the reduced travel flows. In the Danish sites of Greater Aarhus and Seden Strand, it was possible to send the survey directly to the citizens' digital postbox, thanks to, respectively, the Municipality of Aarhus and the Municipality of Odense's support. In these cases, the sampling and the mailing of the survey was completely randomized. Table 2 summarizes the methods and outcomes of each case study's distribution campaign.

Table 2 – Summary of the distribution details across all study sites

Study sites	Number of respondents	Distribution method	Sample type	Collection period
Greater Aarhus – Lake Egå	576	Digital mailbox	Random stratified sample	June/July 2021
Greater Aarhus - Hovmarksparken	258	Digital mailbox	Random stratified sample	June/July 2021
Seden Strand	360	Digital mailbox	Random stratified sample	November/December 2021
Elbe River Delta	433	In person and physical letters	On-site sample	July/August/September 2022
IJssel River Basin	180	In person, flyers and through social media	On-site sample	July 2021
Portofino Natural Park	99	Digital newsletter and social media	On-site sample	June/July/August 2022
Inn River Basin	48	Digital newsletter	On-site sample	May/June 2022

2.3 Analyses

First and foremost the data collected was assessed and compared across sites. Afterwards, in order to determine whether there are any patterns in the value attributed to the NBS, we set up a series of statistical models.

When collecting data, we distinguished between protest and non-protest voters. Protest voters are defined as respondents who do not accept the hypothetical valuation scenario and therefore refuse to state a WTP (Meyerhoff & Liebe, 2008). For all of the following statistical analyses, protest votes were eliminated from the datasets. This is a standard procedure in the analysis of SP results, despite the critiques to this approach (Bernath & Roschewitz, 2008; Ramajo-Hernández & del Saz-Salazar, 2012). Detailed analyses of the protest votes were done in the first study on the application of this survey in the Aarhus site (Viti et al., 2023). Despite the differences registered between non-protest ad protest groups, they were ruled to be not so significant as to be repeated for each examined site. Therefore in this study, the analysis of the protest votes was set aside, and the distinction between protest and non-protest votes done through the questionnaire was accepted without further testing. Furthermore, according to the guidelines for international value transfers (Navrud & Ready, 2007), WTP responses and income data were corrected for differences in purchasing power parity (PPP) between countries using indices from the European Statistical Office (Eurostat, 2022b) and converted into 2021 Euros. This allowed for direct comparison of the WTP bids across sites.

Our statistical analyses were divided into three steps, namely the definition of: single-site models, a joint descriptive model, and a joint predictive model. Because of the limited number of responses obtained from the Inn River Basin site (Table 2), the data from this study site had to be excluded from the statistical modeling, leaving us with 6 study sites for the first step in our analyses.

First, the impact of explaining variables on the WTP bids was assessed with linear regression models, as seen in the literature (Bernath & Roschewitz, 2008; Kutner et al., 2004) (Equation 1). In our case, due to the skewed data distribution, WTP values were log-transformed with a small off-set value to allow for 0 WTP values. The model was repeated two times for each site, one using each WTP variable (WTP*base* and WTP*total*) as the dependent variable, for a total of 12 models created.

$$\log(WTP + y_0) = a + bX + cY + dZ + \varepsilon \quad (1)$$

Once the linear regression models were completed for each study site, we defined a joint descriptive model, i.e. a single model effectively summarizing which variables influenced the WTP of respondents across sites. In order to do that, we pooled the datasets from all the study sites excluding Portofino. In Portofino, the respondents were for the most part “visitors”, travelling longer distances and for longer time in order to visit the site for more extended periods (Fig. S7 and S8). Given their much different background and use of the NBS, it would be difficult to argue for joining these evaluations with those of the other sites.

The descriptive model was built using model only those individuated as significant in the single-site models as explanatory variables. Furthermore, to better explore correlations between the data across sites, the values of the variables were transformed to zero mean and variance 1. The log-transformed WTP bids were once again used as the dependent variables.

Our models needed to cater for the differences in the way the responses were collected (Table 2). Namely, the fact that in some sites (specifically the Elbe Estuary and IJssel River), we did not manage to collect a randomized sample, but rather a sample including only individuals actively using the NBS areas (defined from here onwards also as simply “users” of the area). Therefore, a dummy variable for the “users-only” sites was introduced in the model (USER), as well as interactions between the dummy and the explanatory variables (USER*(X,Y,Z)) (Equation 2).

$$\log(WTP + y_0) = \alpha + USER + \beta X + \gamma Y + \delta Z + USER * (X, Y, Z) + \varepsilon \quad (2)$$

Furthermore, given that in the Danish sites we collected responses from both users and non-users, we tested a second approach (Equation 3). Namely, we directly compared only the users from the Danish sites (A) with the users from the other sites (B), using the Danish non-users as the reference category. We used the same approach as with Eq. 2 of defining dummy variables, adding them to the model and interacting them with the other explanatory variables. The differences between the two descriptive models are summarized in Table 3.

$$\log(WTP + y_0) = \alpha + A + B + \beta X + \gamma Y + \delta Z + (A, B) * (X, Y, Z) + \varepsilon \quad (3)$$

Similarly to the distinction between responses based on their sampling method, we could differentiate between two types of collected variables. Namely the variables that could be gathered only through direct questioning of the respondents (i.e. personal preferences and concerns, reasons of visiting the area), and those that could be collected through statistical or open access data (i.e. distance from the NBS, mean income, average age). Creating a model (Equation 4) based only on the latter (W), would allow us to determine the explanation power of these “non-subjective” variables and compare it to the outcomes of the full models. Moreover, it would lead to the definition of a model that could easily be up-scaled and applied in different contexts for the quantification of non-tangible benefits of NBS (i.e. a predictive model). To do that we employed the same pooled dataset as for the descriptive models, with the standardized variables and log-transformed WTP. Moreover, since the frequency of visits of individual users (e.g. whether they are non-users or users – as in Eq. 3) would not be possible to infer without a direct questioning, we could only apply the first of the two previously defined approaches (as in Eq. 2) (Table 3).

$$\log(WTP + y_0) = \alpha + USER + \beta W + USER * W + \varepsilon \quad (4)$$

All the above mentioned analyses have been carried out in R using the car, ggplot2 and mvtnorm packages.

Table 3 – Overview of the two descriptive models developed.

First joint descriptive model			
Name of group	RANDOMIZED SAMPLE		USER SAMPLE
N# of respondents	785		364
Description	Responses collected through a random stratified sample (corresponding to the responses from the Danish sites)		Responses collected through on-site sampling, with most respondents residing on the NBS area (Elbe and IJssel sites)
Explanatory variables	Variables that were found to be significant in the single-site models (X,Y,Z in Eq. 2), and the interactions between the USER dummy and the same variables (USER*(X,Y,Z) in Eq. 2).		
Second joint descriptive model			
Name of group	OFF-SITE NON-USERS	OFF-SITE USERS (A)	ON-SITE USERS (B)
N# of respondents	145	640	364
Description	Respondents from a Danish site, frequency of visit = 0	Respondents from a Danish site, frequency of visit > 0	Same as above
Explanatory variables	Variables that were found to be significant in the single-site models (X,Y,Z in Eq. 3), and the interactions between the off-site users and on-site users dummies (A,B) and the same variables ((A,B)*(X,Y,Z) in Eq. 3).		
Joint predictive model			
Name of group	RANDOMIZED SAMPLE		USER SAMPLE
N# of respondents	785		364
Description	Same as in the first joint descriptive model		Same as in the first joint descriptive model
Explanatory variables	Variables that could be gathered without questioning of the respondents (W in Eq. 4), and the interactions between the USER dummy and the same variables (USER*W in Eq. 4).		

3. Results

3.1 Descriptive statistics and similarities between study sites

Table 4 presents descriptive statistics of each sample together with WTP bids. The short distance, high visit frequency and low travel times indicate that we mostly managed to capture respondents living close to the NBS sites, except for the Portofino site. The short visit times highlight how most of the respondents routinely pass by most of the areas. The longer visit times in the German site have to be put in the perspective of people residing on the area where the NBS is going to be implemented. The socio-demographic characteristics of the respondents are quite uniform. On average, we have collected answers from individuals slightly older than the median age (Eurostat, 2022a), living with a partner but not necessarily with children, with a majority (excluding Portofino) of male respondents. The percentage of protest votes peaked in areas where the NBS is located in a residential area, while in the touristic sites the valuation scenario seems to be more accepted.

Table 4 – Descriptive statistics by site, including the 95% confidence interval (in brackets). Here non-transformed values are used.

Variables	Aarhus – Lake Egå	Aarhus - Hovmarksparken	Seden Strand	Ijssel	Elbe Estuary	Portofino	Inn River
Mean distance from NBS (km)	12 (11,15-13,74)	9,6 (7,7-11,62)	15 (13,07-16,73)	10,7 (7,78-13,55)	3 (2,56-3,31)	33 (27,8-37,4)	5 (3,14-7,13)
Mean visit frequency	Weekly	More than once a week	Monthly	More than once a week	More than 5 times per week	Ca. twice a month	More than once a week
Mean travel time (min)	31 (29,43-32,65)	27(25,15-28,8)	26 (23,79-28,71)	33 (31,02-35,98)	33 (31,61-34,71)	101 (91,2-111,8)	34 (28,79-38,71)
Mean visit time (min)	66 (62,52-69,56)	31 (29,17-33,85)	48 (42,70-53,30)	91 (83,43-99,23)	157 (152,46-161,90)	112 (101,4-123,4)	97 (80,98-112,77)
Mean age	53 (51,60-54,32)	51 (49,38-53,56)	53 (51,57-54,82)	47 (44,48-48,86)	53 (51,97-54,81)	52 (49,6-54,6)	47 (42,98-51,19)
Gender (% women)	49	49	49	44	42	56	41
Mean family size	2,5 (2,38-2,64)	2,6 (2,42-2,85)	2,3 (2,16-2,42)	2,9 (2,62-3,11)	2,76 (2,63-2,89)	2,7 (2,4-2,9)	3 (2,58 – 3,38)
Mean income (EUR/month/hh)	3276 (3120-3433)	3428 (3181-3675)	3562 (3292-3831)	2859 (2681-3036)	3459 (3267-3651)	2689 (2457-2920)	2921 (2592-3250)
Mean WTP base (excl. protest) (EUR/month)	3,74 (3,15-4,32)	3,27 (2,36-4,17)	3,95 (3,16-4,73)	4,15 (3,25-5,04)	11,32 (9,53-13,12)	4,44 (2,9-5,9)	5,8 (4,5-7,2)
Mean WTP total (excl. protest) (EUR/month)	6,23 (5,18-7,27)	5,46 (3,89-7,02)	6,65 (5,31-8)	11,78 (9,13-14,43)	18,45 (15,58-21,32)	8,8 (5,6-11,9)	10,6 (8,2-12,9)
Protest votes (%)	34	39	30	30	32	27	21

The WTP differs in the various sites. A clear subgroup is highlighted in the three Danish NBS, where the bids are the lowest among the sites and very close to each other, despite two sites being older and well established (Lake Egå and Hovmarksparken) and the other a newer site (Seden Strand). The highest bids came from the German site, most probably due to the fact that the reached respondents were for the most part living on the area where the NBS project is going to be implemented. As shown in the SI (Table S1), the difference of means between WTP*base* and WTP*total* was significant across sites. The significantly higher WTP*total* suggests that respondents on average allocate value to the enhancement of nature benefits in addition to maintaining the NBS areas.

3.2 Results of the models explaining WTP bids for each site

The models of all sites show some transversally significant variables such as high household income, the importance of nature for nature areas and biodiversity enhancement (Table 5). The influence of personal preferences is more noticeable in the models using WTP*total* as the dependent variable. Notably, the variables indicating the use of the NBS area to exercise and/or to pass by (e.g. walking the dog or on the way to work) are significant in the Danish sites (i.e. Lake Egå, Hovmarksparken and Seden Strand). In the case of Hovmarksparken, the only significant variables are found within the personal preference variables, while in Portofino no personal preference variable seems to be influencing the WTP. The frequency of visit is particularly relevant in the Elbe Estuary site, while the gender of the respondent is highlighted in Portofino and IJssel. The concern over hydro-meteorological risks increases the WTP in Seden Strand, while it decreases it in Portofino. Likely, this is because most of the Portofino respondents were visitors. Thus, the risk reduction in the Park's area is not really connected to the respondents' concern over the risk in their residence area.

Overall, high income and high interest in areas left for nature led to an increase in WTP amounts across study sites. However, while the connection between income and WTP appears to be genuinely transversal, the influence of the importance attributed to areas for nature and to the enhancement of biodiversity seems to be predominant in the three Danish sites.

Table 5– Outcomes of the single site linear regression models for WTP base and WTP total. Only the significant variables are reported. The full table with the explicit estimates and standard errors is reported in the SI (Tables S2, S3, and S4a&b).

▲ = p<0.01

△ = p<0.1

		Frequency of visit	Sex (male)	People in household	Household income	Concern over risk	Direct risk experience	Importance of nature areas	Importance of biodiversity	Visiting the area to enjoy nature	Visiting the area to exercise	Passing by the area
WTP base	Lake Egå				▲			▲	△	▲		
	Hovmarksparken							▲				
	Seden Strand				▲	▲		▲				
	Elbe Estuary	▲			▲				▲			
	IJssel River			▽	△							
	Portofino Park				▲	▽	△					
WTP total	Lake Egå				▲			▲	▲	▲	△	
	Hovmarksparken							▲		△		△
	Seden Strand				▲	▲		▲			△	
	Elbe Estuary	▲		▽	▲				▲			
	IJssel River		△					△				
	Portofino Park		△		▲							

3.3 Estimation of joint descriptive models

For the estimation of a joint value function with WTP*base* as dependent variable, the independent variables were the eight variables that emerged as significant in the full linear regression model (Table 5). As for the model using WTP*total*, the same method was used, but the independent variables were ten (Table 5).

As mentioned in Section 2, two approaches were used to formulate a joint descriptive model of the collected data (Table 3). Table 6 shows the results of the first approach, which distinguished between those sites where the collection was random (reference), and those where we collected responses only from users of the NBS sites (USER dummy).

*Table 6 – Outcomes of the first descriptive joint regression models for WTP base and WTP total. Transformed variables were used here. Standard errors are reported in the square brackets. ’p<0.1 *p<0.05 **p<0.01 ***p<0.001*

	WTP base		**WTP total**	
		USER=1		**USER=1**
Intercept	-0.28 [0.06]***		-0.45 [0.07]***	
Frequency of visit	-0.01 [0.04]	0.15 [0.07]*	-0.06 [0.05]	0.22 [0.07]**
People in the household	-0.05 [0.04]	-0.09 [0.06]	-0.05 [0.03]	-0.08 [0.06]
Sex (male)	-	-	0.09 [0.06]	0.16 [0.12]
Household income	0.13 [0.04]***	0.30 [0.08]***	0.14 [0.03]***	0.17 [0.08]*
Concern over risk	0.12 [0.04]**	0.02 [0.07]	0.11 [0.03]**	-0.08 [0.06]
Direct risk experience	0.01 [0.08]	-0.01 [0.13]	-	-
Importance of "nature for nature" areas	0.15 [0.03]***	-0.001 [0.07]	0.18 [0.03]***	-0.03 [0.07]
Importance of biodiversity enhancements	0.11 [0.04]**	-0.05 [0.06]	0.11 [0.04]**	0.005 [0.06]
Visiting the area to enjoy nature	0.20 [0.06]**	-0.36 [0.12]**	0.20 [0.07]**	-0.28 [0.13]*
Visiting the area to practice a sport	-	-	0.15 [0.07]*	-0.25 [0.13] ‘
Visiting the area just passing by	-	-	0.15 [0.08]*	0.03 [0.16]

The results follow quite closely the outcomes registered across the single-site models, with a strong influence of household income and preferences on the WTP in the randomized sample of respondents. This model allows us to note that when the sample is made up of users of the area, the influence of income on the WTP appears to be significantly greater than in the randomized group. Moreover, the frequency of visits turns significant, while the opposite is true for the reason(s) for visiting the NBS site.

Then for the second model distinguishing between users and non-users of the Danish sites, the results are reported in Table 7. For this model, the non-users group from the Danish sites was used as the reference, while the users from the Danish sites (off-site user) and from the NBS where the collection happened on-site (on-site user) where represented by dummies.

*Table 7 – Outcomes of the second descriptive joint regression models for WTP base and WTP total. Transformed variables were used here. Standard errors are reported in the square brackets. The + sign indicates those variables that could only be determined as interacted variables. ’p<0.1 *p<0.05 **p<0.01 ***p<0.001*

	WTP base			**WTP total**		
		Off-site user=1	On-site user=1		Off-site user=1	On-site user=1
Intercept	-0.24 [0.11]*			-0.28 [0.10]**		
Frequency of visit	+	-0.03 [0.04]	0.14 [0.05]*	+	-0.06 [0.05]	0.16 [0.05]**
People in the household	-0.03 [0.06]	-0.02 [0.07]	-0.11 [0.08]	-0.05 [0.06]	-0.01 [0.07]	-0.08 [0.07]
Sex (male)	-	-	-	-0.20 [0.15]	0.35 [0.17]*	0.45 [0.18]*
Household income	0.04 [0.06]	0.11 [0.07]	0.39 [0.10]***	0.11 [0.06]	0.05 [0.07]	0.20 [0.10]*
Concern over risk	0.22 [0.11]*	-0.11 [0.12]	-0.07 [0.12]	0.17 [0.09] ‘	-0.07 [0.10]	-0.13 [0.10]
Direct risk experience	-0.23 [0.23]	0.26 [0.25]	0.23 [0.26]	-	-	-
Importance of "nature for nature" areas	0.15 [0.08] ‘	-0.002 [0.09]	0.0004 [0.10]	0.15 [0.08]	0.03 [0.10]	0.01 [0.10]
Importance of biodiversity enhancements	0.04 [0.07]	0.09 [0.08]	0.009 [0.09]	0.10 [0.07]	0.02 [0.08]	0.01 [0.09]
Visiting the area to enjoy nature	+	0.16 [0.07]*	-0.16 [0.11]	+	0.19 [0.07]**	-0.08 [0.11]
Visiting the area to practice a sport	-	-	-	+	0.15 [0.07]*	-0.09 [0.11]
Visiting the area just passing by	-	-	-	+	0.14 [0.08] ‘	0.18 [0.14]

The second descriptive model appears to confirm the results from the first, while adding some nuances between the different user groups. Preferences still seem to be the main drivers of valuation for the “off-site” group. In the “on-site” valuation income and frequency of visit are the main drivers of WTP. Interestingly, few differences between users and non-users from the Danish sites are registered. This seems to suggest that the distinction between users and non-users is not that significant when attempting to determine the respondents’ valuation drivers. Thus, a more significant impact on WTP should be searched within these sites’ socio-cultural context.

3.4 Estimation of a joint predictive model

The results of our predictive models for WTP*base* and WTP*total* are shown in Table 8.

*Table 8 – Outcomes of the predictive joint regression models for WTP base and WTP total. Standard errors are reported in the square brackets. Transformed variables were used here. ’p<0.1 *p<0.05 **p<0.01 ***p<0.001*

	WTP base		**WTP total**	
		USER=1		**USER=1**
Intercept	-0.23 [0.05]***		-0.25 [0.05]***	
People in the household	-0.05 [0.03]	-0.11 [0.06] ‘	-0.05 [0.04]	-0.10 [0.06]
Age of the respondent	0.003 [0.03]	0.09 [0.07]	0.006 [0.03]	0.06 [0.07]
Sex (male)	0.04 [0.07]	-0.04 [0.13]	0.04 [0.06]	0.16 [0.12]
Household income	0.10 [0.03]**	0.35 [0.08]***	0.12 [0.03]***	0.23 [0.08]**
Direct risk experience	0.10 [0.07]	-0.05 [0.13]	0.09 [0.07]	-0.12 [0.13]
Distance from the NBS area	-0.09 [0.02]**	0.02 [0.07]	-0.08 [0.03]**	0.04 [0.07]
Travel time to the NBS area	0.05 [0.03]	0.02 [0.07]	0.08 [0.03]*	-0.006 [0.07]

As expected, the results of the predictive model show a significant impact of the household income on WTP, which gets even higher in the group including only users of the area. Without the influence of preference variables, the negative correlation between the distance to the NBS and the WTP is picked up in both models, confirming a recognized pattern of higher WTP for NBS closer to one’s home (e.g. Andrews et al., 2017; Tibesigwa et al., 2020). In the model explaining the influences on WTP*total*, the positive influence of travel time becomes significant. This result is likely due to the fact that people who travel longer to visit the NBS site do so for features which are supposed to be improved in the scenario proposed to elicit the WTP*total*. Overall, the differences between the randomized and user groups appear to get smaller when looking at this specific group of variables.

4. Discussion

4.1 Influence of personal preference variables on WTP across sites

In accordance to what is found in the literature (Bernath & Roschewitz, 2008; Derkzen et al., 2017; Hérivaux & Le Coent, 2021; Reynaud et al., 2017) and in our first application of this survey approach (Viti et al., 2023) the contribution of personal preferences does appear to explain a significant part of the value attributed to NBS projects. Nevertheless, the dependency of the WTP on income still seems to be the most transversal across sites. This is also an expected outcome, as the tendency to find higher WTP bids at higher incomes is well documented (Bateman et al., 2011; Bernath & Roschewitz, 2008; Hérivaux & Le Coent, 2021; Ramajo-Hernández & del Saz-Salazar, 2012; Reynaud et al., 2017; Saz-Salazar & Rausell-Köster, 2008). In contrast to previous studies, we find a limited influence of other variables related to the relationship and use of the NBS sites, such as length or frequency of visits.

The perceived function and/or goals of NBS may be influencing these outcomes. Based on these results, it seems that the benefits of NBS on nature (e.g. biodiversity enhancement) have the highest value for the respondents. This finding is also strengthened by the significant difference between WTP*base* and WTP*total* registered in all sites (Table S1). Thus, the capacity of NBS to benefit nature appears to be a strong "selling point" of these strategies, even more than their recreational benefits. However, whether these results are due to a higher willingness to pay a fee for the protection and/or enhancement of nature rather than to pay for the access to recreational areas is also debatable.

Despite the overall significance of personal preferences, our results highlight differences throughout the various contexts. Particularly clear is the influence of the "Danish context", with three sites that present a lower dependency of the WTP on the income of the respondents, and a higher dependency of the WTP on the preferences regarding nature and using the NBS.

4.2 Challenges and impacts of defining joint models

Given the premise of a primary data collection across several NBS with different characteristics and contexts, obtaining overlapping results (Table 5) that could be (partly) summarized in joint valuation models is a fact not to be underestimated. It is a good sign of our methodology's applicability and "up-scalability". Nevertheless, the definition of such models was not completely seamless, since we had to account for having collected responses in a non-homogeneous manner. Different approaches (Eq. 2&3) were used to align the available responses, but some potential biases have to be pointed out. In particular, the distinction of the dummy variables "on-site" and "off-site" users is a bit blurry in some cases. The division between "on-site" and "off-site" was used to distinguish the users living within the NBS area, to those who are not. However, e.g. in the case of Hovmarksparken, we classified the respondents as off-site users, but the NBS in question is an urban park, and we distributed the survey in the suburb where the park is located. Therefore, it is difficult to assuredly state that the respondents answering for that area live "off-site". A similar critique is valid in the Seden Strand case, where it's likely that some respondents were in fact answering the survey from within the NBS area. This lack of definition, combined with the impossibility of defining to which group (e.g. "on-" or "off-site") respondents belong to unless asking directly, supported the use of the model including only the USER dummy for our definition of a predictive joint model (Eq. 4).

The results of our models can be compared to that of meta-analyses. However, to our knowledge, there aren't many other meta-analyses focusing on NBS (or similar strategies) gathering such a comprehensive collection of variables (especially including personal preferences) linked to a monetary evaluation across these many (in our case peri-urban) NBS sites. Among the studies we could find, the influence on WTP of income and the importance of the "existential" value of nature was also shown in Bockarjova et al. (2020). The link with income was also found by Czajkowski et al. (2017). Moreover, similar to what Skrydstrup et al. (2022) observed, the value associated with a NBS did not seem to be influenced by the type of strategy used (see the similar valuations and significant variables for the three different Danish sites). These comparable results seem to point at the use of replicable primary data collection methods not only as base for, but also as possible alternatives to meta-analyses. Data collection through replicable surveys has some of its limits in time and resource intensity, but when considering the applications shown in this study, these limitations may appear as counterbalanced by the range of possible analyses on their results. A wider use of replicable primary data collection methods to assess non-tangible NBS benefits could therefore offer a first step to test potential analyses, on top of providing a more easily comparable datasets for secondary analyses to build upon.

4.3 Limitations of the methods

In this study, we focus on the application of a CV approach across different sites, which has encountered various challenges. Ideally, we would have liked to use the same approach in all sites, specifically a face-to-face distribution, that could have then been supplemented with other methods (e.g. online mails, social media links). However, the on-and-off lockdowns of the COVID-19 pandemic did not allow for such an approach, and we had to adapt by finding the most suitable alternative method for each site. Because of the different contexts and preferences, it was not possible to find a single alternative method of distribution. These circumstances have led to differences in the number and quality of the collected data. In particular, the touristic sites (i.e. Portofino Park and Inn River Basin) suffered from being unable to collect the responses in other ways than social media. This outcome hindered the possibility of gathering enough data on the touristic subgroup of NBS sites, which could have been compared to the residential one.

Another limitation is the fact that the survey layout was strongly influenced by the first case study we collaborated with, namely the Greater Aarhus site. The survey may have therefore had an implicit bias for case studies with similar characteristics (e.g. completed NBS project, residential setting). In order to be able to compare the collected variables, once the questions were set and the survey distributed for the first time, significant changes to the structure or single questions were not possible. Therefore, despite the co-creation undergone with the other sites, the bias could have stayed, for example with the small intervals for the distance, or relating the fear of risk with the WTP (see section 3.2). A "collective" co-design approach may have prevented this, but the limited timeframe and the disruption of the regular in-person meetings within the RECONECT project due to the pandemic significantly restricted our options.

5. Conclusions

In our study, we aimed at examining the differences in NBS valuation across Europe through the use of a novel approach. Our results show common drivers of valuation across the various sites we investigated. First, respondents appear to attach a positive value to the multiple benefits of NBS, and positively react to implementations improving nature. Moreover, income was shown to be the primary influence on the WTP stated, but the personal preferences of the respondents ranked highly as well. The other investigated variables' degree of significance appeared to change according to the different NBS context. Nevertheless, the similarity of the significant variables to explain WTP across sites allowed for the creation of joint valuation models, at least for a sub-group of sites (i.e. the residential ones). Within the residential sites, it appears that the valuation of users of the NBS area, specifically those living on the site of the NBS, is mostly influenced by income and visit frequency, rather than by reason of visit or personal preferences. Conversely, the respondents specifically visiting the NBS site seem to be influenced in their valuation mostly by their preferences and activities done in the area.

Joint models including personal preferences of the respondents appeared to describe our dataset better. Nevertheless, it was also possible to determine a predictive model using only variables that do not need to be gathered via primary data collection. The results of the predictive model would be more useful for an up-scaling approach, possibly as an alternative and/or complementary method to meta-analyses.

In conclusion, we believe that our methodology for assessment across study sites can be the starting point for a broader initiative to analyze and quantify a greater number of non-tangible benefits of NBS. It is fundamental that we start gathering more primary data on the non-tangible valuation of NBS sites, which will be the basis upon which to build a solid and holistic knowledge base on these solutions.

Acknowledgements

We thank the RECONECT colleagues working at the different sites for their valuable input during the co-design of the surveys and for their support during the distribution phases.

This research was funded by the European Union's Horizon 2020 Research and Innovation program under grant agreement No. 776866 for the RECONECT (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion) project.

References

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., & Sanchez, A. (2019). Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management. *Journal of Environmental Management*, *239*(February), 244–254. https://doi.org/10.1016/j.jenvman.2019.03.036

Andrews, B., Ferrini, S., & Bateman, I. (2017). Good parks – bad parks: the influence of perceptions of location on WTP and preference motives for urban parks. *Journal of Environmental Economics and Policy*, *6*(2), 204–224. https://doi.org/10.1080/21606544.2016.1268543

Bateman, I. J., Brouwer, R., Ferrini, S., Schaafsma, M., Barton, D. N., Dubgaard, A., Hasler, B., Hime, S., Liekens, I., Navrud, S., De Nocker, L., Ščeponavičiūtė, R., & Semėnienė, D. (2011). Making Benefit Transfers Work: Deriving and Testing Principles for Value Transfers for Similar and Dissimilar Sites Using a Case Study of the Non-Market Benefits of Water Quality Improvements Across Europe. *Environmental and Resource Economics*, *50*(3), 365–387. https://doi.org/10.1007/s10640-011-9476-8

Bernath, K., & 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. https://doi.org/10.1016/j.jenvman.2007.01.059

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*(September 2019), 106480. https://doi.org/10.1016/j.ecolecon.2019.106480

Cohen-Shacham, E, Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based solutions to address global societal challenges. In E. Cohen-Shacham, G. Walters, C. Janzen, & S. Maginnis (Eds.), *Nature-based solutions to address global societal challenges*. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Cohen-Shacham, Emmanuelle, Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C. R., Renaud, F. G., Welling, R., & Walters, G. (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. *Environmental Science and Policy*, *98*(February), 20–29. https://doi.org/10.1016/j.envsci.2019.04.014

Czajkowski, M., Ahtiainen, H., Artell, J., & Meyerhoff, J. (2017). Choosing a Functional Form for an International Benefit Transfer: Evidence from a Nine-country Valuation Experiment. *Ecological Economics*, *134*, 104–113. https://doi.org/10.1016/j.ecolecon.2017.01.005

Derkzen, M. L., van Teeffelen, A. J. A., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences? *Landscape and Urban Planning*, *157*, 106–130. https://doi.org/10.1016/j.landurbplan.2016.05.027

European Commission. (2015). *Towards an EU research and innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities: Final report of the Horizon 2020 expert* *group on "Nature-based solutions and re-naturing cities."*

European Commission. (2021a). Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change. *European Commission*, *6*(11), 951–952.

European Commission. (2021b). *SOLUTIONS A Handbook for Practitioners*. https://doi.org/10.2777/244577

Eurostat. (2022a). *EU's median age increased to 44.1 years in 2021*. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220228-1

Eurostat. (2022b). *Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates*. https://ec.europa.eu/eurostat/databrowser/view/prc_ppp_ind/default/table?lang=en

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., & Vandewoestijne, S. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*, *159*(September 2017), 509–518. https://doi.org/10.1016/j.envres.2017.08.032

Hérivaux, C., & Le Coent, P. (2021). Introducing Nature into Cities or Preserving Existing Peri-Urban Ecosystems? Analysis of Preferences in a Rapidly Urbanizing Catchment. *Sustainability*, *13*(2), 587. https://doi.org/10.3390/su13020587

IUCN. (2020). IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition. In *IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition*. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2020.08.en

Johnston, R. J., Boyle, K. J., Adamowicz, W. (Vic), Bennett, J., Brouwer, R., Cameron, T. A., Hanemann, W. M., Hanley, N., Ryan, M., Scarpa, R., Tourangeau, R., & Vossler, C. A. (2017). Contemporary Guidance for Stated Preference Studies. *Journal of the Association of Environmental and Resource Economists*, *4*(2), 319–405. https://doi.org/10.1086/691697

Kutner, M. H., Nachtsheim, C. J., & Neter, J. (2004). *Applied Linear Regression Models*. McGraw-Hill, New York.

Lafortezza, R., Chen, J., van den Bosch, C. K., & Randrup, T. B. (2018). Nature-based solutions for resilient landscapes and cities. *Environmental Research*, *165*(December 2017), 431–441. https://doi.org/10.1016/j.envres.2017.11.038

Meyerhoff, J., & Liebe, U. (2008). Do protest responses to a contingent valuation question and a choice experiment differ? *Environmental and Resource Economics*, *39*(4), 433–446. https://doi.org/10.1007/s10640-007-9134-3

Mitchell, R. C., & Carson, R. T. (1989). *Using Surveys to Value Public Goods: The Contingent Valuation Method.* Washington DC: Resources for the Future.

Navrud, S., & Ready, R. (2007). *Environmental Value Transfer: Issues and Methods*. Springer.

Nelson, D. R., Bledsoe, B. P., Ferreira, S., & Nibbelink, N. P. (2020). Challenges to realizing the potential of nature-based solutions. *Current Opinion in Environmental Sustainability*, *45*(October), 49–55. https://doi.org/10.1016/j.cosust.2020.09.001

Ramajo-Hernández, J., & del Saz-Salazar, S. (2012). Estimating the non-market benefits of water quality improvement for a case study in Spain: A contingent valuation approach. *Environmental Science & Policy*, *22*, 47–59. https://doi.org/10.1016/j.envsci.2012.05.006

Reynaud, A., Lanzanova, D., Liquete, C., & Grizzetti, B. (2017). Going green? Ex-post valuation of a multipurpose water infrastructure in Northern Italy. *Ecosystem Services*, *27*, 70–81. https://doi.org/10.1016/j.ecoser.2017.07.015

Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L. S., Capobianco, V., Oen, A. M. P., McClain, M. E., & Lopez-Gunn, E. (2019). Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. *Natural Hazards and Earth System Sciences*, *20*(1), 243–270. https://doi.org/10.5194/nhess-20-243-2020

Saz-Salazar, S. del, & Rausell-Köster, P. (2008). A Double-Hurdle model of urban green areas valuation: Dealing with zero responses. *Landscape and Urban Planning*, *84*(3–4), 241–251. https://doi.org/10.1016/j.landurbplan.2007.08.008

Skrydstrup, J., Löwe, R., Gregersen, I. B., Koetse, M., Aerts, J. C. J. H., de Ruiter, M., & Arnbjerg-Nielsen, K. (2022). Assessing the recreational value of small-scale Nature-Based Solutions when planning urban flood adaptation. *Journal of Environmental Management*.

Tibesigwa, B., Ntuli, H., & Lokina, R. (2020). Valuing recreational ecosystem services in developing cities: The case of urban parks in Dar es Salaam, Tanzania. *Cities*, *106*(July), 102853. https://doi.org/10.1016/j.cities.2020.102853

Turconi, L., Faccini, F., Marchese, A., Paliaga, G., Casazza, M., Vojinovic, Z., & Luino, F. (2020). Implementation of Nature-Based Solutions for Hydro-Meteorological Risk Reduction in Small Mediterranean Catchments: The Case of Portofino Natural Regional Park, Italy. *Sustainability*, *12*(3), 1240. https://doi.org/10.3390/su12031240

Venkataramanan, V., Lopez, D., McCuskey, D. J., Kiefus, D., McDonald, R. I., Miller, W. M., Packman, A. I., & Young, S. L. (2020). Knowledge, attitudes, intentions, and behavior related to green infrastructure for flood management: A systematic literature review. *Science of The Total Environment*, *720*(February), 137606. https://doi.org/10.1016/j.scitotenv.2020.137606

Viti, M., Löwe, R., Sørup, H. J. D., Ladenburg, J., Gebhardt, O., Iversen, S., McKnight, U. S., & Arnbjerg-Nielsen, K. (2023). Holistic Valuation of Nature-Based Solutions Accounting for Human Perceptions and Nature Benefits. *Journal of Environmental Management, 334*. https://doi.org/10.2139/ssrn.4286774

Viti, M., Löwe, R., Sørup, H. J. D., Rasmussen, M., Arnbjerg-Nielsen, K., & McKnight, U. S. (2022). Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies. *Science of The Total Environment*, *841*(February), 156636. https://doi.org/10.1016/j.scitotenv.2022.156636

Wihlborg, M., Sörensen, J., & Alkan Olsson, J. (2019). Assessment of barriers and drivers for implementation of blue-green solutions in Swedish municipalities. *Journal of Environmental Management*, *233*(July 2018), 706–718. https://doi.org/10.1016/j.jenvman.2018.12.018

The Department of Environmental and Resource Engineering is one of the largest university departments specializing in environmental and resource engineering in Europe. The department conducts research, development & scientific advice and provides educational programs and services to society. We are working to develop new environmentally friendly and sustainable technologies, methods and solutions, and to disseminate this knowledge to society and future generations of engineers. The Department has approximately 300 staff of more than 30 nationalities.

Department of Environmental and Resource Engineering

Bygningstorvet, Building 115
2800 Kgs. Lyngby
Tlf. +45 4525 1600

www.sustain.dtu.dk