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Infrastructure Systems in a Sustainable City

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D4.5 Evidence-Based Narratives

Infrastructure Systems in a Sustainable City

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General Information

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About this Document

Background Information

RECREATE (Research network for forward looking activities and assessment of research and innovation prospects in the fields of climate, resource efficiency and raw materials) is a coordination and support action supported by the European Union's Seventh Framework Programme under grant agreement No. 603860.

Referring to the Impact Assessment Work Package of the RECREATE project, DG Research and Innovation has asked for the development of evidence-based narratives for funding and policy activities in the Horizon 2020 societal challenge 5-area with respect to the following DG flagship objectives:

I. Positioning Europe as the continent that realizes a circular economy through a systemic approach to Eco-Innovation
II. Making Europe a world leader in nature-based solutions, which use renewable natural resources and / or ecosystems to address societal challenges, yielding economic, social and environmental benefits.
III. Creating a market for climate information services that enables economic actors to seize climate opportunities, governments to take climate-smart mitigation and adaptation decisions and citizens to optimise quality of life in the face of climate change.

In this respect, evidence-based narratives (EBNs) serve the purpose of assessing potential benefits of investment into innovation. The main focus is on those innovations that—once scaled up—offer favourable effects on the European socio-economic and environmental systems.

The document at hands is a part of a new series of six new evidence-based narratives (EBNs). All of them are related to the topic of sustainable cities. They are grouped along following themes:

1. Material and Waste Management in a Circular City
2. Infrastructure Systems in a Sustainable City
3. Urban Adaptation in a Resilient City

The Document Structure

In order to ensure easy reading and comparability between the narratives, a blueprint has been developed and used for the construction and refinement of each of the narratives. It is to a large part comparable with the blueprint used for the first narrative versions, however contains slight changes that may help the reader grasp narrative findings easier. According to this blueprint, the structure of each of the narratives comprises the following parts:

1. Each Narrative starts with an overview of authors and changes that have been implemented due to the European Commission requests of how to refine the first versions of narratives. Moreover it is shown how the narrative is linked with the innovation subsystems of the RECREATE Scoreboard.
2. The first part, "The Narrative", is a one-pager overview of the narrative and summarizes the most relevant findings. It assists the reader in capturing logic and content of the following parts.
3. The part on "Understanding the Innovation System" establishes an understanding of the current state of the analysed innovation. It explains the actual object of innovation and describes how its current market diffusion looks like.
4. Within the "Estimation of the Investment Case" the amount of effects that can be expected when the considered innovation is up scaled to the European level is described. This comprises an outlook on possible investments and investment types needed in order to push the innovation's diffusion. Furthermore qualitative assessments and indicators considered in that estimation include future market sizes, effects on employment and environmental and social benefits.
5. The part of the "Innovation System Functioning" is based on an analysis of seven different functions of the respective innovation system. In doing so, the transition management analysis tool of a technology innovation system framework is used, (see below). The fulfilment of the innovation's functions is represented in a spider graph, which is amended by a summarizing discussion of drivers and barriers of the innovation system.
6. The part on "Further Evidence on the Innovation System" is an optional one. It includes findings considered relevant by the narrative authors, however, referring to comparability of the cases, could not be easily integrated into other narrative parts.
7. Based on the innovation system function analysis being done beforehand, the part about "Policy Recommendations" depicts a couple of possible actions, DG Research and Innovation could implement in order to push the further diffusion of the innovation.

The methodology is inspired by the technology innovation system (TIS) framework (Hekkert et al., 2007)[1], which is based on the central idea that the analysis of the targeted dynamic innovation diffusion should focus on systematically mapping the activities that usually take place in innovation systems and finally resulting in the innovation diffusion. Those activities are considered to be functions of innovation systems.

As the name implies, the TIS framework concentrates on technological change. The analysed cases comprise as well technological innovations but also non-technological innovations. Since non-technological innovation is related to larger innovation systems, which also include technologies, we have used the TIS framework as a methodological approach for the analyses of all cases both technological and non-technological.

According to Hekkert et al. an innovation system analysis is based on seven functions:

1. "Entrepreneurial Activities" maps the level of concrete actions taken by new entrants or incumbent companies generating and taking advantage of new business opportunities. Possible indicators may comprise the number of new entrants, diversification activities of incumbent actors.
2. "Knowledge Development" maps the system's ability to learn, either by searching (research) or by doing (development). Possible indicators may comprise the number of R&D projects, patents or technology learning curves.
3. "Knowledge Diffusion through networks" maps the flow of information exchange within knowledge networks. Possible indicators may comprise number of workshops and conferences devoted to the specific innovation and other network activities.
4. "Guidance of the Search" maps the selection from the results of the knowledge developing activities. Since financial resources are limited, strategic decisions by industry and government set foci guiding future investments and influencing the direction of change. Possible indicators may comprise targets set by industry or government and number of journal articles related to the specific innovation.
5. "Market Formation" maps the competition process with the embedded solution the innovation aims to replace or to change. Possible indicators may comprise the number of introduced niche markets, specific tax regimes and new environmental standards.
6. "Resource Mobilization" maps the financial and human capital resources that are needed for all the activities within the innovation system. A possible indicator may comprise funds made available for long-term R&D programs.
7. "Creation of Legitimacy" maps the process of how the specific innovation becomes part of an incumbent regime or even overthrows it. This process is guided by advocacy coalitions, parties with vested interests in the "creative destruction". A possible indicator may comprise the rise and growth of interest groups and their lobby actions.

[1] Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., and Smits, R.E.H.M. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change 74, 413–432.

Table of Content

Research Programming of a Sustainable City:

Infrastructure Systems in a Sustainable City

1 Free-Floating Electric Car-Sharing

Author(s):
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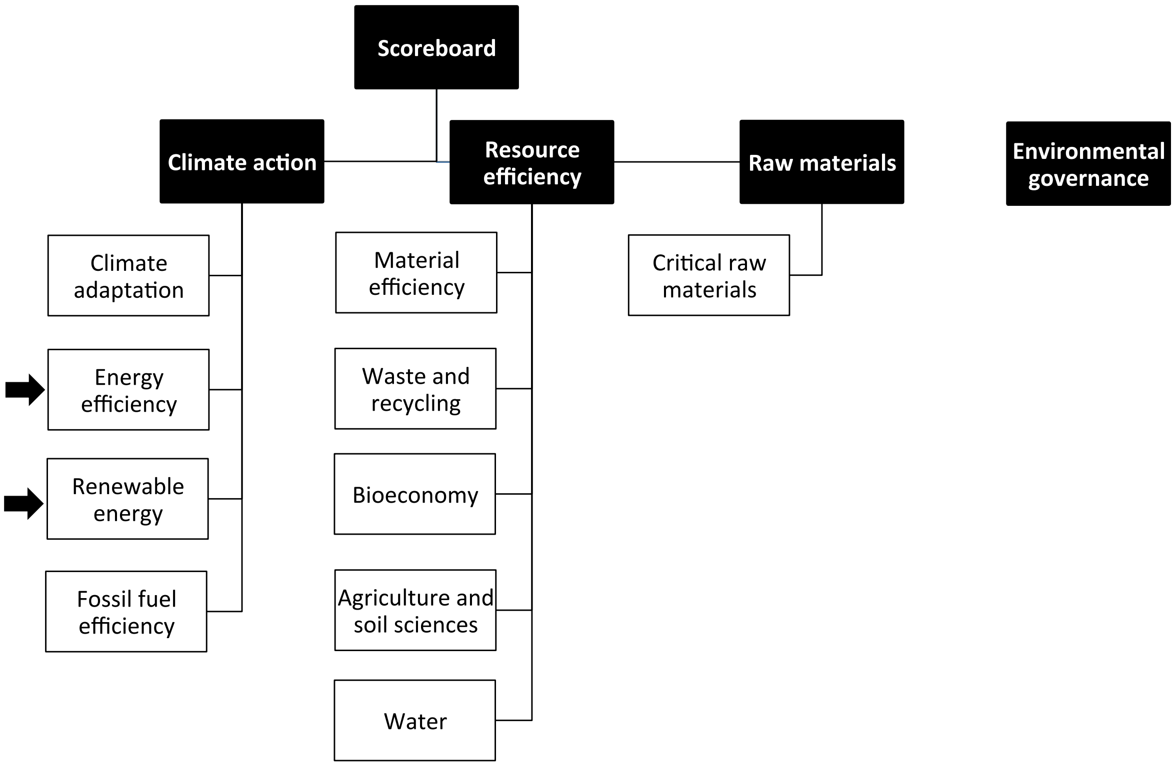
Links with RECREATE Green Horizons Scoreboard



Climate action:
Electric car-sharing especially concerns the share of electricity from renewable resources

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1.1 The Narrative

In the context of the transition towards a low-carbon energy system and higher livability in European cities, the transport sector plays a key role for the implementation of integrated innovative solutions that combine both aspects of urban sustainability, low GHG emissions, and integration of high share of renewables into the energy system of a city.

Most of the pressing issues cities are facing, such as low carbon intensity, local air and noise pollution, increasing traffic volumes and congestion, and high occupancy of public spaces are directly related to high shares of private car traffic in cities (EEA, 2013). Therefore, new paradigms that reduce this traffic are needed for the transport sector and especially in the context of urban mobility. Recognizing the crucial role of public and non-motorized modes of transport for the sustainability of transport systems and people's quality of life, private mobility still has a consistent share in many cities' modal split, mainly due to the convenience, independence and flexibility of private mobility exacerbated by the lack of efficient and reliable alternatives. In light of this need for new transport mobility options, electrical vehicles (EVs) are believed to play a key role in mitigating climate change as well for local air quality improvments, and reduced noise pollution issues attributable to traditional cars. Furthermore, negative externalities of traditional cars also include road congestion, traffic jams and consequent time losses in people's lives, as well as over-occupancy of public spaces in a city. Therefore, in recent years the attention of researchers, public authorities and businesses started to focus on a new paradigm shift in mobility dynamics in order to reduce car traffic in the cities, and it has here been suggested that a shift from ownership-based to access-based mobility, could help to reduce the volumes of private cars in cities (UITP, 2016).

Against this background, access based mobility in terms of car-sharing systems are evolving in order to resemble the comforts of private mobility, while avoiding hight growth in city car traffic, which is thought to be associated with private car ownership. Initially car sharing has been based on round-trip and station-based schemes, i.e. starting and ending a trip in pick-up/drop-off stations. In recent years, however free-floating car sharing schemes have gained popularity thanks to the flexibility of the "one-way trip" scheme. That is, shared cars are "floating" freely in a city, and users can locate the cars through GPS-localisation (e.g. via smartphone apps) benefitting from that flexibility of usage which resembles the one of private cars.

A transition to low carbon intensity in city transport has been a high priority in many cities transportation plans, and this has supported, that car-sharing operators has started to include electric vehicles in their fleet, as a step in the transition towards a decarbonisation of the transport sector, and this has also generated positive side benefits in terms of mitigation of negative local externalities such as air pollution and noise pollution (Firnkorn & Müller, 2011). Nevertheless, the share of EVs in shared fleets is still limited, representing for instance only 10-15% of the aggregated number of shared vehicles in one of Europe's most widespread car-sharing system, i.e. DriveNow.

An exception within this limited deployment of EVs in car-sharing fleets occurs in Copenhagen, where DriveNow decided to enter the city's market with a fully electric fleet. The city of Copenhagen has a very ambitious GHG reduction plan, which sets the target to CO2 neutral in 2025, and it has therefore been a key political framework condition that the City would only approve transportation acitivities such as free-floating cars, if they could contribute to low GHG emissions in the city, and EV's would here be preferred. Furthermore, the CO2 neutrality plan of the City of Copenhagen as well as the Danish energy policy have ambitious goals for renewable energy penetration, 100% coverage of all electricity production in the Danish system by 2050, and this implies that EV's will have very low GHG emissions.

Drawing on the experience of the Copenhagen case and the insights received during interviews with different stakeholders, a set of barriers and drivers have been identified in the attempt to gain understanding of the dynamics which could facilitate a larger uptake of EVs in European cities along with a concerted effort in reducing the volumes of private car traffic. In this context, policy recommendations raised throughout the analysis highlight; the need for research to monitor, evaluate and validate socio-economic and environmental impacts of largely diffused electric and shared mobility; the need to promote behavioural changes in mobility preferences away from private cars; the need to further promote the creation of new business models and collaboration between electric charging providers and car-sharing operators, in light of the potential car-sharing offers in providing a base demand for e-mobility infrastructures; and the need to facilitate the creation of stable long term policy goals at national and local level for the transport system, in order to create a stable and fertile ground for businesses engaged in the e-mobility and shared mobility market development. Further recommendations are highlighted in the "Policy recommendations" section.

Extensive desk research was conducted, collecting qualitative and quantitative evidence from relevant Danish and international sources, both from academic research on the topic as well as grey literature from international organizations, consulting companies and NGOs. In addition, a small number of semi-structured interviews with key representatives were conducted with:The Technical and Environmental Administration officer at the Municipality of Copenhagen and the Business Operation manager of DriveNow Denmark.

1.2 Understanding the Innovation System

The Innovation

Several car-sharing schemes are operating in different European cities, representing different types of schemes and business models. The case study analysed in this narrative concerns the free-floating electric car sharing scheme established by DriveNow, a joint venture between a car manufacturing company, BMW, and a car rental company, SIXT. Specifically, the focus is set on the DriveNow scheme operating in Copenhagen, Denmark, mainly for two reasons. Firstly, it is one of the few free-floating car-sharing schemes with an entirely electric fleet. Secondly, an innovative feature of the DriveNow scheme in Copenhagen consists in the integration of the car-sharing access card with the public transport transit's card (i.e. Rejsekort), which furtherly ease the accessibility to the service for its users, and thereby could be expected to minimise crowding out effects on public transport by making shared cars easily available. Such a presumably only little feature could play an important role in integrating DriveNow into the public transport system of Copenhagen, both physically through the Rejsekort working as access card for the shared vehicles, as well as in the view of the users who can travel using the same card for both public transport and car-sharing.

In the context of facilitating a larger diffusion of EVs that is stated goal in the recently published A European Strategy for Low-Emission Mobility (EC, 2016) car-sharing schemes could help in overcoming major barriers for a large uptake of electric mobility in European cities, as identified by Egbue and Long (2012). Firstly, the initial higher investment cost for EVs and especially the EV infrastructure is "shared" among all users. Secondly, one-way car-sharing schemes tackle the "range anxiety"[2] issue, not because of disruptive advancements in battery capacity itself, but thanks to the setup of one-way schemes, mostly used in urban centres where trips rarely exceed the EV range threshold of about 200 km.

Table 1. Understanding the Business Model of Free-Floating Electric Car-Sharing Schemes

Business model pillars of the Free-floating E-car sharing schemes business model	
1. Product	Users can rent shared vehicles for one-way trips which should terminate within the "home area" designated by the car-sharing operator. The price is minute-based.
2. Target customer	Ideally, the whole population of a city can access the car-sharing scheme. Moreover, same providers in different cities and countries allow for intra- and inter-national accessibility to shared vehicles of a same provider.
3. Distribution channel	Main channels are the company's website and the smartphone app, as well as marketing campaigns across several information channels and events.
4. Relationship with customer	The main interaction between the company and the users occurs through the car's computer. Round-the-clock hotline service is also available, emphasizing the flexibility of the 24/7 nature of the service provided. In general, although customer and provider interact only shortly, the relationship between both of them is of a long-term nature.
5. Value configuration	The car-sharing provider has ownership on the vehicles; users purchase a "mobility service" by the minute for using the cars, hassle free from ownership's burdens. Parking included.
6. Core competence	The core competence lies in the dynamism of the provided service – fast response to users inquiries and constant monitoring of vehicles geographical coverage is key to ensure optimized availability and usability to users.
7. Partner network	Partnerships are established with the municipality for agreement on parking slots and allowances, and also with charging infrastructure providers.
8. Cost structure	Main investment cost is represented by the purchase of the EVs. Operational costs mainly refer to parking fees and maintenance of vehicles, electricity expenditures and e-charging as well as customer relationship and marketing.
9. Revenue model	Revenues are generated by membership fees and minute-based fees for the rental of the cars. Additional revenues may rise through the sale of hourly packages and additional services, e.g. trip in a foreign country.

Registered users can access the car-sharing service through a smartphone app, but also through a website and a hotline, and the availability and location of the vehicles can be detected through a GPS system. A user can decide to reserve a car with a free allowance of fifteen minutes to reach the car, but it also allows for spontaneous renting of a DriveNow car along the streets. Registered users can access the cars through the DriveNow customer card by placing the card on the card-reader placed on the windscreen. In addition to the customer card (the DriveNow card), the innovative feature implemented in Copenhagen allows users to also access the DriveNow vehicles through the public transport's transit card (Rejsekort), thanks to the franchising of its operations to the Arriva, a public transport operator. This innovative integration is a step-forward towards integration of multi-modalities in cities, and by now it is the only example of such integration of car-sharing schemes and public transport transit's cards. Once the car is unlocked, the on-board computer asks the user to entry the personal PIN, state the cleanliness of the vehicles, report any unreported damage on the vehicle, before starting the trip. The rental fee starts from the moment when the car is unlocked through the swipe of the customer card and it ends as well with the final swipe of the card on the car's reading device. The fee is based on the minutes driven and varies from city to city and also

[2] Range anxiety is defined as users' concern over the possibility of "becoming stranded with a discharged battery in a limited-range vehicle, away from the electric infrastructure" (Eberle et al., 2010)

according to the type of car rented, in Copenhagen is set to 54 €cent/min. The only fixed cost users face is a one-time membership fee. When ending the rental, parking is included in the rental fee and vehicles can be parked in all available parking spots in the city. However, users are also allowed to park the car keeping the car rented against a fee of 34 €cent/min, with the exception of night hours during the week where keeping the car reserved is offered for free. In addition, several options for prepaid-packages, savings packages and hourly-packages have been setup to allow regular and frequent users slightly discounted rates.

Public charging infrastructures

Electric car-sharing schemes rely on public infrastructures for charging the batteries of the EVs. In Copenhagen, the EVs charging points utilized by DriveNow are supplied by E.ON, which has invested in the charging infrastructure in partnership with the Capital Region Authority through the "Copenhagen Electric" Program. Part of these charging stations, were already established in relation to the previous ambitious, but closed, EV programme in Denmark, "Better Place", where the business model was to change batteries at charging stations rather than charging by individual drivers. Drive Now thereby had very low investment costs In Copenhagen for charging infrastructure.

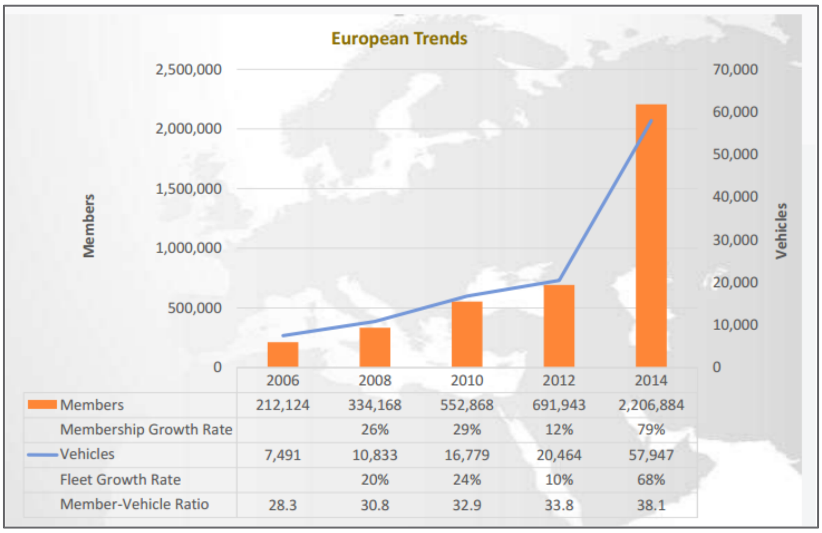
While awaiting for technological development in EVs batteries for extending the battery range, a key factor is the densification of charging points. However, this is often referred to a "chicken-egg" dilemma in the electric mobility discourse, as there is no profitable business model yet for operating public charging stations, due to the low diffusion of EVs (NPEF, 2014). In this regard, electric car-sharing schemes placed in high density areas can actually guarantee the level of basic utilization needed by the public charging infrastructure provider for reaching investments' profitability (Schussler & Bogenberger, 2015). Hence, electric car-sharing schemes help municipalities in expanding the electric mobility infrastructures in first place, foreseeing larger uptake of EVs in the future. As pointed out by the Schussler and Bogenberger (2015) in their study, public charging infrastructure providers and car-sharing operators can complement each other and establish fruitful cooperation for overcoming the "chicken-egg" dilemma when dealing with the establishment of new public charging infrastructures in a city. Several other factors subsequently come into play for negotiations between car-sharing operators and charging infrastructure providers, such as the type of charger (normal or fast charging), the density of chargers, and the location across the operating car-sharing area. It is clear how a transparent cooperation between the charging infrastructure providers and the car-sharing operator is needed for achieving mutual benefits in terms of investment. From the car-sharing operator perspective, a dense and broad network of charging points is key for profitability, as it can considerably cut operational costs due to reduced need of staff service operations, as well as gaining in attractiveness as users are more likely to find available and charged cars in the nearby (Schussler & Bogenberger, 2015). The establishment of close partnerships with municipalities and public charging infrastructure providers is a key factor for favouring the spread of electric mobility in a city's car-sharing scene, as it is has been clearly stated also by the Managing Director of DriveNow[3]:
"*[…] our fleet already includes 20 percent electric cars. But in most of the cities the electric charging infrastructure is by far not sufficient. But to extend the electric amount of our cars it is essential to have a better charging infrastructure.",* and such a structure to a wide extent existed in Copenhagen.

Current Market

Car sharing schemes are offered in many different forms. Starting from the traditional station-based round-trip schemes, the development of the car-sharing concept evolved towards one-way schemes. Initially, one-way schemes still relied on a station-based system, thus having the possibility to drop the car in a

[3] http://innoboard.de/innovation-management/drivenow-nico-gabriel-carsharing/

different station than where it had been picked up. However, due to to the recent development in technologies such as smartphone and geo-localization, the new free-floating schemes came into play, allowing users to find the nearest shared car available through GPS and smartphone apps, in that substantially increasing the flexibility and availability of such a mobility service alternative to private cars. According to the most recent study of the car-sharing market (TSRC, 2016) B2C car-sharing schemes are operating in 33 countries, five continents, and an estimated 1,531 cities with approximately 4.8 million members sharing over 104,000 vehicles. Europe, the largest car-sharing region in terms of memberships, accounts for 46% of worldwide memberships and 56% of global fleets deployed. The world’s second largest car-sharing market, North America, accounts for 34% of worldwide members and 23% of vehicle fleets. In 2014, Mexico maintained the highest member-vehicle ratios (131:1), followed by 107:1 in Italy.

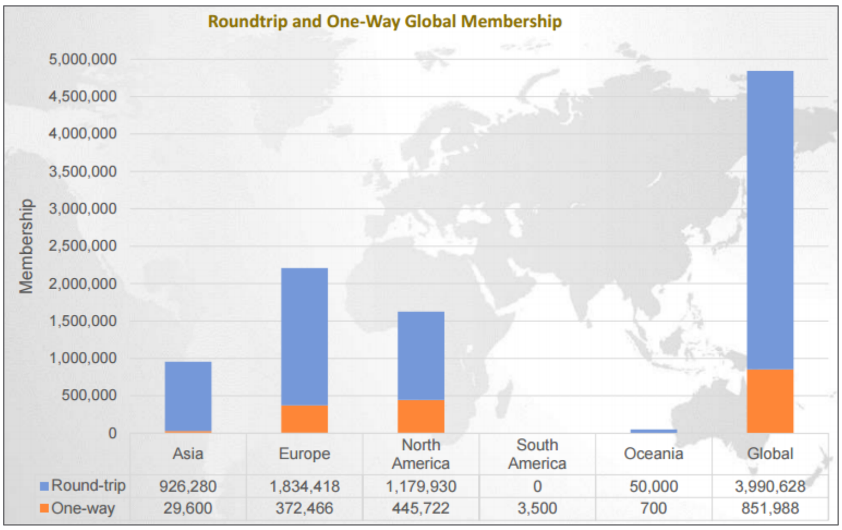


	2006	2008	2010	2012	2014
Members	212,124	334,168	552,868	691,943	2,206,884
Membership Growth Rate		26%	29%	12%	79%
Vehicles	7,491	10,833	16,779	20,464	57,947
Fleet Growth Rate		20%	24%	10%	68%
Member-Vehicle Ratio	28.3	30.8	32.9	33.8	38.1

Source: (TSRC, 2016)

Figure 1. Car sharing European trends

As of October 2014, one-way car-sharing accounted for 17.6% of global membership and 23.3% of global fleets deployed, round-trip car-sharing accounted for 82.4% and 76.7% of global membership and fleets deployed respectively. Regionally, North America has the largest percentage of one-way memberships, representing 27.4% of the continent’s car-sharing membership, whereas Europe has the greatest percentage of one-way fleets, representing 31.1% of the continent’s car-sharing fleet.



	Asia	Europe	North America	South America	Oceania	Global
Round-trip	926,280	1,834,418	1,179,930	0	50,000	3,990,628
One-way	29,600	372,466	445,722	3,500	700	851,988

Source: (TSRC, 2016)

Figure 2. Roundtrip and one-way car sharing - global membership

However, now narrowing down on solely free-floating car-sharing schemes featuring EVs in their fleets, we enter into a niche market with promising potential for future developments – which is the subject of the study in this narrative. The first provider of free-floating car-sharing system featuring the inclusion of EVs in its fleet was "Car2Go" in the city of Ulm, Germany in 2009. Eventually, Car2Go closed its operation in Ulm in 2014 due to profit losses caused by the low usage rate of the car-sharing scheme in the city. The main reasons for the withdrawal of Car2Go in Ulm was due to the population density in some part of the city and the extended business area covered in the Car2Go scheme, which did not meet the "profitable threshold" of 3,000 people per squared km only in a limited area of the city centre, thus making the Car2Go car-sharing scheme not profitable (SWP, 2014).[4] Focusing on the DriveNow case in the city of Copenhagen, as of December 2016 registered users accounted for 35,000 people, against a vehicle fleet of 400 electric cars.

Source: (adapted from: BMW Group - Mobility Services, 2016)

Figure 3. DriveNow registered members in Europe

Table 2. DriveNow operates in 11 cities across Europe as of December 2016

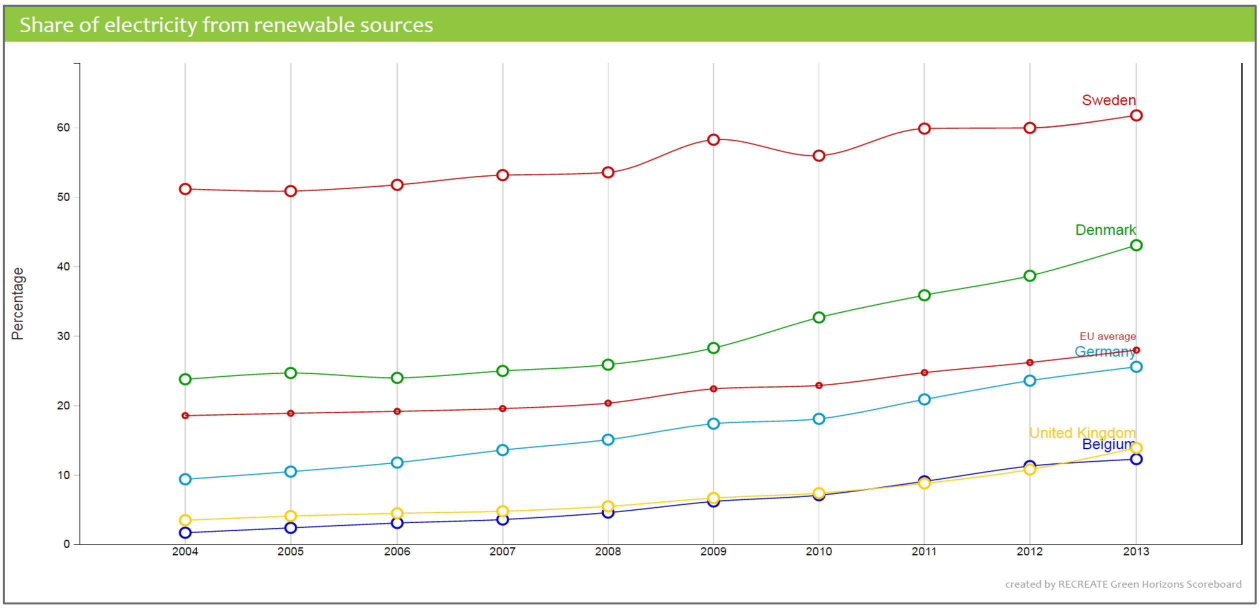
City	Country	Members	Vehicles (as on July 2016)	Type	Start Date
Munich	Germany	124,000	650 (85 e-cars)	ICEVs, EVs	June 2011
Berlin	Germany	170,000	1200 (140 e-cars)	ICEVs, EVs	September 2011
Düsseldorf & Cologne	Germany	105,000	620 (45 e-cars)	ICEVs, EVs	September 2012
Hamburg	Germany	87,000	560 (35 e-cars)	ICEVs, EVs	October 2013
Vienna	Austria	51,000	450 (20 e-cars)	ICEVs, EVs	October 2014
London	UK	16,000	320 (50 e-cars)	ICEVs, EVs	December 2014
Copenhagen	Denmark	25,000	400 (400 e-cars)	EVs	September 2015
Stockholm	Sweden	5,000	300 (20 e-cars)	ICEVs, EVs	October 2015
Brussels	Belgium	n/a	300 (0 e-cars)	ICEVs	July 2016
Milan	Italy	n/a	400 (0 e-cars)	ICEVs, EVs	October 2016

Source: DriveNow website

The establishment of the DriveNow scheme in Copenhagen is of particular interest due to the chosen business strategy of deploying exclusively EVs in the Copenhagen's DriveNow fleet. As depicted in Table 1, in all the other cities where DriveNow is in operation, EVs are only a small share of the DriveNow fleet. The

[4] http://www.swp.de/ulm/lokales/ulm_neu_ulm/car2go-macht-in-ulm-dicht-pilotstadt-war-zu-klein-und-zu-teuer-11136902.html

particular setting of DriveNow scheme in Copenhagen makes it an interesting case study, given the implication that the deployment of 400 EVs in Copenhagen is in line with the integration of higher rates of electricity generated from renewable energy sources in Denmark in accordance with City and national energy plans. In fact, a growth in the deployment of EVs can only be truly beneficial in environmental terms if and only if it is associated with growth in the supply of "green" electricity (Dell & Rand, 2001).



Source: RECREATE Green Horizon Scoreboard5

Figure 4. Share of electricity from Renewable sources for selected countries

In this regard, the symbiosis between a larger deployment of EVs and higher generation of electricity from renewable sources is also entailed in the Climate Plan of the city of Copenhagen aiming at reaching carbon neutrality by 2025[6]. The EU SET energy plan similarly is setting targets for renewable electricity penetration, which will improve the environmental performance of EV's.

1.3 Estimation of the Investment Case

Investment Strategy

DriveNow is a joint venture between BMW and SIXT with an evenly shared initial capital investment. Its operations in Copenhagen are managed by Arriva, a multinational public transport operator, through a franchising contract. As elicited from the interview with DriveNow, the main capital costs for establishing such scheme in Copenhagen is represented by the acquisition cost of the EVs fleet (specifically, 400 BMW i3), whereas major operational costs are attributable to parking fees, maintenance and reparations, and cost of e-charging the fleet. Of particular interest is the discourse on the parking fees, as it was mentioned during the interviews with both the company and the municipality of Copenhagen. Traditional round-trip car-sharing schemes face similar investment structure than free-floating schemes. However, free-floating schemes face higher operational costs as they are generally subject to higher parking fees compared to

[5] http://green-horizons.eu/scoreboard/chart/b/411+373
[6] Copenhagen Carbon Neutral by 2025. *City of Copenhagen* (available at: http://kk.sites.itera.dk/apps/kk_pub2/pdf/983_jkP0ekKMyD.pdf

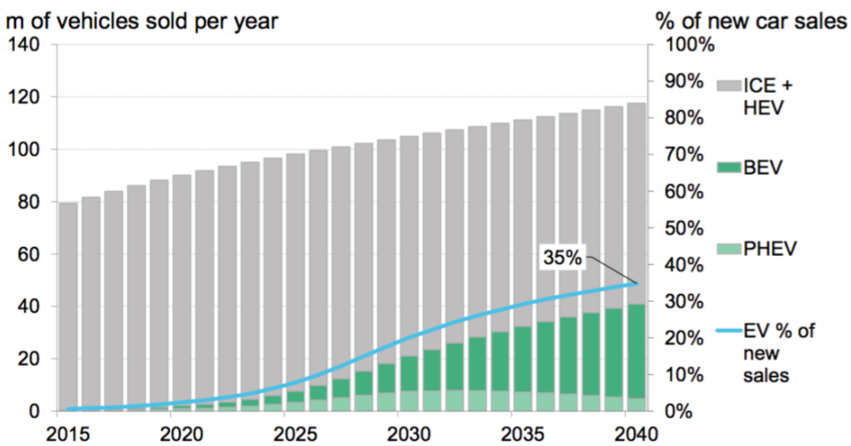
station-based car-sharing, which are entitled to subsidised parking spots throughout the city. The city of Copenhagen has insisted on this discrimination due to the lack of evidence with regards to the positive impact free-floating schemes may have on traffic volumes, i.e. reducing car traffic. The local government emphasizes that priority transportation forms in the city is walking, bicycling, and public transport. Furthermore, free-floating vehicles which cannot be anchored to a fixed parking spot with specific parking fees. These considerations were highlighted in the interview with the Technical and Environmental Administration of the City of Copenhagen. The city of Copenhagen, on the other hand, recognizes the positive impact of traditional, station-based, car-sharing schemes on traffic and congestion in the city, therefore is allowed to grant parking subsidies to companies operating in such schemes (e.g. LetsGo).

The lack of evidence regarding the benefits of free-floating schemes on traffic volumes and congestion has been identified as a major barrier for the larger diffusion of this eco-innovation (see following discussion in Innovation System Functioning). Despite the claims that operators of free-floating car-sharing schemes make on the beneficial impacts of such schemes on congestion and car-ownership, there is still a limited body of empirical evidence for that, mainly due to the fact that such schemes are quite recent in time and the findings are context-specific. Another major barrier, compared to the station-based models, is represented by the nature of free-floating schemes. That is, free-floating vehicles are allowed to be parked anywhere in the city, where allowed, with the parking fee included within the rental fee paid by the user. Hence, the lack of a fixed reserved number of parking spots in contrast with the station-based models makes it harder for municipalities to assign subsidized parking for such free-floating schemes.

Future Market Potential

Following current trends, car-sharing schemes are expected to grow in the next 5 years as highlighted in BCG (2016). By 2021, global membership in a car-sharing scheme is projected to reach 35 million users compared to the 5.8 million users in 2015. At the same time, global projections for EVs sales are expected to reach 35% of all vehicles sales by 2040, mainly driven by reductions in batteries' cost as depicted in fig.6. In this regard, the diffusion of electric cars, car-sharing schemes help in overcoming barriers due to abatement of individuals' investment costs for private electric cars and also in mitigation of the range anxiety issue (King et al., 2013).

Figure 1: Global LDV and EV yearly sales, 2015 – 2040 (m vehicles sold per year, %)

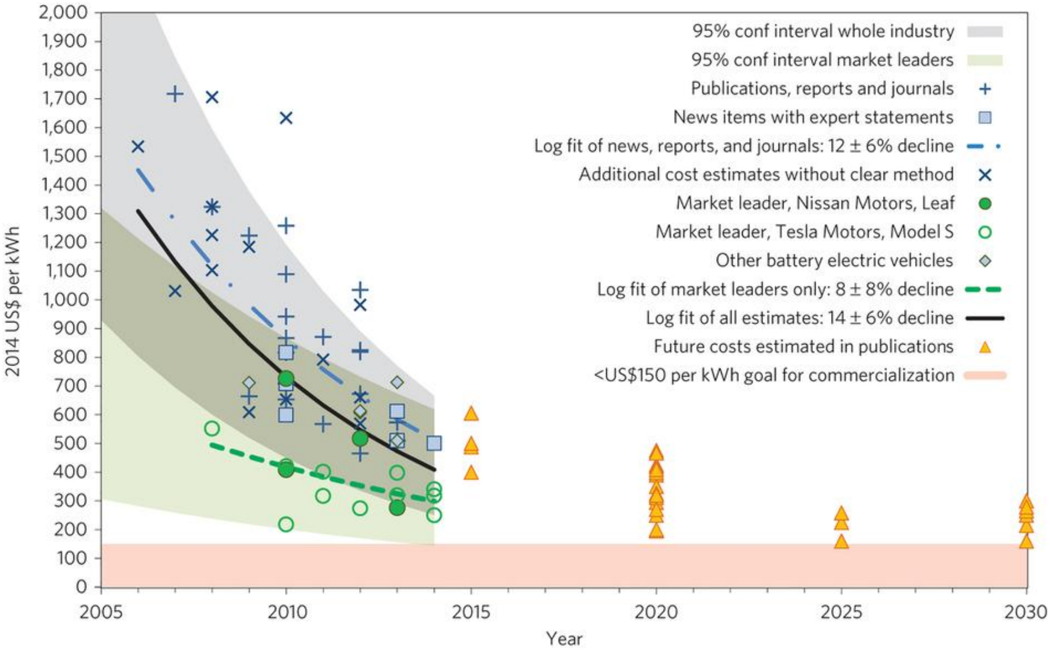


Source: Bloomberg New Energy Finance Note: ICE+HEV = internal combustion engine and hybrid vehicles, BEV = battery electric vehicles, PHEV = plug-in hybrid electric vehicles.

Source: Bloomberg New Energy Finance

Figure 5. Global LDV and EV yearly sales (2015-2040)

Besides technological development which could drastically reduce the costs of electric cars, a key factor for enabling a widespread diffusion of electric vehicles through car-sharing schemes is the installation of proper city-wide infrastructures for electric mobility. In this context, the political will at national and municipality level is a crucial factor in order to enable car-sharing companies to land in a city where electric mobility infrastructures are in place.



Source: (Nykvist & Nilsson, 2015)[7]

Figure 6. Cost of Li-ion battery packs in BEV

On top of the future market potential driven by technological developments in battery technologies and charging infrastructures, car-sharing companies are also focusing on developing new business strategies to expand their outreach of customers. During the interview with DriveNow, it was highlighted that their main goal is to expand car-sharing services to businesses, hence providing a B2B car-sharing service, as an alternative to car leasing and taxies, as the market potential in this B2B sector is high. Hence, future developments of car-sharing targeted towards the corporate sector will likely disrupt traditional business models for companies' mobility options as benefits of a hassle-free car-sharing service for companies may be substantial as confirmed in the study of Shaheen and Stocker (2015) for the US market.

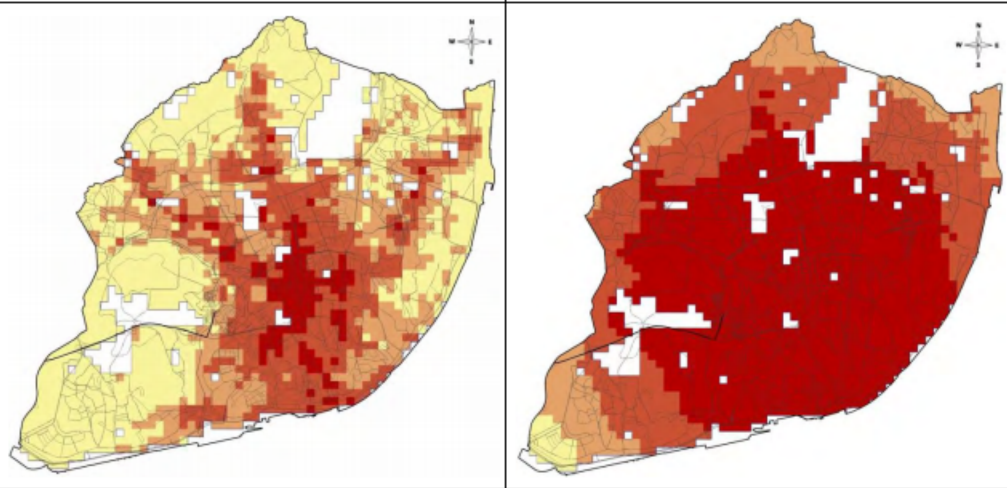
A largely discussed and likely potential development in the future of mobility is represented by autonomous vehicles. Combining free-floating car-sharing with autonomous vehicles is seen by many experts as a key component of the mobility of the future in order to cut costs, improve safety and emissions from road transport. Yet, there is no evidence on the impacts related to free-floating driverless electric car-sharing, and only few studies have simulated potential impacts of such a set-up in the urban mobility of the future. The International Transportation Forum (ITF) carried out a study in 2015 where an extreme scenario has been simulated for a representative mid-sized European capital, where all private cars were replaced by shared cars and shared on-demand buses to meet the current transportation demand of the population attributable to private vehicles. Their findings pointed out that all private mobility demand for a middle-sized European city could be covered by a mere 3% of the current private cars

[7] Data are from multiple types of sources and trace both reported cost for the industry and costs for market-leading manufactures. If costs reach US$150 per kWh this is commonly considered as the point of commercialization of BEV (Nykvist & Nilsson, 2015).

fleet of the city, thanks to increasing the daily average driving time of a vehicle, and increasing the passenger/vehicle rate from the current 1.2 to 2.4 passengers/vehicle. The associated environmental gains of such a scenario would translate in a reduction of 33% in traffic-related emissions, 95% reduction in space needed for public parking, and reduced congestion at peak-hours (see also following chapter on "Environmental and Social Benefits"). In addition, impacts on social dimensions are foreseen to be of great importance with extensively increased accessibility to jobs as highlighted in Figure 7 below, with the same positive impact also occurring for access to health and education facilities (ITF, 2015).

Access to Jobs

Current Configuration	**Simulated three-mode configuration**



Classes of Access by percentage of total jobs
0% to 25%
25% to 50%
50% to 75%
75% to 100%

Equity Indicators

Indicator	Current Configurat.	Three-mode simul. config.
P90/P10	17.3	1.8
Gini coeff.	0.27	0.11

Source: (ITF, 2016)

Figure 7. Access to jobs in the stimulated scenario

Employment Effects

Estimating the employment effect of car-sharing systems is rather difficult. It is not a labour-intensive sector, and the employment of smartphone apps for booking rentals and remote customer service is representative of a general trend of automatization and reduction of personnel required to run such businesses. DriveNow per se has 35 employees in Copenhagen as of September 2016, mainly employed for customer services, web services and marketing. However, from the interview with the company it has been recorded a potential for job creations up to a factor of 3 by 2020 driven by the expansion of the scheme in the city, in terms of both registered members and vehicle fleet. Such a development trend could risk to be in conflict with the goal of limited car traffic in the city.

However, DriveNow and electric car-sharing schemes in general, should be seen in the context of a general trend towards the decarbonisation of the transport sector, supported by both technological advancements in the electric mobility sector as well as innovations in the organization and setup of mobility from an ownership-based model to a service-based model, which will likely reduce the number of cars on the road bringing along societal benefits such as reductions in congestion and local air and noise pollution. An extensive study regarding the employment effect of the development of the electric mobility sector has been conducted by the German National Platform for Electric Mobility (NFP, 2014). In this study, it has been estimated that 30,000 new jobs, both direct and indirect, will be created in Germany by 2020 due to larger diffusion of EVs and the related network of infrastructures, e.g. e-charging networks and the like. However, as it has been highlighted in the NFP study, this achievement will be possible only if a comprehensive regulatory support will remain in place, such as: continuation of the existing extensive support for R&D, support of a rollout of the necessary charging infrastructures, and also direct support for purchases of electric vehicles (NFP, 2014).

Environmental and Social Benefits

Dealing with a systemic eco-innovation that involves the domain of electric mobility based on renewable energy sources as well as the domain of shared mobility, and more in general the sharing economy, the assessment of environmental and social benefits should distinguish between these two separated domains, the convergence of which will bring to an integrated assessment of the benefits of free-floating electric car-sharing systems.

Benefits of shared mobility

The positive impacts of car-sharing systems on car-ownership and traffic volumes have been highlighted in few context-specific studies (Firnkorn & Muller, 2012; Martin et al, 2014). Moreover, the body of evidence is larger for traditional station-based car-sharing as they have been in the market for a longer time. Free-floating car-sharing systems started operating in 2009, but only in the last 4-5 years a larger number of free-floating car sharing started operating in several cities in Europe. Hence, a thorough impact assessment of such systemic eco-innovations is still in the embryonic phase for findings to be generalized and scaled up. Martin et al. (2010) have undertaken a large survey among car sharing users in the US, specifically members of the Car2go scheme, and they found out that for every shared car in either a free-floating or station-based scheme, 9 to 13 private cars are removed from the street. Another study by Firnkorn & Muller (2012), investigated the impact of the same scheme in Ulm, Germany. Their findings point out an increase in passenger/km combined with a reduction in vehicle/km attributable to the implementation of such one-way car sharing scheme. A recent study conducted by the PBL Netherlands Environmental Assessment Agency, surveyed car-sharing users to investigate the impact of car-sharing on mobility behaviour and environmental impacts. Their findings pointed out that for every shared car, three private cars are removed from the roads, hence a 33% reduction in a car ownership among car shares, mostly replacing a second or third car. Moreover, it has been found out that car-sharing affects the driving habits of their users in terms of kilometres driven. In fact, the survey revealed a reduction in car kilometres around 15% to 20% than before they started using such sharing schemes. Due to both reductions in car ownership and kilometres driven, car-sharing schemes contributed to a reduction in CO_2 emissions between 8% and 13% of emissions related to car ownership and car use (PBL, 2015).

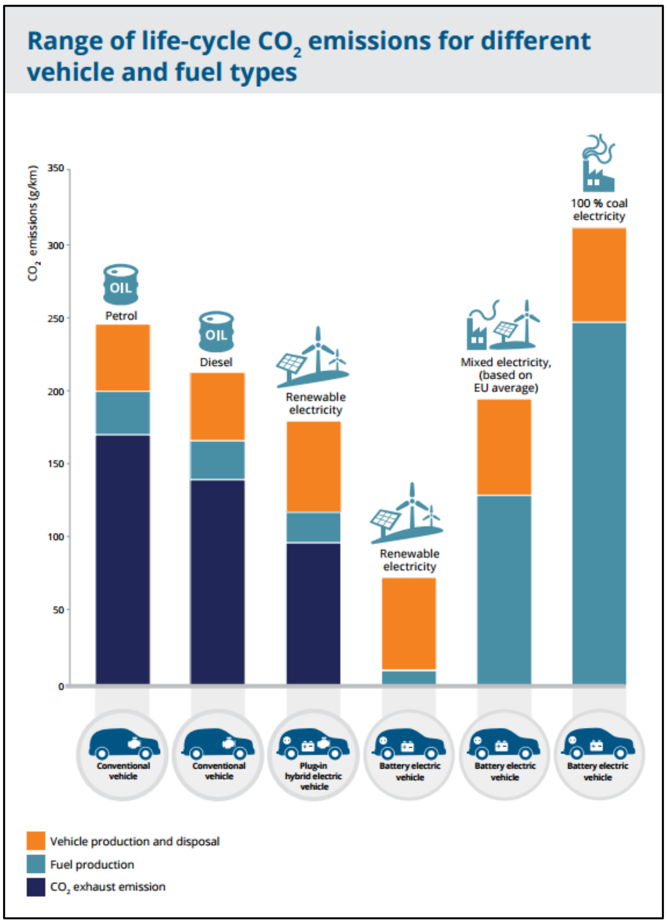
Generally, there is a large consensus on the direct environmental benefits of car-sharing schemes, although differences in magnitude of the impacts, that are due to context-specific variables and dynamics, exist. Nevertheless, there is still some uncertainty in regards to the net environmental impacts of car-sharing due to rebound effects, mainly related to the income effect; hence individuals saving money on purchase of a car may be induced to purchasing other carbon-intensive goods or services, e.g. additional flight. In addition, a counter effect of car-sharing may be the substitution of public transport, cycling or walking towards a shared vehicle, which even though being shared, it is still a car providing a private mobility service. Few studies have been conducted for understanding such potential counter effects of car-sharing schemes, yet at date no studies have been conducted on this matter specifically in relation to the innovative free-floating car-sharing scheme presented in this narrative, mainly due to a lack of observations in time as such schemes have been operating only in the last five years.

The shift from an ownership-based to an access-based mobility industry rise implications in how the business models of traditional automakers should be structured as stressed out in the Ellen MacArthur Foundation report *"A circular economy vision for a competitive Europe"*[8]. In fact, a major disruption in such a shift is represented by the change in the way ownership is treated. In leasing, shared schemes manufacturers are aiming at minimizing production costs, hence maximizing the durability of vehicles and stressing the importance of re-using and recycling vehicles' components when ending the life cycle. Rather than aiming at maximizing sales of single vehicles, in an access-based business model the objective is to produce long-lasting and durable products, so that the rate of usage over the years can be higher and the production costs paid off over the lifetime of each shared vehicle.

Benefits of electric mobility

The environmental benefits of EVs are manifold: When in-use, exhaust emissions of NO_x, PMs, SO_2 are completely eliminated. Air pollution though will still be generated by the non-exhaust emissions related to the motion of the car, i.e. wear of tyres, brakes, and roads. On the production side, EVs are 70% more energy intensive than conventional vehicles (EC, 2015) and the employment of several rare raw materials in batteries and in electric motors which are a scarce "critical" resource should also be taken into account as a larger diffusion of EVs is heavily dependent from the availability of such materials. Therefore, considering the higher energy intensity of EVs production as well as the main feature of EVs, that is the electricity used for propulsion, a crucial factor in assessing the environmental impact of EVs is the source utilized for generating electricity. A life-cycle analysis conducted by TNO and elaborated by the EEA for different vehicles types and scenarios of electricity mix shows how in an extreme "worst-case" scenario where EVs production and usage are fuelled by a 100% coal-based electricity production, it turns out EVs are actually more carbon-intensive than conventional cars (see fig. 7). However, based on the current (2014) share of renewable electricity for EU28 standing at 27.5%[9], life-cycle CO2 emissions related to BEVs are indeed lower than for conventional cars (EEA, 2016b). The targets set at EU level for increasing the share of renewable electricity are well-supportive for the promotion and larger diffusion of EVs across Europe in order to achieve a decarbonisation of the transport sector through electrification.

[8] https://www.mckinsey.de/files/growth_within_report_circular_economy_in_europe.pdf
[9] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_335a&lang=en



Source: (EEA, 2016b)

Figure 8. Range of life-cycle CO2 emissions for different vehicle and fuel types

Benefits of shared electric mobility

The inclusion of EVs in car-sharing fleets is a promising move from car-sharing operators contributing to the decarbonisation of the urban transport sector. Especially, given the current battery range that is between 100 and 200 km, EVs are particularly suitable for short trips within a city; hence, car-sharing schemes represent a great opportunity for a larger uptake of electric cars in dense urban areas where the negative impacts of private mobility on local air and noise pollution, as well as congestion, are prominent challenges for European cities to be overcome (EEA, 2016b).

Therefore, in the case where advanced car-sharing schemes could reduce car driving and support substitution of mobility demand with low-emissions several net environmental gains could be generated in cities across Europe.

1.4 Innovation System Functioning

Following the Technology Innovation System (TIS) framework developed by Hekkert et al. (2007), in this section drivers and barriers for the implementation of free-floating electric car-sharing schemes will be identified, focusing on the analysis carried out on the Copenhagen case. For each of the seven functions within the TIS framework, a score has been assigned by the authors, based on a five-point scale (1- very weakly developed; 2- weakly developed; 3- developed; 4- strongly developed; 5- very strongly developed).

Function 1. Entrepreneurial Activities (EA: 4)

Car-sharing schemes are growing exponentially in many cities worldwide. As pointed out in the "Current Market" section, there are many different organisational forms of car-sharing schemes. From the traditional round-trip and station-based to the most recent and innovative free-floating one-way schemes, entrepreneurial activities are growing in this sector. Both start-ups (e.g. Autolib') but also traditional automakers (e.g. BMW (DriveNow), Daimler (Car2Go), etc.) are entering the business of "mobility as a service", enlarging the B2C car-sharing sector. On the other hand, C2C (peer-to-peer) forms of car-sharing are also growing in number and popularity. However, this type of car-sharing is not treated in this narrative as although the principles are similar, the organizational form and impacts of such schemes are quite different than the B2C model focus of this narrative.

Specifically, inferring from the DriveNow case study, it can be highlighted how traditional automakers have started to join the new disruptive wave of service-based mobility, most likely driven by a shade of fear for lagging behind in the future of mobility, and also pushed by the rise of global competition from Chinese Original Equipment Manufacturers (OEMs) and the need to innovate and diversify. On top of that, car-sharing is seen by automakers as an opportunity for promoting EVs and trigger curiosity and familiarization to potential customers towards EVs. Moreover, automotive OEMs are also driven by the interest of aligning their business with municipal and national goals and related policy instruments for decarbonizing the energy and transport systems at different levels.

Focussing on the inclusion of EVs in shared fleets, it can be noted how the induced entrepreneurial activities are quite important when such a scheme is entering a city's market. In order to put in place a proper, dense and diffuse charging network for e-mobility, providers need a guarantee of stable demand and usage rate to achieve the necessary economies of scale for the feasibility of the investment, thus car-sharing may help in this regard by ensuring a given number of EVs in the system. For this purpose, partnerships between electric car-sharing operators, providers of public charging infrastructures and municipalities have proven to be beneficial for the Copenhagen case when timely established; hence entrepreneurial activities in this regard are quite flourishing.

Function 2. Knowledge Development (KDev: 2)

In terms of knowledge development, the needs for further research have been raised from several stakeholders, aiming at obtaining a deeper understanding of the multitude of aspects such a systemic eco-innovation entails. On one hand, developers of EVs are interested in research advancements on the technology side, where developments in battery capacity and charging infrastructures would play a crucial role in cutting the production costs and increase attractiveness of EVs. On the other hand, car-sharing operators and providers of e-mobility infrastructures are both mutually interested in research advancements on innovative business models and public-private partnerships as well as regulatory frameworks to help overcoming barriers at city level in the transport planning for e-mobility. It is important to establish long term stable policy signals and to coordinate the establishment of charging infrastructure along with penetration of electric shared vehicles to overcome the underlined "chicken-egg" dilemma. At the same time, city planners have also a high stake on advancements in research particularly targeting the socio-economic impact of car-sharing schemes, as well as their potential impact on a city's transport system and the modal split. In particular it will be important to gain knowledge in regards to how car sharing system will influence the development in a city's car transport versus other modes in a short and longer term perspectives.

Moving the horizon a bit further in the future, as elicited from the interviews, both municipalities and car sharing operators are keen on understanding how autonomous vehicles would disruptively enter the car-sharing market, and what would then be the implications for both technology, population and city governance and transport planning. The questions and uncertainties though are particularly challenging and yet little research has been done on the topic.

Generally, knowledge development in both strands of electric mobility and car-sharing is evolving rapidly in the last years, attracting research interests from several disciplines given the multi-facets impacts that such systemic innovation will bring in cities and their societies. However, there is little empirical evidence on the impacts of electric car-sharing schemes on transport systems and the related environmental factors yet. Hence monitoring and assessing the impact of such systemic eco-innovation could support the development of local policy goals as a key factor in larger-scale development and diffusion to more cities. Yet, given the adolescence of electric car-sharing systems, time and evidence-based performances will support the necessary research in evaluating and monitoring the impacts of such systemic eco-innovation.

Function 3. Knowledge Diffusion through Networks (KDiff: 4)

The established network of cities worldwide, such as C40, the Covenant of Mayors, ICLEI, and initiatives such as CIVITAS at the European level are playing a key role for connecting cities, facilitate the sharing of best practices and also the learning from possible failures.

At the same time, cities need to contribute to the knowledge diffusion among their citizens, as people's behaviour in regards to mobility choices, especially when the target is a shift away from private vehicles, is rather conservative. Hence, cities may need to work further on the knowledge diffusion about alternative mobility options, targeting especially the share of population which is usually excluded or not interested in such innovations. On the other hand, municipalities must be careful in preventing possible counter-effects, such as increased congestion due to a shift from public transport, cycling or walking, to car-sharing.

Function 4. Guidance of the Search (GoS: 3)

Large diffusion of electric and shared mobility is greatly supported, both directly and indirectly, through the adoption of Sustainable Energy Action Plans (SEAPs) and Sustainable Urban Mobility Plans (SUMPs) promoted at European level through the Covenant of Mayors, which accounts for more than 6,000 European cities, and the Urban Mobility Observatory supported by the European Commission - DG MOVE. Such supportive frameworks play a key role in establishing a fertile ground by providing a continued political will and stable conditions for the stakeholders investing in innovative and sustainable mobility solutions including electric car-sharing systems.

This holds true for many municipalities in Europe, however context-specific features also affects the degree of support needed for increasing the coverage of car-sharing schemes. As elicited from the interview with the local authorities in Copenhagen, their position towards car-sharing systems is rather reactive, and the agenda has very much been driven by stakeholders and lobbyist within the field, which to some extent in contrast to the city policy objectives would appreciate more car transport in the cities in order to promote their own business. In the pyramid of priorities for the Department of Transport of the city of Copenhagen, pedestrians and cyclists represent the top priorities, followed by public transport modes. Car-sharing as a mobility option is seen just above the use of private cars, which obviously stands at the bottom of the pyramid when it comes to the city's sustainable transport planning. On top of that, the municipal plan for reaching carbon neutrality by 2025 as stated in the Copenhagen Climate Plan[10], provide a sound basis for the development of a symbiosis between a larger deployment of EVs and higher generation of electricity from renewable sources.

Hence, for the Copenhagen case, car-sharing operators decided to invest in the city regardless of strong municipal support for such mobility options, but rather attracted by the "green" image Copenhagen has built in the last decade, making it an attractive city for innovative solutions to be showcased to other cities as well.

Function 5. Market Formation (MF: 3)

The figures in the "Current Market" section show that there has been a very fast growth in the car-sharing market both in Europe and also globally in the last 5 years. Moreover, "Future market potential" section also depicts the likely expansion of the car-sharing market during the next 5 years, with a forecasted growth in registered members in Europe from the current figure of 2 million to 14 million by 2021 (BCG, 2016). In order to couple car-sharing growth with a growing number of EVs included in shared fleets, new business models would need to be developed by traditional automakers, new entrants and start-ups as well as the actors involved in the development of the infrastructure network for electric mobility.

In relation to the EU emission targets for non-ETS sectors, the European Commission has issued a technical strategy paper on the transportation sector (EC, 2016), with the aim to support further progress in the market development. Although the paper is not specifically considering market development for electric car-sharing, it includes a number of recommendations for supporting market creation for e-mobility which will also be important to the deployment of EVs in shared fleets. Recommendations span from improving interoperability and standardisation of electric mobility to enhancing customer information through a review of the "Car Labelling Directive" and incentivizing EVs uptake in public procurement. This policy is in accordance with the EU energy sector SET plan and its targets for renewable energy penetration.

Currently, the market uptake of zero emission vehicles in the EU still suffers from limited alternative fuels infrastructure, relatively high sales prices and consumer scepticism as to their suitability for daily use. The highly uneven share of alternative fuel vehicles across EU Member States shows a clear link to national financial incentive schemes. As technology improves and EV prices decrease, zero emission vehicles will be able to compete with conventional powertrains on a more equal footing. However, in the short to medium term, financial and non-financial incentives may continue to play an important role for their market uptake.

Function 6. Resources Mobilization (RM: 2)

The mobilization of resources for the setup of car-sharing schemes varies substantially in relation to the type of car-sharing scheme. B2C car sharing schemes like DriveNow are fully privately financed. Specifically DriveNow is a joint venture (50-50) between BMW and SIXT, who established the DriveNow scheme in 11

[10] Copenhagen Carbon Neutral by 2025. *City of Copenhagen* (available at: http://kk.sites.itera.dk/apps/kk_pub2/pdf/983_jkP0ekKMyD.pdf

cities across Europe. In regards to the Copenhagen case, a broader plan for expanding the infrastructures for electric mobility has been carried on by the regional office through a financial support to E.ON for the installation of charging points across the capital region. The setup of this partnership between the regional authority, the provider of e-mobility infrastructure and the car-sharing providers is a key factor for the successful implementation of electric car-sharing schemes as pointed out by the stakeholders during the interviews.

It is important to recognize that the capital requirements are relatively small and the investor risk is low as vehicles can easily be relocated and little to none investment is allocated to charging stations or other infrastructure, i.e. fixed capital cost bound to a location. This implies that it is relatively easy for new entrepreneurs to enter in the market, and this also been confirmed by the fact that companies have entered and left the market in Copenhagen. That has also been the case of Copenhagen, where one company, Car2Go, left after three years of operation, and the well-established company DriveNow was last supplemented with a new company, GreenMobility, and a new start-up company, Spiri, is planning to enter the Copenhagen scene of electric shared mobility in 2017.

Besides the privately financed car-sharing schemes such as DriveNow and Car2go, other forms of car-sharing have been established throughout European cities, such as community-based schemes and public schemes which rely on different streams of funds, mainly supported by local governments or self-financing throughout the community willing to establish a shared mobility system for their own.

Function 7. Creation of Legitimacy (CoL: 3)

Creation of legitimacy for e-car sharing schemes should be supported by further research developments for gaining deeper understanding of such innovative mobility solutions in order to validate the positive impacts that free-floating-car sharing seems to have on traffic volumes and congestion. Therefore, further evidence would provide a sound knowledge basis for municipalities incentivised to facilitating entrance of new actors in a city's mobility scene as well as supporting financially (e.g. subsidized parking fees) such innovative mobility schemes.

Following recent trends the market for mobility-as-a-service will grow substantially in the next decade, however a crucial factor for supporting the large diffusion of car-sharing systems is their integration into a well-functioning attractive and multi-modal public transport network. That was highlighted and confirmed at the interview with the city of Copenhagen where their view of car-sharing systems is mainly as a mean for covering the "first/last mile" segment of transport demand.

Nevertheless, disruptive innovations in urban mobility are finding several bottlenecks on their way to implementation and upscaling, mainly due to lock-in effects and resistance of established traditional actors in the mobility sector, see for example the continuous fight between Uber and taxi drivers in several cities around the world. Therefore, creation of legitimacy for innovative mobility services such as free floating electric car-sharing schemes would need extensive support from institutions at all levels in order to create a collaborative environment where all stakeholders and innovative mobility solutions can be integrated towards the formation of a sustainable urban mobility ecosystem. Furthermore, increased legitimacy would also require more solid research and other evidence supporting that the car sharing schemes are not accelerating the growth in private cars. Moreover, by looking at the demand side, behavioural changes in mobility preferences will be needed to move towards a new paradigm of mobility, shifting from an ownership-based model towards the concept of Mobility-as-a-Service, hence an access-based model.

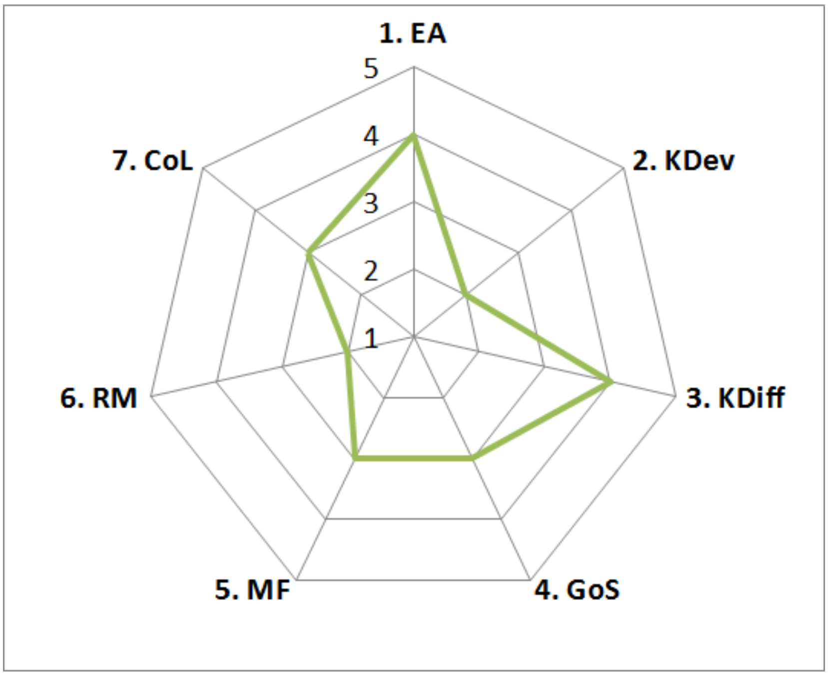


Figure 9. Fulfilment of Innovation System Functions: Free-Floating Electric Car-sharing

Summary: Barriers and Drivers

Throughout the analysis undertaken in this narrative, main barriers and drivers have been identified in regards to the further deployment of electric and shared mobility in cities, in the form of free-floating electric car-sharing schemes. A summary is presented here below:

- Traditional automakers also started to actively participate in the fast growing sector of mobility-as-a-service by establishing car-sharing services mainly in partnerships with car rental companies in a growing number of cities around Europe, and also in the US. By having such big players into the market of service mobility is a driver for large diffusion of such schemes. However, the share of electric vehicles in car-sharing fleets is generally still limited, and the positive impacts on GHG emission reduction and local pollution are therefore limited in many places.
- On average, the higher investment cost for EVs is one of the major barriers hampering the larger deployment of EVs compared to conventional vehicles in car-sharing fleets.
- A major barrier car-sharing operators are facing when it comes to the decision of including EVs in shared fleets is the lack of a dense and diffuse charging network, and investing in such infrastructure is delimited by the absence of long term policy signals for a stable market environment.
- A major operation cost for car-sharing providers is represented by parking fees, unless municipalities could grant subsidies to such schemes on the basis that evidence of congestion relief is provided. Many cities however are increasing parking fees to avoid congestion.
- The well-established networks of cities collaborating towards a low-carbon and sustainable urban development facilitate the sharing of best practices and failures among cities which can learn from each other and supporting the adoption of innovative mobility solutions such as free-floating electric car-sharing schemes.
- On top of that, the existing policy frameworks set through SEAPs and SUMPs at European level and adopted at municipal level provide a fertile ground for investments in innovative solutions in the domains of electric and shared mobility.

- Setting up partnerships between public authorities, charging infrastructures' providers and car-sharing operators has opened up new financing opportunities for upscaling the adoption of electric vehicles in European cities. The Copenhagen case, among others, has been proven to be effectively successful in this regard.
- Incomplete knowledge has within some areas created limited legitimacy of car-sharing schemes, and it has been an important factor in the deployment of car sharing systems as a mobility solution as part of an efficient, integrated and multi-modal public transport network, where shared vehicles play a key role in covering the first/last mile segment of transport demand.

1.5 Further Evidence on the Innovation System

Not relevant for this EBN.

1.6 Policy Implications

Given the setup of free floating electric car-sharing systems, which arise from the convergence of the domains of shared mobility and electric mobility, a number of policy recommendations have been drawn throughout the analysis of this systemic eco-innovation and the interviews conducted with the related stakeholders, highlighting the need for policy-makers to focus on overcoming the identified barriers for facilitating the deployment of EVs within shared mobility schemes in urban centres.

- Decision makers at both national and municipal level are often confronted with conflicting issues and priorities when developing sustainable mobility plans. In order to improve and facilitate the decision making process, impacts of different alternatives should be holistic, transparent and thoroughly assessed. In this regard, electric shared mobility, especially based on free-floating schemes is rather a new concept. Thus, the consequential lack of evidence for the positive impacts such schemes may bring along, is a hindering factor for such schemes in finding the necessary political and financial support from municipalities. In this regard, it is highlighted the need for policy-makers to support research activities to monitor, evaluate and validate impacts of largely diffused electric and shared mobility, especially on car ownership/congestion and local air and noise pollution, and car traffic growth in the city.

- A key factor for attracting businesses into the electric shared mobility domain is represented by the charging infrastructure network. High density of charging stations as well as the type of charging (fast/normal charging) and the accessibility to the infrastructures have been highlighted by the interviewed stakeholders as important factors for ensuring a fertile business environment where electric car-sharing systems can flourish. In order to support and facilitate advancements in this field, it has been identified the need to continuous support for R&I in technology development for charging infrastructures and network development, in order to facilitate the uptake of EVs in shared fleets as well as in the private car market in general. Moreover, as for the nature of the electric and shared mobility domain, new forms of collaboration between stakeholders could support the coordination of investments in both infrastructures and end-user services; hence, the need for the development of new business models for collaboration and partnership between electric charging providers, car-sharing operators and municipalities, in light of the potential car-sharing offers in providing a base demand for e-mobility infrastructures.

- On the mobility demand side, individual choices of which mean of transport to take for moving around a city can be supported through awareness campaigns and behavioural changes in mobility preferences towards decarbonised options of urban transport systems

- Moreover, in order to accelerate the transition towards low-carbon mobility, more stringent vehicle-emission targets at European and national level would be necessary. On top of that, stable long term policy goals at European national as well as local level for the decarbonisation of the transport system would also facilitate the creation of a stable and fertile ground for businesses engaged in the e-mobility and shared mobility market development.

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2 The Utility of Municipal Waste Water in a Green Economy

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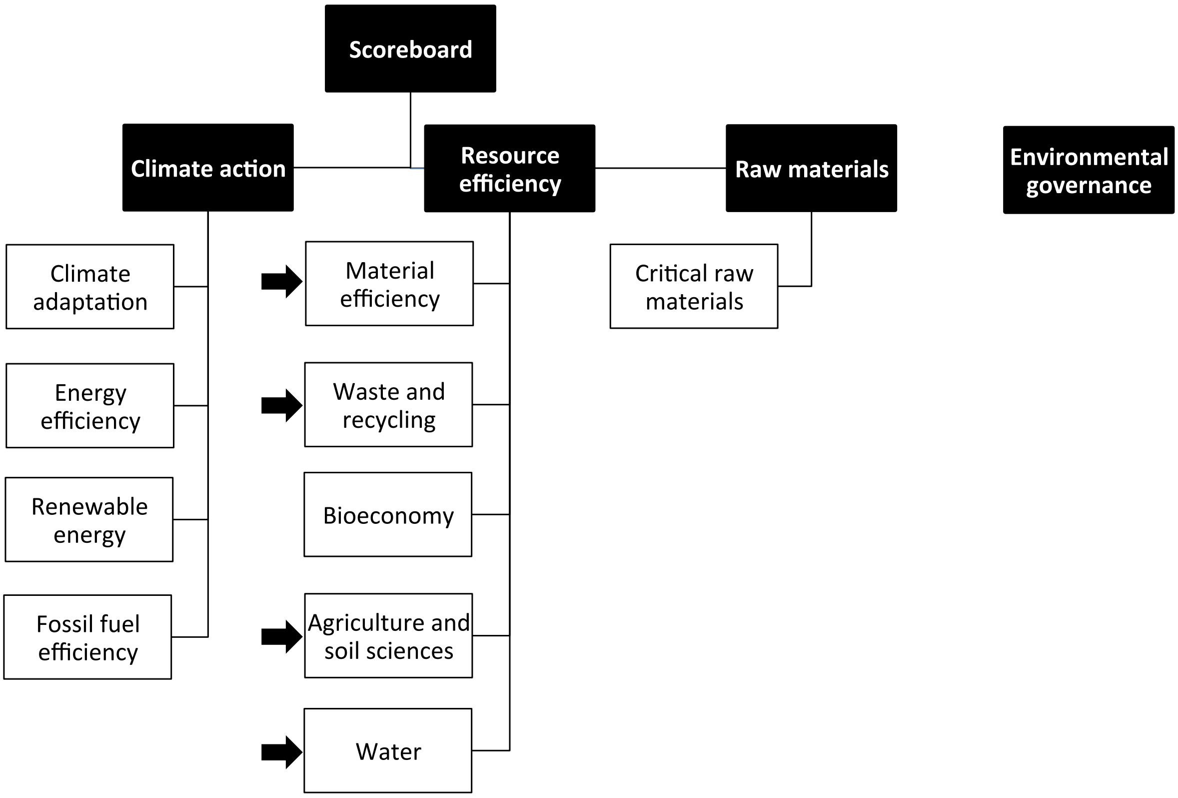
Links with RECREATE Green Horizons Scoreboard



Resource efficiency:
Waste water relates to many aspects of using resources more efficiently

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2.1 The Narrative

Background

Society and businesses are globally trending towards more sustainable behaviour, i.e., as opposed to the conventional 'take-make-consume and dispose' model of growth. Underpinning this development is amongst other pathways the principle of decoupling economic growth and development from the consumption of finite resources, which demands a transition to renewable resources and less dependence on the finite resources. The European Union has actively supported this development, and with the recent introduction of the Circular Economy Action Plan in 2015, the European Commission proposed a concrete implementation plan to pave the way for a more sustainable, low carbon, resource efficient and competitive European economy (European Commission, 2015; 2017). A main objective of this Action Plan is to ensure that the "value of products, materials and resources is maintained in the economy for as long as possible, and that the generation of waste is minimized" (European Commission, 2015).

The prospective economical, societal and environmental benefits of moving towards a more circular economy and away from the linear economic model are striking: According to the Ellen MacArthur Foundation by 2030, Europe expects to see a doubling of economic benefits, 11% growth in average disposable incomes and a halving of Carbon Dioxide emissions (The Ellen MacArthur Foundation, 2015).

Water represents an essential but also constrained resource, which is increasingly stressed in many geographical locations - including Europe - due to pressures from, e.g., rapidly growing populations, rising industrial demand and a changing climate. For example industrial water consumption makes up 22% of global water use (UNWATER, 2012). However, in Europe and North America (2009) the use of industrial water accounts for roughly half of the total national water use, whereas in developing nations industrial water use ranges from 4-12%. This means, according to the World Water Assessment Program, that if industrial demands in developing countries increase to similar rates due to projected industrial development (WWAP, 2009), then the global industrial water use will potentially increase by as much as a factor of five in these countries, increasing pressures on often already scarce water resources even more.

The demand of water for sanitation represents another major source of water consumption worldwide. The spreading of modern flush toilets, connected to wastewater treatment plants (WWTP), has solved severe health and environmental problems that densely populated communities have suffered for thousands of years. With the increasing urbanisation these problems have been made even more burning and turned cities into virtual concentration hubs of nutrient and energy flows carried by water. Globally, urbanisation is accelerating and by 2050, over 60 % of the world's population is expected to live in cities (World Urbanisation Prospects: The 2014 revision). This is likely to imply increasing amounts of drinking water and other types of water of high quality being turned to wastewater in sewage systems, increased consumption of energy and chemicals due to wastewater treatment and that higher concentrations of nutrient leakage will continue to burden water bodies surrounding urban areas.

The potential for optimizing, recycling and reusing (waste) water, including the recovery of useful materials therein, on the other hand is enormous. For example each day, 900 m^3 of municipal wastewater and 9,5 million m^3 of human excreta is generated globally (Mateo-Sagasta et al. 2015, Anderson et al. 2016). Theoretically, the resources embedded in this could irrigate and fertilize millions of hectares of crops and produce biogas to supply energy for millions of households. Likewise, there are often tremendous environmental benefits associated with the proper reuse of water, i.e., as addressed by the EU Water Framework Directive (European Commission, DG Environment, 2000-2017) and the EU Urban Wastewater Directive (e.g. EU Commission, DG Environment, 2010). That said, despite the potential and well-documented benefits of treatment and reuse, managing wastewater is in general still primarily perceived as a cost and, e.g., valuable sewage sludge mostly ends up in landfills or incinerators.

Potential role of wastewater in a circular economy

In the emerging context of a circular and more resource-efficient economy combined with the prospects of ever more stringent national and EU regulation, e.g. as regulated by the EU Water Framework Directive (European Commission, DG Environment, 2000-2017), it is unsurprising that calls for shifts in water treatment and sanitation practices are becoming stronger both from within the European and global community (Brands, 2014). This is reflected by both the public and private part of the water sector, and indeed constitutes some of the key policy objectives proposed by vast stakeholder organizations such as the International Water Association (IWA), European Water Association (EWA), European Innovation Partnerships on Water (EIP Water) as well as national and regional bodies. Likewise, the EU has a long record of supporting related research, innovation and demonstration in the water sector through its framework programmes up to and including Horizon 2020.

As a result, in particular, water, sanitation and wastewater utilities – often in symbiosis with public and industrial consumers – have recently starting to see water as a medium of valuable resources and to identify new roles for themselves in the circular economy. To varying degrees, water utilities in Europe and worldwide have therefore started to take steps towards a new “sanitation paradigm” focused on increasing the local resource recovery and, e.g., the reutilisation of energy and nutrient contents of urban solid waste and wastewater. According to the IWA and confirmed by other key stakeholders and expert interviews the way, European water utilities have mainly addressed the challenges caused by water scarcity, increasing energy prices, environmental pressures and nutrient loading, is through increased emphasis on **demand management**, **resource diversification**, **operational optimisation** and **nutrient recovery** (IWA, 2016). Furthermore, according to the IWA, while water utilities have generally optimized their processes, they have also started increasingly to co-operate with energy producers to reduce operational costs, in some cases to gain extra income flows. That said, the paradigmatic shift towards multifunctional symbiotic collaboration with other industries has been very slow, and the IWA as well as other major stakeholders highlight this as a critical barrier in terms of turning wastewater treatment plants (WWTPs) into efficient engines for the circular economy. Thus, they call out a great need for radical rethinking and “rebranding” of WWTPs as multifunctional “biorefineries”, which provide raw materials, energy and water services, as opposed to the current situation where other than water treatment functions are generally regarded as mere by-products of public water treatment services (IWA, 2016).

Exploiting the utility of wastewater through urban symbiosis

Given the evident economic and environmental incentives, an already strong knowledge base and pushes by the EU as well as from the public and private/commercial sector towards adopting more holistic approaches to current and future challenges related to water and wastewater, the question naturally emerges. Why is the utility of wastewater still underexploited –both in general and in the context of a “green”, circular and resource-efficient economy?

A review of relevant projects from the CORDIS database (http://cordis.europa.eu/; see below), which were funded by the EU through Horizon 2020, FP7 and earlier framework programmes, clearly suggests that the relevant technologies, e.g., for extracting energy and/or nutrients/fertilizers from sewage water are at the moment more or less mature and available due to earlier efforts. On the other hand, such a review also reveals that tools for cross-disciplinary and cross-sectoral collaboration and novel governance approaches towards co-developing business models, linking the supply and demand side, are lacking and is likely to be a main barrier for a systemic transition towards a circular water economy in the area of municipal sewage treatment. This challenge has already been recognized by the European Commission and is currently being addressed in the work programme for 2016-2017 of Societal Challenge 5 through the topical call CIRC-02-2016-2017: Water in the context of a circular economy (see Box 1, Appendix A)

Box 1. Water in the context of a circular economy

The topical call CIRC-02-2016-2017: Water in the context of a circular economy, which is part of the Horizon 2020 work programme 2016/2017 is an innovation action (the full call text has been reprinted in Appendix A) comprised by two sub-calls:

a) **Demonstrating the potential of efficient nutrient recovery from water (2016)**
b) **Towards the next generation of water systems and services – large scale demonstration projects** (2017)

The topical call acknowledges that the "European water sector is very diverse and fragmented", and that it "needs to revolutionise the way public and private actors work together so as to address water-related challenges and seize on opportunities strengthening a demand-driven approach". It goes on to propose that a "systemic approach, incorporating both the physical structure of the system and the rules governing the operation, performance and interactions of its components, could address those issues in an integrated manner. Such an approach should go beyond the pursuit of wastewater treatment and reduction of water use to inspire **technological**, **organisational** and **social innovation** through the whole value chain of water (i.e. water as a resource, as a productive input and as a waste stream), moving towards a circular economy approach".

While the (a) sub-call in line with the majority of previous EU projects seems mainly aimed at developing new technological innovations for the water sector, part (b) addresses specifically the issue of organisational and social innovation, the need for developing new collaborations, business models and value chains.

In the following, we have made the same distinction between *technological*, *organisational* and *social innovation* as indicated above, and we analyse the value adding potential, along with the related drivers and barriers, of innovative **urban wastewater symbiosis,** with a primary focus on an organisational and social perspective. As found from, e.g., reviewing previous and on-going EU projects funded in the water area, the potential of such innovations has so far been poorly addressed and demonstrated. It is not meaningful, however, to separate this discussion entirely from the potential of the underlying technologies, since the economic and environmental potential of such symbiosis will obviously rely on the availability and efficiency of, e.g., these technological advances. Hence a large part of the data underpinning our analysis naturally stems from existing technological demonstration, e.g. as mediated by national or EU-funded projects.

In a transition to more sustainable city operations with the adoption of new technologies and management practices, it is clear that organisational and social innovations are urgently needed to facilitate the shift from linear to circular urban metabolism (Wielemaker et al., 2016). In this EBN, we assess (based on data drawn from the European Research Area) the potential of novel *urban wastewater symbiosis* (Lenhart et al., 2015) between water utilities, chemical industry, fertiliser industry and energy production, i.e., in terms of turning municipal wastewater into profitable "waterial" through, e.g., multifunctional waste-to-energy and waste-to-fertilisers business ecosystems. Developing such a symbiosis is not an easy, technological fix emerging after feasible technologies are available. Its prerequisite is the ability of the operators of different activities, pursuing different agenda in different sectors to align their interests too. Similarly, the development of actionable policies and pathways to guide the transition for water utilities, their allies and consumers will be crucial, i.e., pathways which pay attention to the regulatory and market requirements that can accelerate and scale-up recent scientific and technological advances (e.g. IWA, 2016). Hence while progress has been made in optimizing the utility of wastewater, at least two significant drawbacks remain: an impeding regulatory environment and opaque market conditions hampering the market penetration of sludge derived products and services. Furthermore, the rearrangement of actor networks of linear water and included material flow towards circularity demands for new practices of information sharing (data sharing platforms), material stream traceability, infrastructure sharing, new models for conventions and agreements between different partners, building consumer trust for new products and new end product distribution networks. As has been noted by IWA experts and other interviewed experts participating in this study, this also requires innovative governance approaches. In particular, attention should be paid on organizational arrangements enabling to overcome the asymmetries between different potential symbiosis allies in terms of their dependence on other symbiosis partners, share of e.g. infrastructure expenditure, market position, risk taking and abilities to bear risks and varying expectation concerning payback time or return of investments

Methodology

The principal objective of this assessment has been to synthesize and communicate relevant information to facilitate the implementation of, e.g., projects funded under the abovementioned topical call CIRC-02-2016-2017, support the development of relevant policies with the Directorate General of Research & Innovation, and through this the scoping of Societal Challenge 5 and future initiatives.

The economic and environmental potential of urban symbiosis is well documented and by its definition engages traditionally separated entities (industries, water utilities, municipalities, etc.) in a collective approach to a competitive advantage involving physical exchanges of materials, energy, water and other by-products; its key is collaboration and the synergistic possibilities offered by close geographic co-location (Chertow, 2004). In the following, we introduce present and emerging business cases drawn from the European Research Area, indicating the potential for urban wastewater symbiosis to provide business opportunities and public benefits for various actors. We have also conducted a review on the R&D initiatives supporting these activities. Based on these we discuss the needed next steps in terms of R&D initiatives and governance efforts to overcome the organizational lock in and societal and market constraints preventing the full exploitation of possibilities offered by recent technological advances.

As part of preparing this narrative analysis, the authors conducted extensive desk research, collecting qualitative and quantitative evidence from relevant national and international sources e.g. primarily reports, minutes of meetings and workshops, strategy documents and journal papers (a subset of these sources are listed below). The focus of this research was not to detail recent technological innovations in the field of water treatment but rather to collect and highlight experiences with different business and/or collaborative models for optimizing the utility of water in a green and circular economy. These were drawn from existing European and North American cases of industrial/urban symbiosis. Furthermore, we also conducted an extensive review of recent and on-going EU research and innovation projects in this field to get a comprehensive overview of cumulated knowledge base.

As a second step, i.e. in order to validate our findings and to bring in current stakeholder perspectives, the authors then conducted a series of semi-structured interviews with plant operators, key experts and other relevant stakeholders from the private and public sector. Third, based on the preliminary recommendation from our project officer, representing the Directorate General for Research & Innovation, we carried out a review of relevant projects from the CORDIS database (http://cordis.europa.eu/;), which are/were funded by the EU through Horizon 2020, FP7 and earlier framework programmes. In addition we have also added information from the RECREATE Green Horizons Scoreboard to support our narrative analyses.

Lastly, a thematic workshop involving altogether 31 stakeholders was organized in the city of Tampere, Finland, in collaboration with Dwellers in Agile Cities project, funded by the Academy of Finland Strategic Research Council. The participants ranged from frontrunner industries (e.g., Outotec, Gasum) to SMEs operating in the chemical industry, fertiliser industry and equipment supply, public authorities, city planners, water utilities and NGOs exploring possibilities to organise urban wastewater symbiosis in a new urban development area. In the outcome from this workshop many concrete barriers and drivers for establishing urban wastewater symbiosis can be identified, and accordingly also a range of relevant policy recommendations were formulated.

2.2 Understanding the Innovation System

The Innovation

Urban wastewater symbiosis creates an organisational model for interdependent multi-actor partnerships for efficient exchange of information and utilisation of side streams and infrastructure of wastewater treatment. In many cases, urban waste water symbiosis also requires new alliances with solid waste management in terms of coprocessing solid waste and waste water sludges thus expanding the symbiosis not only to processing of by-products of wastewater treatment but also to develop alliances for dealing with a variety of waste material feedstocks across sectoral boundaries. By adding, e.g. a biorefinery, wastewater treatment goes from a public cost factor to a value product.

Over the last decades, in parts due to the increasing needs for infrastructure investment caused by ageing sewage systems, strict regulations for phosphorous recovery, rising energy costs and developments in the energy production technologies, promising concepts of multifunctional wastewater treatment ecosystems have started to emerge both in Europe and in the US. In these ecosystems, sewage sludge, which is the energy and nutrient rich by-product of WWTPs is turned into a raw material for fertiliser industry, energy production and chemical industry. Moreover, promising technological and organisational innovations have been introduced to solve the problems caused by linear urban metabolism and to promote circular metabolism in which output of one process is an input to other processes. The aim of these innovations are to collect, transport, distribute and treat wastewater, possibly together with solid organic waste, to reuse and recycle water more efficiently (e.g. using water streams of different qualities and composition for different purposes), recover resources, reduce energy costs of wastewater treatment and to reduce the negative environmental impacts of wastewater treatment. In other words: to turn wastewater into an asset and to transform the otherwise costly wastewater treatment process into a value-adding biorefinery and/or energy production facility for the benefit of the economy and the environment.

WWTPs around Europe and the US have increasingly started to invest in energy production and to collaborate with energy companies to utilise the energy production potential of wastewater, directly exploiting the heat content of the water and/or unlocking the energy content of sewage sludge, making it a valuable feed for biogas production in anaerobic digestion. Furthermore, the recovery of phosphorous and other nutrients from wastewater is increasingly conducted in WWTPs. These are, however, only the first steps on the way to turn wastewater into “waterials”. A further step in the recovery of precious materials of wastewaters could be to process the digestate of biogas production into fertilisers and industrial chemicals. To do this efficiently however requires radical rethinking of wastewater management as an initial point in a broader industrial value adding process. Thus, a range of experts from the water sector, including the IWA, which were confronted, have suggested that the current development and rate of upscaling in this area is very slow, and that recent initiatives almost entirely focus on improving the economic and environmental performance of the individual WWTPs.

Box 2. Selected value potentials of municipal wastewater

- Nutrient recovery (phosphorous recovery, struvite precipitation)
- Cellulose recovery and production of platform chemicals for e.g. bioplastics industry
- Biogas production (anaerobic digesters)
- Biochar production (soil conditioner)
- Soil conditioners and fertilisers (combined to biogas production – incineration, composting of digestate, biochar production)
- Electricity production (fuel cell technology)
- Algae cultivation for feed production and chemical industry (bio-oil, bio-degradable plastics, ingredients for cosmetics)
- CO_2 for food industry

Current attempts at closing the water loop while at the same time enabling *urban harvesting* (Wielemaker et al., 2016) through cost efficient and value adding processing of various materials (see Box 2) demand novel business ecosystems and innovative partnerships between water utilities, energy companies, chemical and fertiliser industry; in some cases also the food industry can be involved. A seminal example of this type of partnership in industrial context is the industrial symbiosis in Kalundborg, Denmark, which is often highlighted as the original "textbook" case and one of the most comprehensive of its kind in the world (e.g. Jacobsen, 2006 and references herein).

The symbiosis in Kalundborg brings together the local wastewater treatment plant, municipality, and co-located companies, including a 1,300-MW (2002) power plant (Asnæs), an oil refinery (Statoil A/S), a biotech and pharmaceutical company (Novo Group), a producer of plasterboard (Gyproc Nordic East), and a soil remediation company (Soilrem A/S). Similar examples of collaboration between WWTPs and energy production and fertiliser producers centred around wastewater treatment can be found in particular in Europe and the US though mainly of lesser complexity.

Despite the obvious advances the development of generally applicable and scalable business models for cross cutting collaboration between different industries and public utilities are yet to be innovated and as result many such business efforts effectively still remain in the prototype or start-up phase. Hence it is still arguable (as in the case of Kalundborg; see below) whether many of the existing industrial symbiosis relationships can be attributed solely to market-driven arrangements or whether they evolve as a consequence of factors beyond pure market forces. As a result finding new collaboration models for different business ecosystems to interact as well as identifying pathways for municipalities to better support the emergence of novel wastewater business ecosystems is generally deemed necessary to ensure the upscaling and unlocking of the potential of new technological innovations related to the recycling and reuse of water.

The concept: Urban wastewater symbiosis

In urban wastewater symbiosis, which can be considered a special case of industrial symbiosis, the emphasis is not on a technological novelty or ground breaking business innovation, but on a rearrangement of actors in a specific local context to allow novel value creation opportunities for partners and to enhance efficient exchange of information, material and energy flows and facilities. This kind of symbiosis is about systemic change creating mutual dependencies and benefits and as such represents a fairly radical kind of innovation.

Urban wastewater symbiosis is based on cooperation between plants to allow for the safe treatment of wastewater as well as the efficient use of different by-products, typically by taking advantage of the geographical proximity of different industrial functions. The aim of this type of industrial symbiosis is to create (physical) linkages between different industrial organizations in order to improve environmental and resource efficiency (e.g. Chertow 2004) and to promote 1) by-product reuse, 2) infrastructure sharing and 3) joint service provision. To reach these functions in an urban context and to align the social goals (guaranteeing safe and efficient wastewater treatment) with low costs, while fulfilling also the economic goals of the companies, Lenhart et al. (2015) has proposed that new public-private partnerships are needed, e.g. to enable resource exchanges between industries and urban infrastructure functions (Lenhart et al. 2015).

The basis of urban wastewater symbiosis as mentioned above are new technological innovations, which allows for turning of WWTPs into energy factories and biorefineries in which nutrients and minerals are extracted and energy content is efficiently utilized. To exemplify the production of recycled phosphorous fertilisers as part of wastewater treatment is currently on the rise following recent advances in phosphorous recovery technologies. Also, solutions to utilize ammonia removed from water in the production of ammonium sulfate fertilizer have become viable. Another important part of wastewater symbiosis is the production of biogas, which is the result of sewage sludges being processed into energy through anaerobic digestion and thermal hydrolysis. Anaerobic digestion is a bacterial decomposition process that stabilizes organic wastes and produces a mixture of methane and carbon dioxide, which is a valuable energy source. Furthermore, it sterilizes the sludge. The water content in sewage sludge is high, and hence typically almost 50 % of the energy produced though wet digestion processes are needed to dehydrate the sludge itself. Using efficient techniques for drying and dehydrating the sludge are therefore critical points in this process. The remaining energy produced can be utilized e.g. in other wastewater treatment processes to reduce the overall energy costs of plant operations. In cases where the energy production exceeds the internal needs of the WWTP the excess production can furthermore be injected into the public grid and/or shared through direct links with local (e.g. industrial) energy consumers. If biogas is produced, this product can be further upgraded into more advanced fuels. The digestate, which is a conventional by-product of water treatment processes, is currently often landfilled or incinerated, producing yet another cost factor. Having a high nutrient content and favourable microbes for soil amendment, however, it can be further processed for soil conditioning products (e.g. biochar, fertilisers etc.). Upgrading the sewage into components of biopolymers aimed at the chemical industry is also a possibility option. Lastly, it will in some cases be feasible to use the CO_2 by-product to improve growth conditions in greenhouses if located near the WWTP.

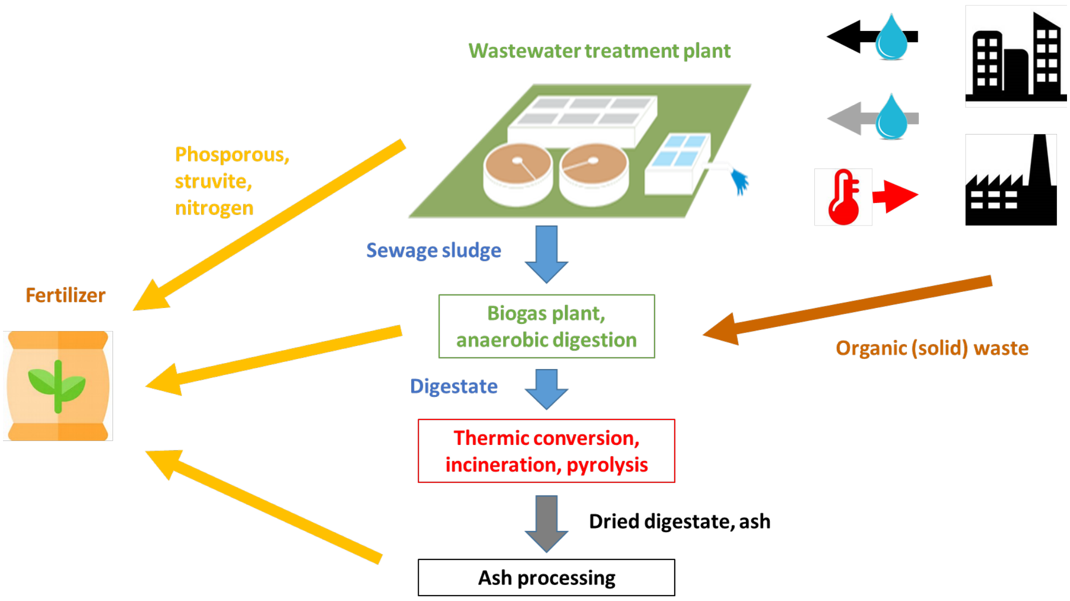


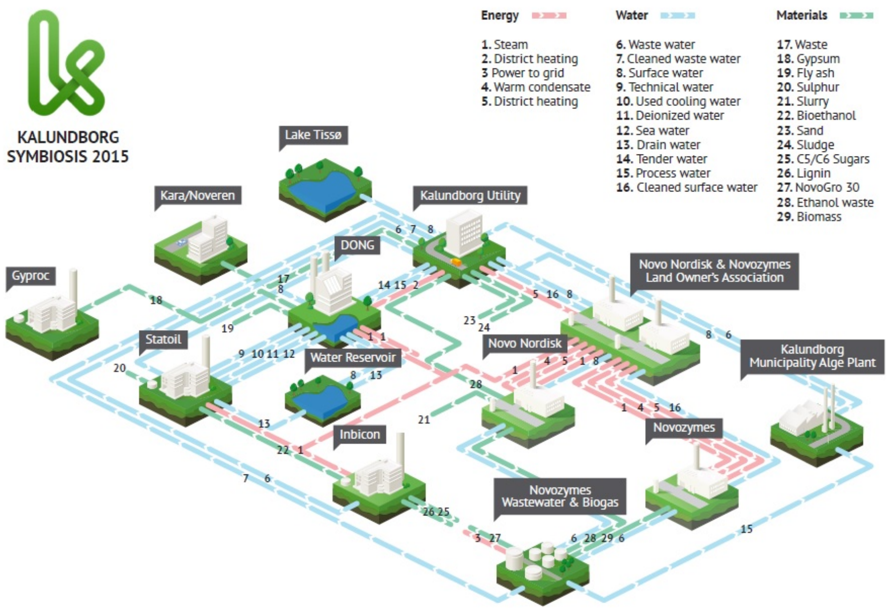
Figure 10. The concept of urban water symbiosis

As indicated above, most of the abovementioned technologies needed for upgrading WWTPs to treat the sewage water accordingly already exist, and have been found to be largely cost-efficient. Thus, over the last decade many WWTPs have already embraced some of these options e.g. energy production from waste, and considerable experience have been achieved. Rather, the current bottleneck for broader urban wastewater symbiosis - and consequently a fuller systemic utilization of the potential of sewage water - seems to be lack of relevant competences, interest and networks of WWTPs to enter into by-product markets and to step outside their own expertise area in developing technologies and business networks for novel products. While wastewater treatment companies are in principle all set to enter the potential new markets, such activities are not their traditional core business and as a result there is still great reluctance in the sector to embrace these opportunities. Also, the costs of establishing the infrastructure needed to set up, for example biofuel distribution or the marketing and logistics costs of distributing soil amendment products, are usually significant and pose a steep barrier for further product and service development. Conversely, where successfully implemented, extensive partnerships have generally been established between companies with specific expertise e.g. in upgrading wastewater, efficient distribution networks and logistics and/or marketing the end products to increase the profitability of e.g. sewage-biogas-fertiliser symbiosis. In addition, to increase the economic viability of sewage sludge processing co-digestion with other organic wastes would, in many cases be reasonable. This, however, requires collaboration with waste management sector. In addition, regulatory restrictions may constrain co-digestion.

Circular urban solutions

While WWTPs across Europe and the US have increasingly started to unlock their energy production potential, and novel technological innovations have emerged for utilizing the valuable substances of wastewater e.g. to upgrade sewage sludges, it is evident that the value potential of wastewater is still far from realized as was also recognised in the Horizon CIRC-02-2016-2017: Water in the context of a circular economy call. Hence, symbiotic business relationships mimicking the complexity in Kalundborg, which as mentioned above is often used as the 'blue print' for urban symbiosis, continue to be rare.

The following figure shows an outline of the Kalundborg solutions with arrows depicting the various material flows among the companies based on water, solid waste, or energy exchanges, respectively. Wastewater and cooling water from the refinery are reused at the power plant: the wastewater for secondary purposes, the cooling water as feeder water for the boilers producing steam and electricity, and also as input water for the desulfurization process. In turn the desulfurization process produces industrial gypsum, which is used in the production of plasterboard at the co-located Gyproc factory, partly replacing the use of natural gypsum. The co-generating power plant also produces heat for the town and steam for the Novo facility and the Statoil refinery. The Novo facility is exclusively supplied with steam from the power plant, whereas the refinery has production-related in-house steam generation capacity, partly supplied by preheated boiler water from the power plant in a total-supply-security system. Heated cooling water from the condensation process at the power plant is piped off to a nearby fish farm, increasing the efficiency in the farm, as the heated cooling water ensures full-scale production of the fish throughout the year. Lastly, solid by-products such as fly ash from coal combustion, sludge from the local WWTP, and biomass from biogenetic fermentation at the Novo facility are recycled in various ways, both locally and non-locally. In total, the urban symbiosis in Kalundborg counts more than 25 different by-product exchanges in operation related to water, energy and material flows.



Source: http://www.symbiosis.dk/diagram

Figure 11. The urban (industrial) symbiosis in Kalundborg

There are several reasons for the apparent failure in upscaling the innovations tested in Kalundborg and similar large-scale demonstrators of urban (wastewater) symbiosis. One reason is the integration of previously separate systems characterized by their own (economic) goals, infrastructures, actor networks and organizational cultures (Vernay & Mulder 2016). Integrating such systems typically means overcoming several types of organizational and cultural barriers like missing information on available inputs, lacking legal frameworks or trust between partners or the lack of infrastructure-enabling collaboration. Furthermore, urban infrastructure is very path dependent. Existing water management infrastructures including sewage networks, WWTPs and building solutions are often not been planned or constructed in ways which underpins the seamless integration of resource streams, including new and/or more efficient management of wastewater and the recovery of its value potential. Systemic upgrades which would better support the implementation of urban symbiosis initiatives include for example the source separation of grey and black water or vacuum toilets for reduction of water usage. Moreover, comprehensive distribution networks connecting WWTPs, companies and neighbourhoods are needed to utilize e.g. the excess heat of wastewater in production processes or to provide central heating for buildings.

Business models

As focal points of concentration of nutrients, energy and minerals in urban environments, WWTPs serve as a platform for a variety of different value adding industrial activities. Because the business ecosystems of "wastewater to 'waterial'" are typically comprised by multiple actors including companies and public actors with different value creation strategies, the related business models vary. In general, key value offers are based on:

(1) Off-setting the costs of the wastewater treatment itself, particularly energy costs and costs of handling bio-solids (can account up to 30% of the costs of WWTP),
(2) Revenues made out of sales of processed products, services and raw materials.

In some cases, revenues can also be generated from sales of (processing) technologies. Table 1 summarizes a few marker examples of the different types of value offers and business models inferred from wastewater treatment.

Table 3. Examples of sewage water based business models

Off-setting costs
Marselisborg plant, Aarhus, Denmark (http://www.aarhusvand.dk/international): Conventional centralised wastewater treatment is very energy intensive and thus energy consumption of energy is a major cost factor. The Marselisborg plant in Aarhus which annually treats more than 30 million cubic metres of wastewater and serves 300 000 customers runs its operations with energy produced from sewage combined with household waste. Furthermore, it produces excess heat, which is sold to the public grid and meets the energy consumption of 500 households.
The **Tilburg WWTP and "Energy Factory" in the Netherlands** was constructed as part of an ambitious Dutch national strategy to exploit the resources of wastewater and to make local water authorities the largest producers of green energy in the Netherlands. The Dutch national strategy aims to produce green energy for 500,000 households and to reduce emissions from CO_2 equivalents corresponding to the load of approx. 200,000 cars. The Tilburg project was made operational in 2015 and is based on production, R&D and marketing pillars. Technically, the principle of the energy factory is relatively simple, the sludge from the wastewater treated in an thermal hydrolysis plant and the activated sludge process is collected in a digester. In the digester it ferments, and biogas is produced and used as a local energy resource. The WWTP in Tilburg produces approx. 9 million m^3 biogas, which makes the plant energy neutral, and a surplus of about 3,8 million m^3 biogas is generated.
Newton Creek Wastewater Treatment Plant, New York, United States: In 2013, the Newtown Creek Wastewater Treatment Plant started to receive pre-processed organic food waste from the state's waste management to further process it with wastewater sludge to increase the production of biogas. The excess biogas is then upgraded to pipeline quality and injected into the public grid for residential and commercial use in collaboration with the national grid authorities. This partnership decreases the costs of waste management costs and the potential energy production equals the heating nearly 5,200 New York City homes[11].

[11] http://www.nyc.gov/html/dep/html/press_releases/13-121pr.shtml#.WQHW7k1PrIU

Off-setting costs combined with revenues made out of sales

Danish Mash Biotech, Denmark (http://www.mash-biotech.com) has successfully entered the rapidly growing Asian markets by providing WWTP services for sludge treatment and oil production from sewage sludges. The company offers WWTPs as a turnkey solution for the final processing of sewage sludges without fees and produce oil, which is sold to markets. The WWTPs also get their share of the fertilizer product, which is the byproduct of oil processing.

Recently, **Soilfood from Finland (http://www.soilfood.fi)** has rapidly expanded on the markets of recycled fertilizers and soil conditioning services in Finland by providing biogas companies with dedicated services to take care of the digestates. Their business model is based on efficient logistics to collect digestates and a variety of other organic side streams from agriculture and forestry combined with broad distribution network of processed products among farmers.

ASH DEC Umwelt AG from Austria has developed technologies to incinerate sewage sludge in such a way that pathogens and pollutants are destroyed along with further thermal and chemical treatment of the ashes into fertiliser product, which contains several nutrients. These fertilisers are sold under the brand “PhosKraft”.

Revenues made out of sales of processed products, services and raw materials

Canadian company Ostara (www.ostara.com) is specialised in phosphorous recovery technologies and offers these services for WWTPs. One of its services is a phosphorous recovery technique to remove struvite out of wastewater. In addition to the provision of technologies, Ostara also distributes struvite for fertiliser markets under the brand “Crystal Green”. It shares the revenues with the partnering WWTPs.

Veolia Cella concept. Veolia Water has developed, together with several WWTPs situated in different countries (Belgium, Netherlands, Denmark), technologies to produce biopolymers as part of the wastewater treatment process. The first biopolymers were produced by Swedish subsidiary AnoxKaldnes in prototype plants in Sweden and Belgium in 2011. The end product, polyhydroxyalkanoate (PHA) polymers, can function as raw materials for bio-degrable plastics production. This innovation is not yet commercialised but has been shortlisted as one of the most innovative new technologies by **Industrial Alliance Awards**[12]

2.3 Estimation of the Investment Case

Investment Strategy

As indicated above both new and existing WWTPs have a growing emphasis on resource recovery and reuse of water. Furthermore, several companies have entered the markets of processing and upgrading the by-products of sewage treatment thus searching for alliances with water utilities. This is readily confirmed by the International Water Association (IWA, 2016), the rapidly expanding number of operational facilities worldwide as well as our stakeholder interviews. Current market predictions for wastewater management unanimously indicate that the demand for products and services derived from municipal wastewater will continue to grow driven in parts by economics and increasing demand for materials efficiency and in parts by the growing environmental pressures on water resources, exacerbated jointly by the increasing global population and the impacts of climate change. The information collected attributes this to several factors, including:

[12] https://www.wateronline.com/doc/revolutionary-tech-makes-plastic-from-wastewater-0001

(1) Expected future water scarcity. According to the Intergovernmental Panel for Climate Change (IPCC) the number of people living under water stress in Europe will rise from 28 million to 44 million by the 2070's (Alcamo et al., 2007).
(2) The shift from a "fossil economy" towards a more sustainable and resource efficient economy, which is largely bio-based.
(3) A strong policy focus on environmental protection at both national and international levels and the according implementation of a wide range of measures to reduce or prevent e.g. the pollution of water bodies, as addressed in the EU Water Framework Directive.

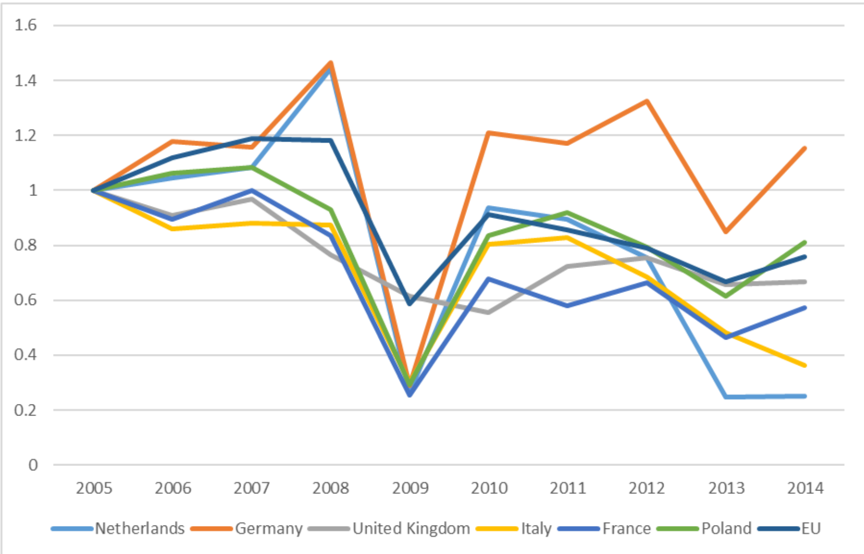
All three goals are currently advocated through several policy programmes driving towards same direction. For example the principal objectives of the EU Water Framework Directive and EU Urban Wastewater Treatment Directive is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors. In particular the latter concerns the collection, treatment and discharge of domestic wastewater, mixes of wastewater and wastewater from certain industrial sectors. The costs of upgrading current water treatment procedures in all EU countries to compliance level were assessed by COWI in a recent report from DG Environment (European Commission, DG Environment, 2010). The economic assessment revealed investment needs amounting to about 17 billion EUR starting from 2005/2006 and until the relevant compliance date. These estimated investments only count towards service improvement and extensions; renovations; re-investments and operations (and minor maintenance) of the current infrastructure. Establishing new infrastructure and WWTPs are not included.

Concerning the *specific market potential* for concepts of urban sewage water symbiosis the authors were unable to find dedicated market data. Reviews of relevant literature, workshop results and interviews with industry stakeholders however defines the expected market potential as potentially "enormous". Thus, the future market potential of urban sewage waste symbiosis relates to a number of trends including accelerating urbanisation and increasing concern of water protection (BCC Research 2016, Research and Markets 2016.), which are all expected to strongly stimulate the growth of such a market:

- **Increasing need for sanitation investments:** According to market estimates by analysts Frost & Sullivan (2015) wastewater utilities in Europe and the US are aging and investments for new ones are needed. Aging wastewater systems already generate problems in many locations and incurs considerable extra costs. Estimates by the US Environmental Protection Agency (2016) suggests that correction measures, replacement of existing conveyance systems and the installation of new sewer collection systems will account for 52% of the US$271 billion in investments needed to meet the country's wastewater infrastructure needs (United Nations Water Development Report, 2017). These investments need to be combined with new technologies allowing energy production in WWTPs and co-digestion of household wastes in integrated biogas plants and hence provide a unique opportunity for adopting novel approaches.

- **Export opportunities for Asia, India & Africa:** China and India both offer excellent market opportunities for export of technology supporting the production of power and fertilisers from sewage water. Generating power from sludge is an official part of China's emission reducing strategies, which aim to tackle both the increasing problems caused by massive amounts of sewage and the severe air pollution caused by fossil (coal) based energy production. Several cities, including Beijing, Changsha, Chengdu and Hefei are currently investing in new integrated sludge to power installations (Zhong et al. 2016). In addition, a lot of communities in developing countries in Africa are currently not covered by centralised sewage systems, instilling a strong demand for decentralised sanitation solutions in many place allowing also for energy production and nutrient recovery. For those conditions scalable technology and development of low-cost designs as well as the provision of turnkey solutions, which implements the complete value chain from the separation of bio-waste separation to the production of bio-based methane for grid injection and fertilizer production.

- **Nutrient markets:** Europe is heavily dependent on imported phosporous. 90% of the annual demand for phosporous is currently met by imports from politically unstable areas in Middle East and Africa. On the other hand, recycled fertilizers are at the moment not competitive, since the market is dominated by the very cheap mineral fertilizers from these areas. Moreover, the overall demand has declined in recent years. Even so, as phosporous is an exhaustible resource which is estimated to deplete with the next 50-100 years (e.g. Van Vuuren, 2010), its value is expected to rise.



Source: RECREATE Green Horizons Scoreboard. The apparent consumption is calculated as Production + Imports - Exports. The figure shows the observed trends for selected European countries plus the EU as a whole. The largest share of phosphorus is used as basis for nitrogen-phosphorus-potassium fertilisers, globally utilised on food crops. The figure shows generally a downward trend consistent with a reduction in the consumption of phosphorous, however, from 2013-2014 this trend seems to reverse. Due to lack of data beyond 2014 this trend cannot be validated.

Figure 12. Apparent consumption of phosphate rock expressed in tonnes

- **The global increase in energy consumption combined with policies supporting renewable energy**: Increasing concerns of negative environmental impacts of fossil fuel utilisation and related policies supporting renewable energy sources are also expected to drive the market for biological waste-to-energy technologies. According to market analyses by BCC Research concerning waste to energy markets, industrialized countries of Europe such as Germany, Belgium, Denmark and France have a competitive advantage in these technologies, granting European companies favourable market prospects globally. This advantage is confirmed by data presented at the Green Horizons Scoreboard (see Appendix B), which further nominates, e.g., the Netherlands, as a market leader within the area of water. BCC Research have also estimated that Europe currently leads the global market for biological waste-to-energy technologies with annual revenues of $1.1 billion in 2013 and that the European market is expected to reach $2.0 billion by 2019, growing at a compound annual growth rate (CAGR) of 9.7% from 2014 to 2019. Asia-Pacific is expected to be the fastest growing regional market for biological waste-to-energy technologies with estimated growth of 13.8% from 2014 to 2019. Finally, Table 2 indicates the development of integrated biogas production in WWTPs in Europe, based on a number of sources (see caption).

- **Shift from fossil based materials to bio-based products:** The attempts to move away from fossil based materials and to prevent e.g. plastic waste is expected to open up future markets for bio-plastics, providing market opportunities for emerging solution for sewage water-to-bio-polymers. According to BCC Research Report on global markets for biorefinery products (BCC 2017) bio-based chemical markets are increasing rapidly and are expected to continue to expand in the short term (at least until 2021), largely as a result of a growing awareness of the benefits of being able to market renewably sourced bio-products.

- **Regulatory drivers including prevention of landfilling of sewage:** reduction of landfilling opportunities in several European countries increases the costs of sewage sludge treatment for municipalities. According to recent work by BCC Research (2016) this is expected to drive the biological waste-to-energy technology market at least in the short term.

Box 3. Current production of biogas from sludge in Europe

Among the EU countries, (see Table 2) the production of biogas from sewage sludge in WWTPs has increased steadily over the last decades. In fact since 2009, the biogas production in WWTPs account for over 10% of the total biogas production in the EU. The range of utilizing sewage sludge for biogas production among the different countries is, however, very large. In the lower end range the production is around 1-10 GWh/yr per million inhabitants, e.g. in countries like France, Italy and Spain, representing a highly unused potential. Other countries such as Denmark, The Netherlands, Sweden and Switzerland are already utilizing their sewage sludge biogas potential to a greater extent, exhibiting production rates over 40 GWh/yr per million inhabitants. The potential for increasing biogas production from sewage sludge in such countries is therefore limited. That said, organic fractions of other waste streams can be co-digested to increase the biogas yield. These are e.g. waste-streams from industries, agriculture or the organic part of municipal solid waste. Also, a significant share of the digester capacity in WWTPs is unused on an annual basis in many countries, e.g. around 20% in the case of Germany, where co-digestion could ensure greater capacity utilization and increase biogas production (Schwarzenbeck et al. 2007. Currently, most of the sewage sludge biogas production takes place in centralised municipal WWTPs. Certain industries may have very specific wastewater treatment requirements, making it more economically feasible to carry out water treatment in smaller scale decentralized WWTPs located on-site or nearby.

Table 4. Measures of total biogas production and biogas from sewage sludge in the European area

Country	Year of estimate	Total biogas production GWh/yr	Biogas production in WWTPs GWh/yr	% of total production	Utilization of potential: GWh/yr/capita
Austria	2009	1,919	220	11%	26.5
Belgium	2009	1,448	24	2%	2.2
Czech Republic	2009	1,511	392	26%	37.7
Denmark	2012	1,218	250	21%	44.6
Finland	2013	567	126	22%	23.3
France	2012	1,273	97	8%	1.5
Germany	2014	41,550	3,050	7%	37.9
Greece	2009	682	142	21%	12.8
Hungary	2009	357	120	34%	12.0
Italy	2009	5,167	58	1%	1.0
Norway	2010	500	164	33%	32.5
Poland	2009	1,140	675	59%	17.7
Slovakia	2009	189	172	91%	31.9
Slovenia	2009	260	35	13%	17.5
Spain	2009	2,127	116	5%	2.5
Sweden	2013	1,686	672	40%	70.4
Switzerland	2012	1,129	550	49%	68.8
The Netherlands	2013	3,631	711	20%	42.3
United Kingdom	2013	6,637	761	11%	11.9
EU total	**2009**	**97,059**	**11,671**	**11%**	**23.2**

Source: Entries from 2009 are from Bodik et al. 2011. Other entries are from IEA Bioenergy Task 37: Sustainable biogas production in municipal wastewater treatment plants.

Environmental and Social Benefits

The environmental benefits of adopting the described technological innovations within a context of urban sewage water symbiosis are obvious and have already been mentioned. They include:

- Reductions in public and industrial water use and/or substitutions of water of drinking water quality with water of lesser quality, resulting in smaller pressures on critical water resources.
- "Green" energy production from wastewater leading to energy savings in WWTPs, reducing the footprint of CO_2 equivalents, potentially substituting energy produced from fossil sources with an environmentally superior product.
- Overall reductions of waste produced in production processes and hence on associated environmental pressures.
- Reduced transportation costs as well as the associated CO_2 footprint. Sludge is easier to dehydrate after the digestion process and dry matter content can be increased, reducing the cost of transportation e.g. of the residual solid fraction to incineration plants.
- Decreasing needs for chemicals in wastewater treatment, i.e. due to reductions in the amount of sewage water.
- Facilitating a closed nutrient loop from the agricultural sector back to natural soils in the form of

fertilizers. In addition, soil improvement through maintenance of humus and creation of carbon sinks to soil. Concerning the isolation and separation of useful wastewater components, it is likely that urine collection and use will become an increasingly important component of ecological wastewater management, as it contains 88% of the nitrogen and 66% of the phosphorus found in human waste (Maksimović and Tejada-Guibert, 2001; Vinnerås, 2001; United Nations Water Development Report 2017).

To exemplify the city of Kampala in Uganda with 1.5 million inhabitants could according to estimates from the Stockholm Environment Institute completely replace the use of firewood in local households with fuel pellets made from the city's faecal sludge, sewage sludge, and organic municipal solid waste (Wayda Diba et al. 2016[13]). Since deforestation is one the biggest environmental problems of the area this would provide substantial environmental benefits.

Similarly, the environmental benefits from the urban symbiosis in Kalundborg are reported to be huge (e.g. Jacobsen et al., 2006, Supplementary Information, www.symbiosis.dk, and other sources) and include:

- 3 million m3 of water saved through recycling and reuse (reductions of 60% along at the Asnæs power plant)
- Extensive amounts of biogas made out of yeast slurry from the production of insulin.
- Reduced emissions of CO_2 and SO_2
- 97,000 m3 solid biomass (2002)
- 280,000 m3 liquid biomass (2002)
- Recycling of 150.000 tons of gypsum from desulphurization of flue gas (SO_2) replaces import of natural gypsum ($CaSO_4$) (2010)
- Recovered nickel and vanadium
- Wastes avoided through interchanges: (2002)
  - 50-70,000 tons fly ash
  - 2,800 tons sulphur as hydrogen sulphide in flue gas from Statoil (air)
- Fertilizer equivalent to Novo Nordisk sludge (1,300 tons Nitrogen and 550 tons Phosphorus) (2002)

The direct social benefits from urban sewage water symbiosis are poorly measured, however, it is quite clear that job creation is the main factor in countries like Germany, Belgium, Netherlands, Denmark and France that currently have competitive advantages within the field and the underlying innovative technologies. With current market projections and investments expected to soar both in the short and long term (see above) the number of jobs created related to the deployment of urban sewage water symbiosis can similarly be expected to rise.

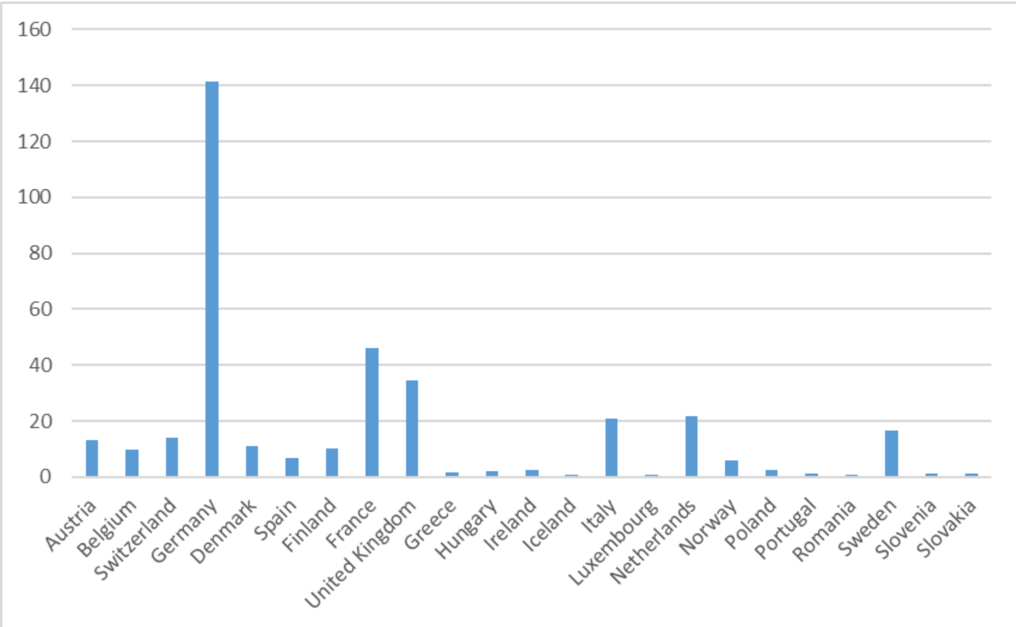
2.4 Innovation System Functioning

Function 1. Entrepreneurial Activities (EA: 4)

Although comprehensive, multifunctional urban waste water symbiosis are rare due to organisatory barriers, wastewater treatment as such is an established business sector. This, in fact has also created path dependencies preventing the needed sociotechnical changes towards turning waste water treatment into an engine of circular water economy. Currently, strong international companies are however leading the

[13] https://www.sei-international.org/sustainable-sanitation/news-and-updates/3507-do-you-know-the-value-of-your-citys-sewage

development of new integrative technologies. For example Veolia and Outotec are global leaders in providing wastewater treatment solutions including resources recovery and drying and dehydrating the sludges. They are also driving collaboration actions on developing technologies and business models for sludge based value creation. Furthermore, several energy companies have taken up leading roles in integrated treatment of sewage sludge into biogas production. For example in Finland, gas company Gasum has increased its activities during the last two years and continues to expand. Water solutions is also presently an attractive area for start-ups. According to a recent review by Lux Research start-ups in the water area have performed slightly better (31% reached profitability) after a 10-year-check than similar enterprises in the areas of electronics, energy, agriculture, nutrition, life sciences and infrastructure. It is to be noted, however, that this review covers start-ups in the broad area of water solutions and not only wastewater related development[14].



Source: Green Horizons Scoreboard.

Figure 13. Number of patent applications filed to the European patent office (EPO) for inventions within wastewater related technologies in the period of 1980 to 2013.

As a "proxy" for the state of European entrepreneurial activities within the area of water/wastewater the figure above shows the number of patent applications filed to the European patent office (EPO) for inventions within wastewater related technologies in the period of 1980 to 2013 (Source: Green Horizons Scoreboard). The numbers shown are not adjusted for, e.g., population. Unsurprisingly the largest number of applications was filed by the largest of the European countries, though "small" countries like Belgium, Denmark, Finland, the Netherlands and Sweden also stand out, confirming the presence of substantial experimentation in these countries.

As discussed already the creation of urban wastewater symbiosis requires new value networks and collaboration between actors from various fields, including municipalities, wastewater treatment companies to energy producers and distributors and agrochemical industry, just to name few. Entrepreneurial activities facilitating systematically the integration of new ecosystems on the other hand are far less developed than individual business areas. Publicly owned, often regionally focused development companies, play important roles as match makers, incubators and system integrators as is

[14] https://techcrunch.com/2015/06/22/turning-water-problems-into-business-opportunities/

the case with many local eco-parks planned for industrial symbiosis. The challenge in building scalable models for organising actor relations within urban symbiosis is the characteristic locality of actions. Urban symbiosis are bound to geographically constraint areas and dependent of available resource flows within these areas. Therefore, the models are typically always local; this finding was confirmed by our stakeholder workshop.

Function 2. Knowledge Development (KDev: 4)

Knowledge development in many of the areas of great importance for urban water symbiosis has been intensive during the last decade, particularly regarding the sludge to energy as well as phosphorous recovery technologies. Among others, the EU has recognized the need to find solutions for harnessing the potential for value adding production as part of wastewater treatment and following from that, a number of research and innovation projects have been funded already under the EU FP7 and previous programmes to develop technologies and business models for that purpose. These efforts continue during the Horizon 2020 programme. This creates a solid knowledge base for building urban symbiosis in terms of available technologies. However, the social and organisational barriers preventing the formation of this symbiosis are yet less explored.

Box 4. Review of on-going/previous EU projects

To map the state of the art in this area, we conducted an extensive review on projects in the EU CORDIS project database dealing with resources recovery and energy production in municipal wastewater treatment and industrial symbiosis wastewater treatment. We searched for projects with key words "waste water reuse" and identified altogether 21 projects contributing directly to this issue under FP7 (table 7)and 10 under the on-going H2020 programme. The criteria for choosing the reviewed projects was the projects' focus on reutilization of sewage sludge, and on municipal wastewater related industrial symbiosis. We excluded projects focusing on either general urban water management or reuse of industrial wastewater as the challenges and opportunities in these areas differ to some extent from those concerning the treatment and upgrading of sewage sludges.

Table. Projects contributing to urban water symbiosis under FP 7 programme

Sludge to agricultural production	END O SLUDGE, TREAT & USE, ROUTES, PYROCHAR,
Phosphorous recovery technologies & markets for recycled phosphorous	RECOPHOS, P-Rex, STRUVITE
Energy production & sludge dewatering	FP7: MFC4Sludge, Enercom, INORGASS, BIOGAS2PEM, SLUDGEtreat, AQUAFUELS, BIOALGAE
Biopolymers production	SYNPOL, OPEN-BIO, END O SLUDGE
Plant level optimization, Decision making tools & Knowledge exchange platforms	WE&EU, TRUST, PREPARED, DEMOWARE, R3WATER

As shown in the table above, the FP7 framework programme has particularly contributed to the knowledge base on nutrient recovery technologies and facilitated the processing of urban wastewater sludges for safe and viable nutrient resource recovery for agricultural production. In addition, sludge to energy technologies including also exploration of novel promising routes such as algae based electricity or fuel production (AQUAFUELS, BIOALGE) have been studied and piloted. The technological development in these area have been impressive and several technologies have reached high TRL levels or reached the stage of full commercialization. Furthermore, projects have produced novel sludge derived products, including biopolymers or organo-mineral fertilsers (eg. END-O-SLUDG project). As most of the above-mentioned projects have investigated or demonstrated technological innovations, less knowledge has been produced about the socio-economic dynamics of opening the markets for, e.g., sludge derived products. This knowledge gap was clearly indicated in the results of P-REX project, which in addition to exploring various phosphorous recovery technologies also produced an extensive market analysis of recycled phosphorous products. According to the results of P-REX (P-REX Policy Brief), the barriers for the spreading of extensive production of recycled phosphorous fertilisers and their market penetration lies in the legal, social and market constraints set by regulatory frameworks and consumer behavior. Furthermore, lack of scalable organizational models and business models connecting WWTPs with fertilizer production and distribution network were lacking. Therefore, the results of P-REX indicate that new match making instruments are needed to align different actors.

The enhancement of cross-sectoral collaboration is at the heart of developing functioning circular economy business. Consequently and in spite of the impressive knowledge and technology development on nutrient recovery/sludge derived biopolymer production, including interesting business case examples (for example Canadian Ostrava's production of recycled phosphorous, which has been addressed by P-Rex) it requires a paradigm shift in understanding the role of WWTPs as not solely guaranteeing safe water but also acting as hubs of various business operations to take the final step towards turning WWTPs into engines of circular water economy. Several projects have targeted this issue from the perspective of plant level of optimization of operations and decision making tools to support this aim have been developed for example in DEMOWARE and R3WATER projects. Plant level perspective does not however cover the dilemma of creating symbiotic relations between different systems and actors operating in the separate fields of agriculture, chemical industry, energy production and water services.

Hence, knowledge development in other areas than water technologies becomes also important, i.e., to enhance the integration of different systems for holistic circular water economy and to create organizational models of how to align different actors for this goal. This dilemma has been addressed in two FP 7 programmes, namely WE&EU and TRUST through multi actor networking and visioning. In addition to these kinds of joint processes also concrete ICT solutions to connect actors, allow traceability and fractionating of materials and provide markets for novel products become important. In the new Horizon2020 programme these issues are addressed for example under specific call WATER-4a-2014 - Dissemination and exploitation, ICT, knowledge, gaps, research needs, etc., which aims to help cluster eco-innovative companies in the water sector and to develop a coordinated approach to the integration of the water and waste sectors in the 'Smart Cities and Communities' EIP. This is, however, according to our stakeholder informants, in many ways an under investigated domain, and therefore more activities are needed in this field.

As the technologies to recover resources and produce energy from sewage sludge have developed during the recent decade, the on-going Horizon 2020 programme has funded several demonstration and pilot projects building linkages between WWTPs and other industry sectors, including energy and fertilizer production. Examples focusing on energy linkages include for example p-DRIVE, where vehicle gas is derived from waste materials, DEMOSOFC focusing on fuel cell technologies, HCT4Waste and TCR focusing on thermal conversions and DIMINU on dewatering technologies. In addition, energy production technologies within WWTPs are also demonstrated by BIOSTEP. Development also continues in the field of phosphorous recovery for example in the demonstration projects of HTCycle. In the field of biomaterial production demonstrations are carried out under the innovation action (project) Innovative Eco-Technologies for Resource Recovery from Wastewater. Furthermore, a particular subprogramme for Water in the context of Circular Economy (see Appendix A) has also been launched to strengthen the systemic understanding of how to incorporate the physical, technological and societal aspects of the needed paradigm shift in an integrated manner and to develop social and organisational innovations for circular water economy. So far, two demonstration projects directly related to reuse of municipal wastewater have been funded under this programme, namely Run4Life and Water2Run focusing on nutrient recovery from wastewater. Furthermore, a SMART-plant project (http://smart-plant.eu/index.php/the-project/about-smart-plant) develops and demonstrates a holistic concept for WWTPs for integrated production of water services, energy, nutrient products and industrial chemicals.

Our review indicates that the technologies for turning wastewater into "waterials" are already more or less mature enough for allowing a paradigm shift in the sanitation sector but the societal, regulatory and market barriers for making the production - particularly related to nutrient products and industrial chemicals - are still strong. In addition to water related research, these market barriers are also investigated in for example in the field of bio-based materials research (examples of market analysis of bio-based polymers for example SYNPOL, OPEN-BIO) and organizational models for industrial symbiosis on organic sludges are investigated in one on-going project focusing on brick production (BIO-OXIDATED S2). However, the socio-economic dynamics of creating interdependent alliances between heterogenous actors from different sectors in uncertain markets is not yet profoundly addressed.

In line with the general dilemma of a circular economy transition, the most burning challenge for urban water symbiosis to become a mainstream solution is not the lack of technologies but rather the lack of organizational models to align actors from municipalities, the water sector, chemical industry and energy production. That is to collaboratively collect and exchange dispersed knowledge concerning different business areas, to develop scalable models for organizing urban water symbiosis, and finding ways to penetrate markets with the models' offerings. So far, the development has been supply driven instead of market or demand driven. This concern was shared by a number of experts interviewed as part of the RECREATE Factor Deep Dive analysis, suggesting that what is most urgently needed at the moment is "partnerships and governance at local regional level to address local characteristics". Also, the regulatory and legislation frameworks to make things happen are needed: unconventional "innovation hubs" in Europe, e.g., cities or specific locations or clusters of research, public and industrial organizations that function as long term "living labs" for research, development and innovation over a sustained period of time in order to accelerate required breakthroughs and solution development (RECREATE Water Management Factor Deep Dive Report).

As the Horizon 2020 programme is still on-going, it is too early to evaluate, whether such tools will be innovated. However, based on our findings it seems that the emphasis of Horizon 2020 is still very much on the technology side, and this strongly suggests that also here a paradigm shift may be required. Thus, at this stage the policy focus should rather be how to integrate the fragmented knowledge of the potential of, e.g., sludge-derived production and on connecting actors into collaborative searches for novel organizational models to exploit these potentials. Furthermore, the explicit addressing of the power asymmetries between different actors needed for symbiosis implied for example in the data ownership and sharing and position in financial markets is necessary to create pathways for mutually beneficial collaboration and trust between actors.

Function 3. Knowledge Diffusion through Networks (KDiff: 3)

As urban wastewater symbiosis activities relate to different business and knowledge fields ranging from urban planning and renewable energy production to biochemistry and decentralised sanitation solutions, networks are critically important in knowledge diffusion to allow combining the scattered and dispersed knowledge base from different substance areas. This challenge is frequently mentioned in the results of past EU funded projects investigating the possibilities to utilise sewage sludge as a raw material in other industrial sectors. To facilitate knowledge sharing, experience transfer and networking for opportunities between various stakeholders and actors within these related fields as well as to encourage private investments, the Commission have launched a European Innovation Partnership (EIP) on Water. The EIP also hosts the City Blueprints Action Group working under Water EIP, which provides an active network for European cities to share best practices on Urban Water Cycle Services. Further, in 2013 a particular innovation platform to encourage the recovery of exhaustible phosphorous, the European Sustainable Innovation Platform, formed.

In addition to platforms organised by official bodies, knowledge of water related issues is efficiently produced and promoted by a plethora of national and international (and often non-profit) networks and associations, gathering high profile international experts together. This include such organizations as the International Water Association (IWA) and the European Water Association, who are both actively promoting the need for a paradigm shift in wastewater management towards reutilisation and upgrading the materials and energy contents of urban sewage sludge (e.g. IWA, 2016). Likewise, Europe has many strong research hubs in water technologies including for example the Centre of Expertise in Watertechnology in the Netherlands - one of the leading countries in water related research (confirmed, e.g., by Appendix B). In 2006, a European level platform gathering organisations from industry, government, NGOs and the research sector named the European Water Partnership (EWP) was formed to exchange knowledge and form partnerships on water innovations. In addition to promoting innovation in water, EWP also aims to impact on European Water policies to advocate sustainability transition in water management.

The challenges of bringing particularly SMEs together to exchange knowledge of available industrial material flows in particular areas has been widely acknowledged but remains a challenge. In this field, organisations collecting experiences of how to align different actors for symbiotic collaboration can become central facilitators of transition. For example in Britain, a National Industrial Symbiosis Programme (NISP)[15] was launched in 2003 by International Synergies Limited to develop tools for facilitating the formation of industrial symbiosis. The NISP has been applied in over 25 countries and it offers a resource pool for actors advocating circular economy innovations globally. As a further example, in Finland Motiva Ltd, a non-profit agency specialised in energy and material efficiency, has applied the NISP model to facilitate knowledge exchange, map and store available resources in a shared database - and to identify possible synergies between businesses in different regions around the country. The NISP model has been modified for the Finnish operational environment, and a national Finnish Industrial Symbiosis System (FISS)[16] has been launched. Another European level knowledge exchange forum for the promotion of industrial symbiosis is the European Industrial Symbiosis Association (EUR-ISA)[17], which was formed in 2013 to connect diverse industrial symbiosis networks together to share best practices and successful concepts and models. EUR-ISA provides an increasing repository of different innovation platforms, corporate venture programmes and innovation accelerators.

Function 4. Guidance of the Search (GoS: 4)

Currently, Europe is a global frontrunner in the provision of water solutions and sanitation technologies. Regardless of the steadily increasing share of WWTPs engaged in utilising the energy potential and material flows of wastewater, however, resource recovery is still relatively limited in linear centralised wastewater treatment systems, particularly concerning nutrients. In general, it can be observed that low-value by-product exchanges (such as untreated sewage sludge) in symbiotic networks are often motivated by policy requirements or environmental regulations like the adherence to the EU Water Framework

[15] http://www.nispnetwork.com/
[16] https://www.motiva.fi/en/frontpage/areas_of_operation/material_efficiency/industrial_symbiosis
[17] http://www.innovationseeds.eu/Network-Library/Core-Articles/European-Industrial-Symbiosis-Association-EUR-ISA.kl

Directive or the EU Wastewater Treatment Directive and only indirectly to economic benefits. Conversely, high-value by-product exchanges are often motivated more by direct economic benefits related to the value of the by-product itself. Between these two extremes there are a number of intermediate stages, which often move from low-value status to high-value status as a result of upgrading, or the gradual creation of a new market and thus more direct economic benefits. Consequently, it is evident that a purely market-based explanation for specific exchanges must be supplemented by a more detailed explanation that considers the individual actors as well as social factors during the development of an urban wastewater symbiosis project. For example in Netherlands, the interview with a high-level research manager from the waterboard Waterschap De Dommel revealed that regional policies in support of the development of urban wastewater symbiosis, e.g. the case of the Tilburg Energy Factory, to a large extent emphasises environmental and social concerns over economic ones. Alternatively, in Denmark, the development of initiatives such as the "iconic" Kalundborg case but also other Danish cases to a high degree have so far been incentivized by the objective of creating "living labs" for the further development of services and technologies with a high export potential. Moreover, as was indicated by a high level official interviewed in connection with this study, it may be important to be open for new partners and new technologies, i.e., since for example the current urban wastewater symbiosis in Kalundborg is the product a gradually expanding community and a mix of technologies. This implies that the successful implementation of urban wastewater symbiosis requires a more sophisticated view of the bottom line, considering both short-term economic and long-term environmental and operational aspects that might lower initial entry barriers to public and private sector engagement. Following from this, high emphasis is put on the regulatory environment and policy level support in market creation. This is especially true in the early project development phase when exact benefits are unclear and uncertainty is high.

The tightening of environmental legislation in many European countries as well as the EU Water Framework Directive, aiming to safeguard the ecological status of water bodies, is currently one of the main drivers in shifting the paradigm and practices of municipal wastewater treatment towards more circular solutions. As mentioned above national and international regulations generally form the regulatory frameworks for guiding research and innovation activities. The Urban Wastewater Framework Directive for example sets the standards for European wastewater treatment and in its article 12 encourages the reuse of wastewater whenever appropriate. Together with more stringent regulations preventing e.g. landfilling of sewage as clear policy targets aimed at guiding the search for new solutions to treat and reuse municipal sewage sludge therefore already seems to be set up at the European level.

Integrated energy production in WWTPs is also encouraged in several European countries by feed in tariffs for "green" energy, including biogas produced from sewage water, promoting innovation in the field of urban wastewater symbiosis. This is the case for example in Germany, Luxemborg and Switzerland. Likewise, the climate policy targets set up by the Paris Agreement and related national Climate and Energy Programmes across European nations also highlight the importance of novel renewable energy options further contributing to a favourable policy environment and further direct R&D resources for developing waste to energy solutions. Last but not least, overall strategies to shift away from a fossil economy towards a more bio-based economy, articulated in European and national bio-economy programmes, also emphasise the need to direct resources for the R&D in the field of bio-based materials, which is expected to support "sewage water to bio-polymer" innovations in the long run. Having said that, the lack of comprehensive materials policy supporting the market status of bio-based materials vs. fossil-based materials at the European level was brought by our informants as one barrier for market the access of bio-based polymers or example.

Function 5. Market Formation (MF: 2 / varies)

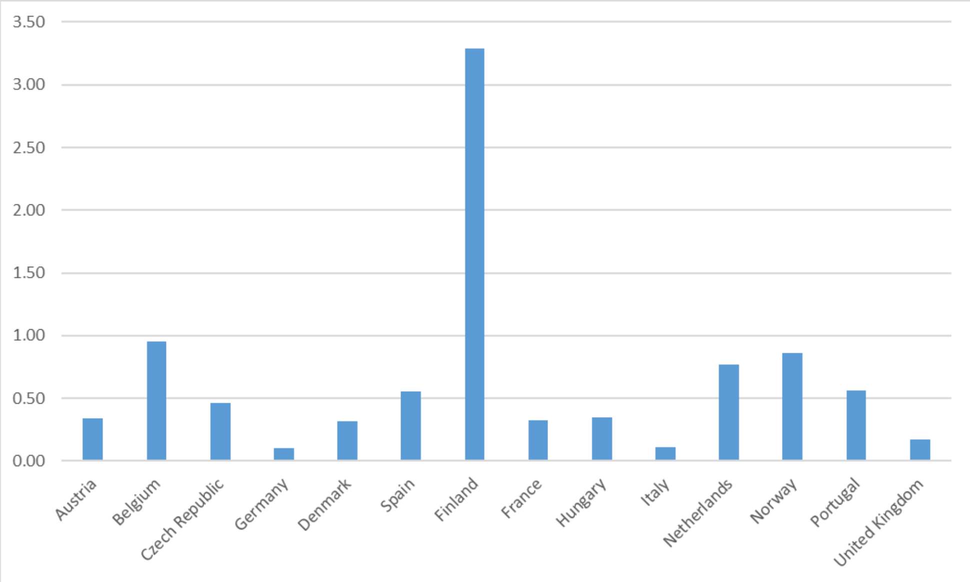
The formation of markets for sewage sludge is in many ways geographically restricted. The transportation of sludge is expensive and due to low value, not profitable for long distances. As a result the processing is usually done in close proximity of WWTPs. In many cases, an important part of the business strategies of companies collaborating with WWTPs and processing sludge are based on gate fees concerning the treatment of sludge. Therefore, the price of raw material is either very low or negative. As was mentioned earlier, the strict regulations at the moment restricting landfilling and incineration of sewage sludge has created an increasing market for alternative treatment solutions. This development is likely to continue. The markets for processing services and end products are in many areas well established yet vary depending on the product. The demand for renewable energy and distributed energy solutions is steadily increasing.

Markets for recycled fertilisers are at the moment poorly formed but emerging. At the moment only 5 % of the available bio-waste is recycled, including household organic waste as well as industrial and agricultural side streams. According to estimates, Europe could replace approx. 30 % of its exported mineral fertilisers with recycled ones provided the production and distribution systems were more efficient (European Commission, 2016). Bio-plastics Magazine has reported that according to several market analyses, markets for bio-based polymers are rapidly expanding despite the low oil prices along with increasing demand for bio-based plastics[18]. Bio-polymers are applied in several industrial sectors, including for example construction and chemical industries. The packaging industry is a significant driver of this growth and shows great interest in biodegradable materials and produces large amounts of end products. A market study from Nova Institutes (2013) claims that at the moment markets in Asia and Africa are more interesting for investments in the production of bio-polymers as Europe has yet to establish a regulatory and policy environment to support the production of bio-polymers. Nevertheless, the market is still expected to rise and accordingly the Nova market study estimates that the capacity for the production of bio-based polymers production will triple from 3.5 million tons in 2011 to nearly 12 million tons in 2020 (Nova Institute 2017).

Function 6. Resources Mobilization (RM: 3)

As already indicated in this analysis the full implementation of the EU Wastewater Treatment Directive is likely to stimulate investments in the order of 17 billion euros, which is going to be provided by a combination of public and private investments. At the same time annual revenues from the market of waste-to-energy technologies, where a few European countries currently pose as global market leaders, are expected to grow in the short term towards a value of about 2 billion euros.

[18] Worldwide growth bio-based polymers despite difficult market environment. Bio-plastics Magazine.com. http://www.bioplasticsmagazine.com/en/news/meldungen/20170222-Bioplastics-market-expands--but-slower-than-before.php



Source: Green Horizons Scoreboard

Figure 14. The average business enterprise expenditures on research and development (BERD) within the fields of sewerage, waste management, and remediation activities, measured in Purchasing Power Standard (PPS) per inhabitant at constant 2005 prices and for the period 2005-2015.

The figure above shows the average business enterprise expenditures on research and development (BERD) within the fields of sewerage, waste management, and remediation activities. The diagram shows only those countries where data was available for the period 2005-2015 (measured in Purchasing Power Standard (PPS) per inhabitant at constant 2005 prices; see also Appendix B for more detailed information). As can be seen from the graph, it is in particular smaller European countries, where significant investments seem to be taking place like Finland, Netherlands, Belgium, etc.

At the local level, where urban wastewater symbiosis, is realized the picture looks slightly different. As discussed previously investments at the operational level i.e. to unlock the economic and environmental potential of urban sewage water symbiosis requires an approach considering both short-term economic and long-term environmental and operational aspects that might lower initial entry barriers to public and private sector engagement. In many cases this uncertainty hinders the widespread engagement of SMEs, but also larger enterprises often prove reluctant in providing the necessary bold investments.

Mobilization of resources to underpin new technological innovations concerning efficient water reuse and recovery of value products from municipal wastewater is considerable and supported by several national and international innovation actions as well as commercial R&D. For many years the European Union has thus been very active in promoting innovation in water management, supporting this through its framework programmes, including Horizon 2020.

Function 7. Creation of Legitimacy (CoL: 3)

In general, the legitimacy of urban wastewater symbiosis is high due to the widely acknowledged need for more sustainable water management practices as well as the presence of successful and economically viable solutions or prototypes in many countries. Moreover, urban wastewater symbiosis is in line with the general shift towards circular economy in Europe and as such highlighted as one of the priority areas in

European resource policies. Having said that, the viability of particular solutions or exchange streams is still frequently questioned both from a perspective of profitability, environmental concerns and social acceptability.

One such example lies in the utilisation of sludge derived fertilisers and soil conditioners in agricultural production.. Using such products have been found to introduce serious concerns due to the risks of soil or groundwater contamination and possible harmful impacts on soil, vegetation and humans (i.e. through the food cycle). In particular, heavy metals, organic pollutants and remains of pharmaceutical substances have raised concerns. As a result, the utilisation of fertilisers and soil conditioners recovered from wastewater streams is strictly regulated in EuropeTechnologies to eliminate these harmful substances, such as pyrolysis or other thermic conversions are currently under development and already now, according to a recent report from the European Commission on the implementation of Community Waste Legislation, the amounts of heavy metals are on average well below the threshold values in Europe[19]. The image factor is however also important in defining the market success of these products. Eco-labeling is not possible for agricultural products when sludge derived fertilisers are used in the fields. Furthermore, one of our interviewees, a long term professional in wastewater treatment emphasised that her education has taught her to be cautious of harmful substances included in wastewater and to focus on removing remains of human feces from food cycle rather than finding ways to direct it to fields. Similarly, an expert from IWA, professor Willy Verstreate talks about "cultural disgust factor" as a major barrier in the reutilisation of municipal wastewater (IWA, 2015). Further actions in this issue area are therefore still needed to create legitimacy. For this aim, to guarantee the quality and to increase the consumer confidence in recycled fertilisers, Sweden, for example, has established a REVAQ certification system operated by the Swedish Water & Wastewater Association, the Federation of Swedish Farmers (LRF), The Swedish Food Federation, and the Swedish food retailer's federation, in close cooperation with the Swedish Environmental Protection Agency[20].

Summary: Barriers and Development Needs

Analysing the seven innovation system functions (ISF) typically results in insights with respect to drivers and barriers that are inherent to the specific innovation, (Suurs and Roelofs, 2014) . Based on the information provided in the preceding chapters, the levels of ISF fulfilment are scored by means of a five-point scale (1—very weakly developed, 2—weakly developed, 3—developed, 4—strongly developed, 5—very strongly developed). It is based on the author's own assessment—the scores were given at the end of each innovation system discussion (see above).

Based on our combined analysis, the table 5 presents a summary of barriers towards urban waste water symbiosis identified on the basis of our stakeholder informants, workshop results and literature review. In the following we will briefly highlight the most important hindrances related to the character of urban wastewater symbiosis as a systemic, and therefore disruptive innovation, i.e., necessitating changes also to the surrounding socio-technical network. One of the most critical barriers, as mentioned above, is related to organizational aspects, including the need to establish deep and committing partnerships between actors from different business fields and between public and private sector (Lenhart et al., 2015) and to break down and reorganise the existing, siloed sectoral divisions between solid waste treatment system, water services, energy services and agricultural systems in order to jointly develop a coherent agenda for

[19] http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A52006DC0406
[20] REVAQ Certified Wastewater Treatment Plants in Sweden for Improved Quality of Recycled Digestate Nutrients. 2015. IEA Bioenergy Task 37.

promoting new emerging circular economy business fields.

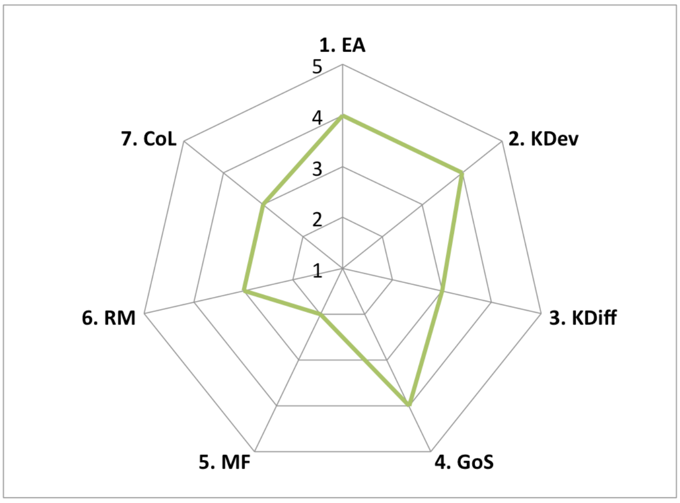


Figure 15. Fulfilment of Innovation System Functions: Utility of Municipal Wastewater in a Green Economy

Another principal barrier towards investments in innovative urban wastewater symbiosis is the high upfront costs of new water treatment installations. This implies that particularly SMEs will have great difficulties to enter the markets without strong partnership. This partnership puts them into an asymmetric power position and makes them dependent on their allies thus creating particular type of vulnerability. Furthermore, major shares of the budgets of existing operators are in general spent in maintaining capital-intensive facilities, something, which also prevents them from investing in innovative solutions (EIP Water 2014). Further, from the utility perspective, the focus is on maximizing the value of the existing water infrastructure instead of building a new one. This gains further importance with the fact that in many ways the existing water treatment infrastructure is fulfilling well the needs of the public, e.g. in terms of water quality. Related to that, experts responsible of water services are often particularly trained for guaranteeing safe and hygienic household water for citizens and preventing environmental pollution and they are, according to our informants, not eager to start experimentations, which risk to compromise these goals. Combined this suggests that new roles, skills and business orientation must be adopted or gained through extending the collaboration network when aiming to turn public water services into profit making raw materials factories.

The inertia caused by existing capital-intensive water treatment, energy production and distribution infrastructure constitutes a further hindrance. It is simply easier in most cases to continue business-as-usual practices instead of building whole new, costly infrastructure. An illustrative case of this is offered by attempts to develop hydrogen fuel cell cars in Japan. Toyota collaborates with a wastewater treatment facility in Fukuoka to convert biogas produced out of sewage sludge into hydrogen for use in fuel cell cars. To upscale this technology and to create markets for fuel cell cars and hydrogen demand the construction of an extensive distribution network is required. There is, however, no incentive for that, since there is basically no existing volume of cars using this technology[21]. In this case creating a market would require a pioneering actor and network integrator to create a vision, gather key actors around it and push forward as a systemic change.

[21] https://qz.com/785654/toyota-is-using-sewage-sludge-to-power-its-new-electric-car/

The case of building a sewage-to-transport-fuel symbiosis in Stockholm illustrates the challenges and success factors of creating new urban symbiosis (see Box 5). Two strong and dedicated system integrators, the city of Stockholm and AGA Gas were needed to create new infrastructure and markets and to get over the "chicken and egg deadlock", which is typical for systemic innovations brought up in the above example of Fukuoka Japan, requiring parallel changes across industrial sectors, governance structures and consumer action. Furthermore, the process took time as in addition to infrastructure building, also new alliances and roles between actors and new habits for customers needed to be created.

Box 5. Sewage to biofuel symbiosis in Stockholm, Sweden

The city of Stockholm made a decision already in 1997 to create a Green Olympic Village in the Hammarby area to support its on-going bid for the Olympic Games in 2004. An essential part of this village was the production of biogas from sewage water and the upgrading of this gas into traffic fuel. To be able to create a distribution network for fuel, Stockholm Water needed oil companies as partners, and to provide an incentive for non-reluctant oil companies, the city of Stockholm decided to invest in 300 hybrid vehicles to create internal demand for such fuel. In addition, the city provided financial support for building biogas tanking stations. Lastly, the city provided a tanker lorry to transport the fuel from the sewage plant to gas stations and introduced a tax relief and special parking fees for users of biogas vehicles. Despite the efforts, the markets for biogas fuel remained too small to be attractive for oil companies, and as there was limited availability of fuel, consumers did not adopt biogas vehicles. The development of a comprehensive network for biogas distribution was another issue and out of the competence fields of both Stockholm Water and oil companies as is typical for new fields emerging between existing systems. Finally, in 2004 the oil company AGA Gas achieved the sole rights for biogas produced by Stockholm Water and started to heavily invest in such a distribution network. As a result the demand for biogas vehicles started to boom (from 2006 onwards) and several other WWTPs also invested in biogas production.

When talking about radically new approaches to sanitation such as decentralised (house or neighbourhood based) new sanitation solutions (as in the Sneek Installation Pilot - see Box 6), changing and/or optimizing existing urban planning culture and conventional urban planning and building solutions can also be a great challenge. Thus, users and stakeholders may not be accustomed to decentralised sanitation with related energy production and nutrient recycling. These solutions demand for space and may cause fear of environmental harms such as odour or noise. Similar demand of space and risks of harmful side effects characterise also wastewater symbiosis around more traditional, centralised WWTPs, thus requiring careful collaboration with urban planning system and functioning monitoring and quality schemes to prevent negative social impacts. According to the results of our stakeholder workshop, these risks also set a barrier for water utilities and public authorities in engaging into novel arrangements as their main responsibility is to guarantee the quality of environment and water, not to produce industrial raw materials .

Box 6. Sneek Installation Pilot, Netherlands

The Sneek installation in the Netherlands was initiated in 2006 for research purposes as a pilot of a decentralized sanitation system, which enables the efficient local recovery of resources from wastewater. 32 houses and a retirement home are connected to a source separating vacuum toilet system. The aim of the system is to minimize the usage of water and to enable the efficient recovery of different valuable substances from domestic wastewater. Black waters are directed to a biogas plant in the neighbourhood to utilize the energy potential of feces and digested together with kitchen waste. The University of Wageningen further tests the ability to recover nitrogen and phosphorous of urine with a microalgae cultivation. The system functions both as a testbed for new sanitation technologies and as a showcase for promoting source separating local sanitation systems. The market demand for such systems is well-documented in areas of sewage networks, and the technology has also demonstrated great market potential in emerging economies, which lack extensive centralized sewage networks (e.g. United Nations Water Development Report, 2017).

When talking about an emerging business area characterised at the same time by novel technological innovations, new alliances and collaboration networks and new end products and services, it is crucial to understand that the credibility of new business arrangements comes as a result of all these functions succeeding at the same time. One of the main barriers for urban wastewater symbiosis in Table 5 is the lack of trust between partners. This barrier may be categorized as "social". It is important to understand, however, that trust also relates to technical and market aspects. As long as there is quality problems in raw materials provided for partners or some allies have great market risks regarding for example the demand of their products (for example biopolymers or recycled fertilisers), trust building between partners is difficult regardless of how much effort is put into communication and collaboration. Therefore, the importance of collaborative experimental platforms for partners to test new socio-technical arrangements in various living labs backed up by private and public risk funding instruments was emphasised by our informants. Similar suggestions were brought up by RECREATE Water Factor Deep Dive expert interviews.

All of the abovementioned results have largely been confirmed both by the thematic workshop in Tampere and by stakeholder interviews, pointing toward the following factors, identified and summarized in Table 5 (see below) as the principal barriers for the formation of urban wastewater symbiosis, regardless of whether they represent centralised or decentralised efforts.

Table 5. Identified barriers for urban wastewater symbiosis

Category	Subcategory	Hindrances
ECONOMIC	Financial	High upfront costs of wastewater treatment facilities
		Lack of substantial private risk finance
		Uncertainty about the profitability of partnership vs. need of long term infrastructural investments
		Mutually conflicting time horizons for payback times of investments between different actors
	Market related	Low or even negative price of sewage as a raw material
		High costs of transportation of sewage
		Uncertain market demand for sewage derived product (restrictions and negative image for recycled fertilisers & competition with cheap mineral fertilisers; competition of biobased polymers with fossil polymers etc.)
		Market failure: environmental costs and benefits not internalized in market prices
		Lack of customer contacts and distribution networks concerning the by-products of sewage treatment by WWTPs
	Between companies	Weak tradition of cross sectoral collaboration
		Lack of scalable business models for different value network actors
SOCIAL		Strong focus on core business: WWTPs have strong tradition of orientation to guarantee safe household water and prevent environmental pollution – step towards markets oriented production of raw materials is significant
		Silos and strict division of expertise between different administrative

		sectors (water services, waste departments, energy production, housing, agriculture)
		Lack of time and resources in water utilities to focus on issues other than water services
		Lack of trust between actors
		Different organisational cultures between private and public actors
TECHNICAL		Existing capital intensive sewage infrastructure hinders systemic change towards e.g. Decentralised sanitation.
		By-products of sewage treatment may not fit directly the quality requirements of other systems (humidity, substances…)
		Misfits of temporal synchronisation of different systems (heat in the summer not needed in the heating systems etc.)
		Difficulties in arranging transportation of sewage for treatment
		Extensive need of space near the WWTPs in dense urban areas
INFORMATION RELATED		Lack of knowledge about the possible side streams, their content and quality
		Lack of matchmaking and knowledge exchange platforms between actors
		Lack of clear certificates and standards for communicating the quality of products for customers

Considering, that the technologies needed to enable the emergence of urban wastewater symbiosis are more or less mature due to recent R&D efforts and based on the social, economic and information related barriers identified above, we have prioritised in the below list the key development needs to foster urban wastewater symbiosis and related action point suggestions. This list is based on the experiences of our informants.

1. Lack of knowledge about the available raw material streams, their content and quality in a particular region (development need identified: shared data platforms, IoT solutions to increase traceability, standards to monitor and guarantee the quality of raw materials and end products)
2. Asymmetries between potential allies with regards to data ownership, infrastructure expenditure & financial risks (development need identified: models for agreements & sharing best practices on how to solve these imbalances)
3. Lack of infrastructure allowing cost efficient and reliable logistics (development need identified: partnership between public and private actors)
4. Mutually conflicting time horizons for payback times of investments and goals of different actors – private businesses typically needs shorter returns on investments, public actors have longer perspective (development need identified: models for agreements & sharing best practices on how to solve these imbalances)
5. Risks due to increasing interdependencies between actors (development needs identified: conventions for trust building, robust legal frameworks)
6. Lack of culture of experiments – it is easier to continue with existing infrastructure solutions than to test potentially risky new practices, which in some cases may even push existing regulatory boundaries (collaborative knowledge production in living labs)

2.5 Further Evidence on the Innovation System

Not relevant for this EBN.

2.6 Policy Implications

This narrative clearly indicates that the technological development supporting efficient water reuse and recovery of value products from municipal wastewater is strong and supported by several national and international innovation actions. The European Union has also been very active in promoting innovation in water management as was presented in the project overview in Section 2.4, and this trend seems to continue. In addition to novel technologies, urban wastewater symbiosis requires rearranging actor relations and the establishment of new collaboration concepts and models supporting novel interdependent partnerships characterised by different aims, goals and power positions. The knowledge of how to build this kind of *institutional capacity*, however, is currently less developed, and here the role of future innovation policies becomes particularly important.

The following are the policy recommendations inferred from this narrative analysis, supported by desk research, expert and stakeholder interviews and the stakeholder workshop in Tampere, Finland.

(1) Urban wastewater symbiosis requires the rearrangement of existing socio-technical relations. This clearly requires relevant policy interventions as well as joint vision building to promote systemic change, where public actors can act as facilitators. The existing asymmetries between water utilities, established market actors, SMEs, start ups and public actors with regards to data ownership and exchange, market risks and access to finance should be explicitly addressed to unlock the social and organisatory lock ins preventing the full realisation of opportunities provided by recent technological development in the area.

(2) Because urban symbiosis is often motivated by social and environmental benefits, public actors need to play a key role in the process. In particular, public-private partnerships should be encouraged and can be essential for the success and profitability of urban wastewater symbiosis.

(3) Disseminating information about urban wastewater symbiosis plays a key role as is already well recognised in several EU level initiatives building networks and platforms for knowledge exchange. According to our results, mere dissemination of information and best practices is however not enough. To facilitate the transition towards a new paradigm of circular water economy in urban areas, different actor and stakeholder groups need to be convinced, and strong mutual relationships built. For this aim it is essential to involve these groups in the work and to find out what they really need, which capacities need to be developed and in which form. This will help convincing the actors that it is possible to reuse water and to recover, reduce and re-use energy and material flows from the water cycle. Demonstration projects can significantly contribute to overcome barriers that might hinder the implementation of the innovation. As urban wastewater symbiosis are always characteristically local, the lessons learned from demonstration projects need to be customised and localised for regional particularities. Therefore, collaborative, regional knowledge co-creation on the basis of existing examples should be systematically exercised.

(4) As demonstrated by on-going projects knowledge exchange platforms concerning available resource and side streams in different localities are needed. The development of these also requires particular attention on the issues of data ownership and privacy. Furthermore, to increase consumer trust in waste

water driven products and to tackle the quality concerns between companies, ICT solutions focusing on the traceability of materials should be a major development area.

(5) Agile piloting is needed, e.g. to underpin and document realistic investment cases, and hence diverse funding mechanisms for experiments, prototypes and living labs, e.g. through instruments such as Horizon 2020, Water KIC and Climate KIC, must be pursued. This includes experimentation with new business models. Also, many existing successful symbiotic relationships continue to develop over time, adding or replacing new processes or exchanges, which can provide the blueprint for whole new installations. This must be considered by new and existing funding mechanisms, which should provide access to resources not only for new initiatives but also for running, profitable operations.

(6) Comprehensive economic assessments and Life Cycle Analyses of the "wastewater to waterial" symbiosis can help build the required legitimacy of the innovation and help unlock investments and engagement from the private sector, while at the same time ensuring the social acceptability of the general public.

(7) Robust regulatory frameworks, standards and monitoring are needed to increase consumer trust in products based on wastewater as well as to pave the way for the needed collaborative frameworks and for the formation of transparent market for services and technologies related to urban wastewater symbiosis.

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Appendix A

TOPIC: Water in the context of the circular economy (topic identifier: CIRC-02-2016-2017)

Source: European Commission – Research & Innovation – Participant Portal.

Specific challenge:

The European water sector has a prominent position in economy and society, but it is very diverse and fragmented. It needs to revolutionise the way public and private actors work together so as to address water-related challenges and seize on opportunities strengthening a demand-driven approach. A systemic approach, incorporating both the physical structure of the system and the rules governing the operation, performance and interactions of its components, could address those issues in an integrated manner. Such an approach should go beyond the pursuit of wastewater treatment and reduction of water use to inspire technological, organisational and social innovation through the whole value chain of water (i.e. water as a resource, as a productive input and as a waste stream), moving towards a circular economy approach.

More specifically, with an increasing global demand for food, feed and fibre, the demand for nutrients is growing. Although increasing food and biomass production necessitates a higher application of nutrients, current fertilisation practices use resources inefficiently. At the same time accumulation of nutrients is causing major environmental problems. The EU legislation is already aiming at regulating nutrient emissions to the environment but more can be done to encourage a transition to an efficient nutrient recovery and recycling. Water is the most used carrier of nutrients and, at the same time, an important resource itself. Water treatment management models and technologies have the potential to create new business opportunities for an extensive nutrient recovery and contribute to the circular economy. However, an extensive implementation of integrated nutrient recovery technologies and the use of the recovered nutrients at European level is still lacking and this is proposed to be addressed in the 2016 call for proposals.

In addition, today's water services aim mainly to save water and to improve its quality. However, water becomes more and more a scarce resource as a result of urbanisation, increased competition between various uses, economic sectors and extreme weather events. To deal effectively with these pressures, there is a need for improving water systems by considering the whole water-use production chain and by identifying solutions that enhance both the economic and environmental performance of the system. These innovative solutions should be in line with the objectives of the circular economy, contributing to the challenges of a depletion of raw materials (e.g. through the recovery of resources from wastewater) and climate change (reducing energy needs or producing energy) and should be demonstrated at large scale. This is proposed to be addressed in the 2017 call for proposals.

Scope: Proposals shall address one of the following issues:

a) Demonstrating the potential of efficient nutrient recovery from water (2016): The objective of this topic is to implement large scale demonstration projects to tap the potential of nutrient recovery and to encourage the use of these nutrients throughout Europe. Projects should cover the whole value chain from recovery of nutrients to their recycling. The demonstration may involve recovery technologies implemented in any water sector (i.e. industrial, agriculture, or municipal). Treatment schemes should be optimised to allow better recovery rates and material qualities adapted to users' needs and capacities. A life-cycle assessment approach should be used together with environmental and health risk assessment methodologies. New business models exploiting the benefits associated with nutrient recovery and recycling should also be implemented and tested. The proposals should include an outline business plan which can be developed further in the course of the project. Relevant legal, societal and market challenges affecting the recycling of recovered nutrients and their market uptake should be addressed. Involvement of social sciences and humanities disciplines is deemed necessary, for instance to address issues such as attitudes to and acceptance of recycled products. Prospective end-users need to be involved in the projects, informing them about the quality and safety requirements to be met by the products derived from nutrient recovery, thus ensuring the involvement of the demand side to increase market success. Proposals should include participation of industry partners from relevant sectors, and active participation of SMEs where relevant.

This topic supports the implementation of the EIP Water, addressing several priority areas such as water and wastewater treatment, including recovery of resources, and water reuse and recyling.

Where technological innovation is concerned, TRL 5-7 should be achieved.

The Commission considers that proposals requesting a contribution from the EU of between EUR 6 million and EUR 8 million would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude submission and selection of proposals requesting other amounts.

b) Towards the next generation of water systems and services – large scale demonstration projects (2017): The objective of this topic is to demonstrate innovative solutions at a large scale (i.e regions, cities and/or river basins), in line with EIP Water priorities and the objectives of the Water Framework Directive. Proposals should focus on developing the water services of the future, going beyond water supply sustainability addressing the different water value chains. They should integrate, for instance, the management of water resources and the provision of water services, expanding the re-use of treated wastewater and the use of desalinated water (where appropriate), ensuring carbon neutral water services, and closing the water cycle by increasing the efficiency of wastewater treatment plants, including the recovery of energy and the re-use of chemicals and nutrients.

Projects should build on experience already gained in areas where integration of various aspects of water management and other economic and social activities is already taking place at different levels, with replication potential in other areas of Europe or at wider scale, thus demonstrating a real added-value at EU level. Successful projects should engage all relevant stakeholders, especially user communities, at an early stage in the co-creation process, bringing together technology push and application pull. This is also necessary to show the potential of using systemic eco-innovative approaches in water, to overcome related barriers and bottlenecks and to create new opportunities for jobs and growth in various regions and river basins. Participation of industry partners from relevant sectors is considered essential and the active participation of SMEs is encouraged. The application of new business models and new value chains is encouraged. The proposals should include an outline business plan which can be developed further in the course of the project. Where relevant, integrated environmental impact assessments and risk assessment of potential harmful substances should be considered. Relevant socio-economic issues, in particular, regulatory/governance issues, social behaviour and acceptability should also be addressed, requiring the participation of social sciences and humanities disciplines such as political sciences, economics, governance and business studies. To enhance the systemic approach and the transformation of water services toward a more circular economy approach, digital technologies and ICT tools should be also considered. Activities aiming at facilitating the market uptake of innovative solutions, including standardisation, should also be addressed.

Within the projects funded, additional or follow-up funding should be sought, be it private or public, so as to achieve a more effective implementation and deployment at larger scale and scope of the innovative solutions addressed. Additional funding sources could include relevant regional/national schemes under the European Structural and Investment Funds (ESIF), such as under the European Regional Development Fund (ERDF), or other relevant funds such as the Instrument for Pre-accession Assistance (IPA II). In these cases, contacts could be established with the funds' managing body during the duration of the projects. In case of relevance for the Research and Innovation Smart Specialisation Strategies, the project proposals could already indicate which interested regions/countries have been pre-identified. Please note, however, that reference to such additional or follow-up funding will not lead automatically to a higher score in the evaluation of the proposal.

Where technological innovation is concerned, TRL 5-7 should be achieved.

The Commission considers that proposals requesting a contribution from the EU of a range of EUR 10 million would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude submission and selection of proposals requesting other amounts.

For both (2016 and 2017): Within the projects funded, possible regulatory barriers should also be addressed, as appropriate. In particular 'Innovation Deals' may be proposed. By 'Innovation Deal' an innovative better regulation instrument is understood, in the form of voluntary agreements with external stakeholders to identify and overcome regulatory barriers to innovative solutions that would enable policy or legislative objectives to be better achieved.
Expected Impact:
Projects are expected to contribute to:

a)

- decreasing the dependency on primary nutrient resources and increasing the supply security at European level;
- reducing the adverse effects of nutrient emissions on the environment;
- closing the water and nutrients cycles in the whole production and consumption value chain;
- improving the quality of data on nutrient flows, thus providing important information for investments into the recycling of recovered nutrients;
- creating new green jobs and industries around nutrient recovery and recycling, including exports;
- creating new business opportunities for industry and SMEs in the EU, contributing to the exploitation of EU innovative solutions, and improving the competitiveness of European enterprises in the global market for eco-innovative solutions;
- improving the policy and market conditions in Europe and globally for large scale deployment of innovative solutions;
- providing evidence-based knowledge regarding the enabling framework conditions (such as the regulatory or policy framework) that facilitate a broader transition to a circular economy in the EU.

b)

- significant reduction of the current water and energy consumption at regional and/or river basin scale by closing the cycles of material, water and energy, using alternative water sources and supporting the transition towards smart water services;
- interconnectivity between the water system and other economic and social sectors;
- increased public involvement in water management;
- increased citizen satisfaction with water services;
- replication of new business models in other areas and replication of models for synergies between appropriate funding instruments at regional, national or European level;

- closing of the infrastructure and investment gap in the water service sector;
- creation of new markets in the short and medium term;
- providing evidence-based knowledge regarding the enabling framework conditions (such as the regulatory or policy framework) that facilitate a broader transition to a circular economy in the EU;
- implementing the Sustainable Development Goals (SDGs), in particular SDG 12 'Ensure sustainable consumption and production patterns' and SDG 6 'Ensure availability and sustainable management of water and sanitation for all', as well as the conclusions of the COP21 Paris Agreement[1].

[1]The Paris Agreement was adopted at the 21st Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change, in Paris on 12 December 2015.

Appendix B

Selected indicator-based analysis of the innovation system related to water/wastewater using the RECREATE Green Horizons Scoreboard (http://www.green-horizons.eu/)

A description of the individual data sets are provided in the captions of each figure.

Knowledge development and diffusion

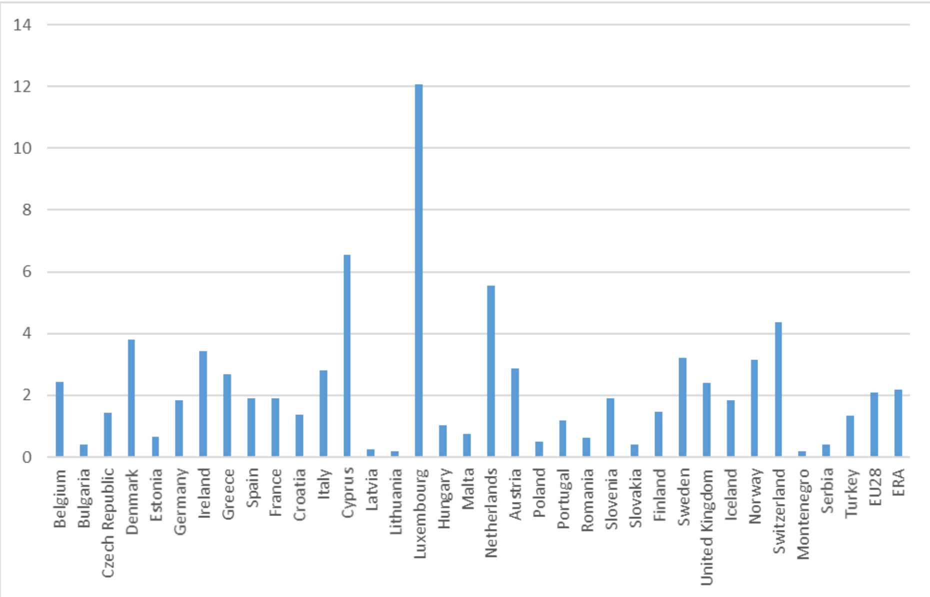

Figure A1. Scientific Publications – Water & Wastewater. Number of publications per thousand researchers published in the top 20 journals within the "water & wastewater" research area in the period 1990-2015. The highest intensity with respect to knowledge development (measured scientific publications) is found in the **Netherlands, Switzerland and Denmark** followed by their neighbouring countries. The peaks corresponding to Luxemburg and Cyprus are artefacts caused by a low number of researchers and publications. Data on publication activity was retrieved by querying the Web of Science database, whereas the number of researchers (expressed in FTE) in the higher education sector was retrieved from Eurostat.

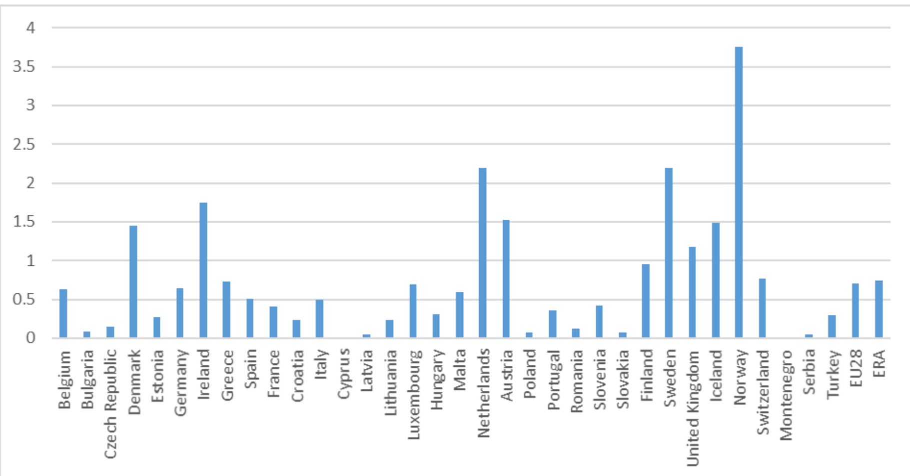

Figure A2. Scientific publications - Environmental governance. Number of publications per thousand researchers published in the top 20 journals within the "Environmental Governance" research area. The highest intensity with respect to knowledge development concerning environmental governance (measured scientific publications, and not restricted only to the area of water and wastewater) is found in **Norway, the Netherlands, Sweden, Ireland, Austria and Denmark** followed, in general, by their neighbouring countries. Data on publication activity was retrieved by querying the Web of Science database, whereas the number of researchers (expressed in FTE) in the higher education sector was retrieved from Eurostat.

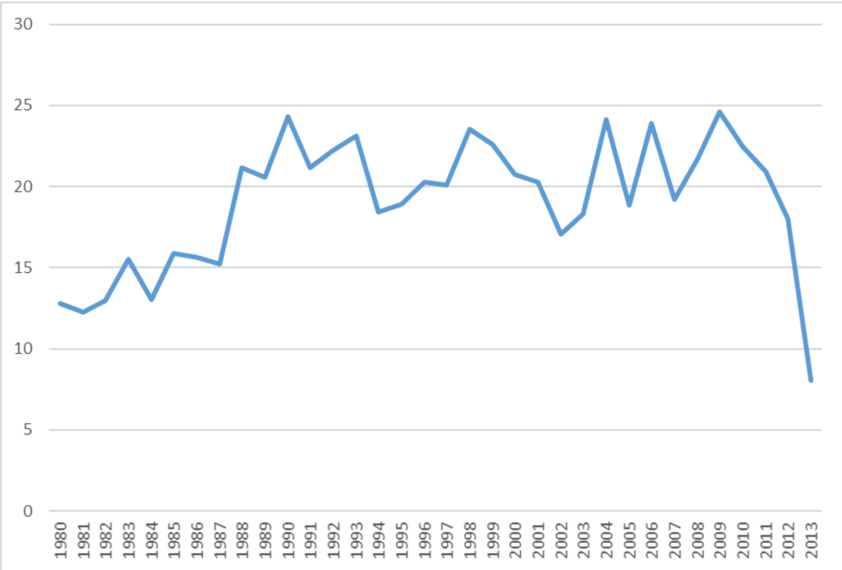

Figure A3. Total number of patent applications filed to the European patent office (EPO) for inventions within wastewater related technologies in the period of 1980 to 2013. The graph is based on data for 23 European countries: Austria, Belgium, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Hungary, Ireland, Iceland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Sweden, Slovenia and Slovakia. An increase in the number of patent applications is observed from 1980 – 1990 after which the total number of applications per annum has remained more or less constant until 2011. For 2012-13 a decline is observed, however, due to lack of data from 2014-2016 it is not possible to conclude, whether the observed trend is robust.

This indicator was based on data collected by the OECD. The OECD has created a search strategy for environment-related technologies (ENV-TECH) based on more than 200,000 different classification symbols, containing both International Patent Classification (IPC) symbols and Cooperative Patent Classification (CPC) symbols http://www.oecd.org/environment/consumption-innovation/env-tech-search-s...). The classifications cover a broad spectrum of technologies related to environmental pollution, water scarcity and climate change mitigation. The classifications found in the ENV-TECH search strategy have been grouped according to their relevance within the RECREATE innovation systems. Not all the classifications found in the ENV-TECH search strategy have been used to provide the indicator shown on the Green Horizons Scoreboard. Here, for each innovation system, a list of the relevant CPC and IPC schemes is created. The raw patent data found in the OECD REGPAT database (which contains all patent filed to the EPO) is then filtered for each list. This yields the number of patent applications relevant within each innovation system. These are allocated fractionally to the inventor(s) country according to inventor share. The patents are then sorted according to the priority year of filing.

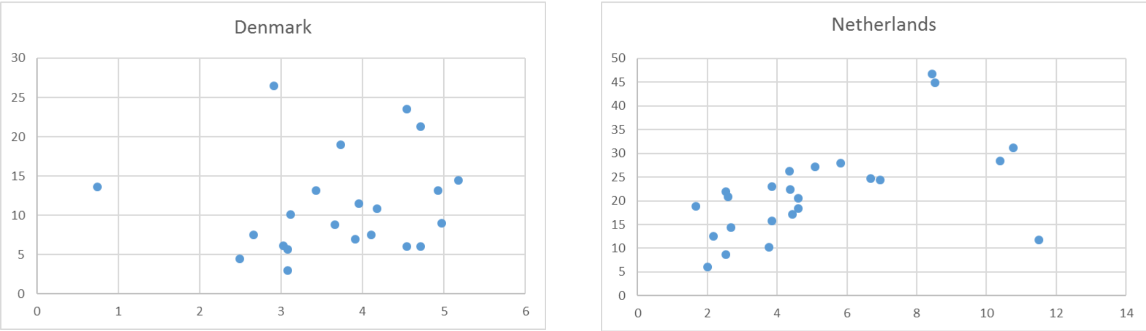

Figure A4. Relationship between knowledge production and patents filed. The figure shows the total number of patents filed to the European patent office (EPO) for inventions within wastewater related technologies as a function of the number of publications per thousand researchers published in the top 20 journals within the "water & wastewater" research area in the period of 1980 to 2013. Data are shown for **Denmark and the Netherlands**, both of which are amongst the leading Member States of the EU when it comes to research & development concerning water/wastewater and environmental management (see the figures above). In the case of the Netherlands a near linear trend is observed, which seems to indicate that technologies developed in the Netherlands have a high level of efficiency with respect to (potential) commercial exploitation (measured by patent applications). A somewhat similar trend is observed for Denmark though here the data points are much more scattered.

Resources mobilization

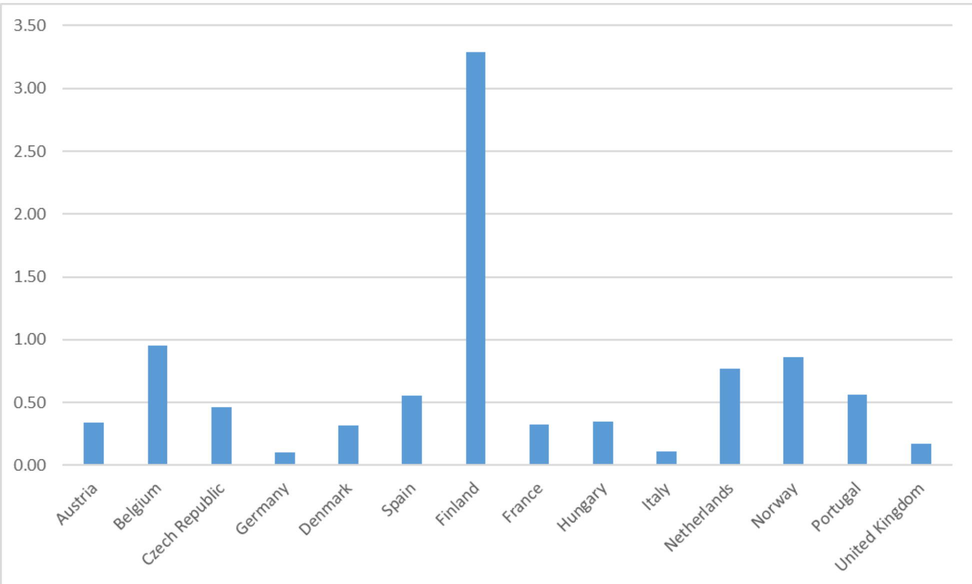

Figure A5.The average business enterprise expenditures on research and development (BERD) within the fields of sewerage, waste management, and remediation activities, measured in Purchasing Power Standard (PPS) per inhabitant at constant 2005 prices and for the period 2005-2015. The data on business enterprise expenditure was found to be highly fragmented and incomplete, and hence the figure shows only countries where data was available for at least five years in the period 2005-2015. **Finland** by far is the country with the highest average business enterprise expenditures on research and development, followed by **Belgium, the Netherlands and Norway**. Here the Green Horizons Scoreboard replicates data collected by Eurostat.

Influence on the direction of search

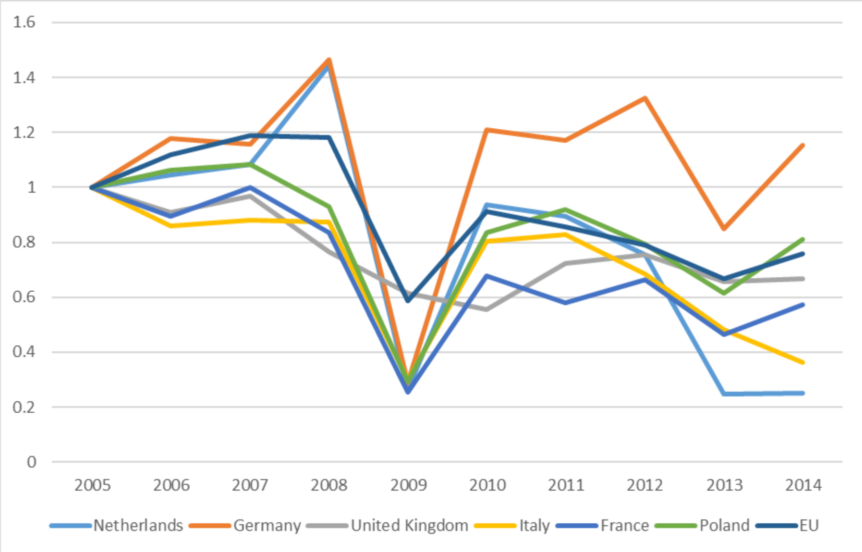

Figure A6. Apparent consumption of phospate rock expressed in tonnes. The apparent consumption was calculated as Production + Imports - Exports for each country in the ERA. The figure shows the observed trends for selected European countries plus the EU as a whole. The largest share of phosphorus is used as basis for nitrogen-phosphorus-potassium fertilisers, globally utilised on food crops. The figure shows generally a downward trend consistent with a reduction in the consumption of phosphorous, however, from 2013-2014 this trend seems to reverse. Due to lack of data beyond 2014 this trend cannot be validated. Original source: http://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS.