D4.7.a Evidence-Based Narratives – part 2

Please note: In line with the RECREATE Description of Work (version of 10 June 2014), this document is the first out of several documents that together will constitute D4.7.

Triangulation of Selected Narratives

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Draft- First Part	December 2015	-	Narrative on "Urban Climate Information Services" is still under work and will be submitted as soon as possible. The remaining four narratives, presented in this document, are final drafts.
Draft- Second Part	December 2015	Martin Drews	Narrative on "Urban Climate Information Services" is included.

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 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. For the selection of relevant innovation cases following criteria having been used:

- Size of future markets (in terms of revenues, jobs and EU market share)
- Amount of investments and possible return on investments
- Extent of benefits on the environment and society
- Stage of development
- Extent of systemic innovation.

Since the selection of innovation cases has taken place before the actual assessment performance, few case works have revealed a different extent of effects than initially anticipated. This circumstance is an inherent challenge of the requested selection and analysis process and is presented in the following casework as transparently as possible.

Against this background, the RECREATE consortium has developed fourteen evidence-based narratives[1] covering the three DG Research and Innovation flagship objectives that were presented to the European Commission in March 2015.

[1] http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.1-SEI_final_clean_0.pdf, http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.2-NBS_final-clean.pdf, http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.3-CIS_final_clean.pdf

On the basis of evidence-based narratives presented to the DG Research and Innovation in March 2015, the RECREATE consortium has been asked to deepen the investigation concerning selected narratives. The present deliverable represents the output of this request.

In this regard, the document at hands contains advanced versions of the evidence-based narratives publicly available and presented to the European Commission earlier this year and covering the before-mentioned flagship objectives of DG Research and Innovation. They represent a refined second version, respectively can be viewed as "evidence-based narratives 2.0".

While the first versions of evidence-based narratives were almost exclusively based on desk research, including both published and unpublished works, for the second versions additional data and information were obtained from direct exchange with relevant experts and stakeholders. Conducting extensive interviews has been an explicit request of DG Research and Innovation in order to better tell the actual story behind the discussed innovation.

Refining the evidence-based narratives has been realized in five parallel processes, each of them requiring a distinct approach—in terms of definition of the different expert target group, development of time planning and ways of contacting experts.

As a result of refinement activities, more than one method and approach to the investigation of a research question has been used in order to enhance confidence in the developed findings. Desktop research has been combined with derived findings from bilateral expert interviews and interactive expert workshop sessions. This combination of approaches is what is referred to as "triangulation" (Bryman, 2003)[2]. Referring to this, the present deliverable containing refined evidence-based narratives has been entitled as "Triangulation of Selected Narratives".

[2] Bryman, A. (2003). Triangulation (SAGE Publications).

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)[3], 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.

[3] 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.

The process having led to the present output consisted in a wide range of coordination activities including several feedback and discussion loops within the project consortium and DG RTD. Since the launch of the respective Work Package in July, following activities have been conducted in order to generate the available evidence-based narratives.

Period (2014/2015)	Activities
July to August	Diverse rounds of case collection within the whole RECREATE consortium
September	Selection of most promising cases and building of narratives Presentation of selection to European Commission
October	Re-selection of most promising cases and re-building of narratives Presentation of refined selection to European Commission
November	In-depth research and preparation of narratives Exchange with Advisory Group Members
December	Development of zero drafts Presentation of drafts to European Commission
January	Feedback from European Commission
March	Completion of deliverables (EBNs 1.0)
March	Selection of narratives to be investigated further in a second step
May to August	Preparation, realization and analysis of expert interviews
September	Presentation of narratives at RECREATE workshop to stakeholders and European Commission
October	Integration of workshop feedback
December	Presentation of drafts to European Commission (EBNs 2.0)

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Evidence-Based Narratives for Research Programming

1 Selling Solar Services

Author(s):
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with comments from:
Ton Bastein (TNO)

Changes based on request of European Commission:
The following descriptions build on a previous narrative version, developed in December 2014 and published in March 2015[4]. It has been amended and refined due to the specific request of DG Research and Innovation to

(a) Specifying barriers and drivers for a further diffusion of the innovation analysed
(b) Telling the entrepreneurial stories of both start-ups and incumbent bigger energy companies
(c) Formulating more detailed policy recommendations.

In order to fulfil this request, it was explicitly recommended to widen the narrative's evidence base by conducting interviews with relevant market participants and stakeholders about their particular story. Referring to this, all in all, five intensive telephone interviews were conducted in the period between July and August 2015. The following market participants were available for an interview:

- Two start-ups offering solar services: Solease[5] and DZ-4[6]
- One manufacturer of solar photovoltaic (PV) systems: Conergy[7]
- Two incumbent energy companies: RWE[8] and Trianel[9].

Findings of interviews with these five respondents are explicitly named in the following narrative. Additionally, interviews were amended by short telephone calls, among them

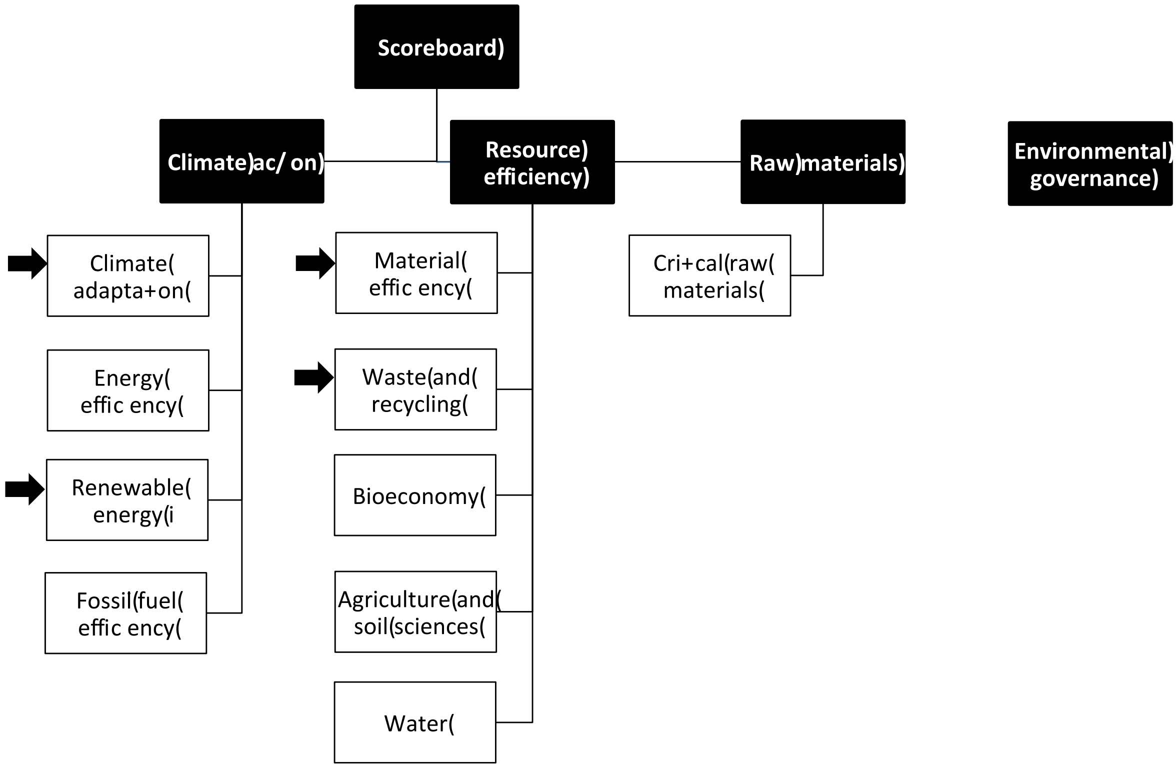
- One manufacturer of energy equipment and
- Two loan providers.

Results of these calls are indirectly incorporated into the text. Overall, an even larger number of stakeholders was contacted for an interview, however only the above-mentioned interviewees have responded to the interview request.

Findings have also been presented and discussed in a session on "Selling Solar Services" at the 2nd RECREATE Strategic Workshop.

[4] http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.1-SEI_final_clean_0.pdf
[5] Pierre Vermeulen, CEO of Solease (https://www.solease.nl)
[6] Tobias Schütt, CEO of DZ-4 (https://www.dz-4.de/)
[7] Anke Johannes, CEO of Conergy Germany (http://www.conergy.de/)
[8] Philipp Birkenstock, Head Business Clients of RWE (https://www.rwe.de/web/cms/de/1161982/geschaeftskunden/)
[9] Michel Nicolai, Head Decentralized Production of Trianel (http://www.trianel.com/)

Links with RECREATE Scoreboard:



Climate)ac/ on:)
Enables(uptake(of(solar(energy,(supports(transi+on(to(energy(system(based(on(renewables,(contributes(to(low(carbon(economy(

Resource)efficiency:)
Incen+ves(to(reduce(total(costs(of(ownership(supports(resource(efficient(behaviour(

Note: Links are marked with an arrow.

1.1 The Narrative

"Selling Solar Services" represents a business model innovation that depicts a snapshot of the envisaged transition from a centralized fossil fuel-based energy system towards an energy system that is based on the decentralized self-production and consumption of renewable energies. A company offering solar services does not sell solar PV systems to rooftop owners anymore, but instead the service of providing the use of solar electricity produced on the customer's roof. This service is realized by means of a financial and organisational leasing construct that includes financing, installation, monitoring, and in parts also maintenance and repair. In this construct, the ownership remains on the part of the solar service company, it is not passed on to the end-customer—as it is done in the conventional outright purchase model.

Solar services might be seen as part of a series of connected changes towards a more sustainable future. In this regard, it could be part of a systemic eco-innovation[10]. The narrative about solar services has been assigned to the realization of a circular economy. For one part this link has been carved out because the concept of an economy using its resources in cycles also includes a renewable energy and thus a potential low-carbon strand. A business model focussing on the deployment of solar PV technology can be assigned to this strand. For the other part this link has been emphasized because in an ideal circular economy, ownership and responsibilities of products and materials and therefore also incentives of resource usage are changed. Since this kind of mechanisms is primary part of the solar service business model, it has an overlap with this strand, too. In addition, it represents a blueprint for how other material- and capital-intensive product systems might be transformed from a linear to a circular resource flow system.

The model has started at a point at which the realization of grid parity and competitiveness of solar PV systems, increasingly also of storage solutions, has been realized in selected markets of the EU. In the coming years, it is expected that this business model will mark the point of transformation towards even more integrated solar energy solutions. This could include storage solutions making self-sufficiency nearly completely possible integration and exchange with e-mobility infrastructure and also small self-consumption neighbourhood grids. Companies offering solar PV leasing options today see themselves as energy management companies of the future. In the Europe of 2020, those companies might have realized a turnover of $ US 46 billion and created jobs in the range of approximately one million (whereas the highest share of jobs stems from indirectly caused activities).

While respondents have assessed that the market is already out there, currently active companies still face different barriers that prevent a faster diffusion of solar services. Above all, they comprise funding barriers. This is especially true for start-ups that find it difficult to convince private investors, or to receive public funding. Also, pioneers having started with first market activities around 2012 could have developed a higher market share meanwhile, if they would have been able to convince more investors. Therefore, the entrance of more market players, especially in the form of incumbent energy companies, making the model more known and trustful is explicitly welcomed. Knowledge generation and diffusion towards potential investors is as well needed as towards potential end-customers, who do in large parts do not even know about the solar service option.

Policy actions specifically targeted at the further diffusion of solar service offers could improve the start-up funding situation, establish confidence-building competitions and awards, improve level of awareness and understanding among investors and customers, organize pilot customer projects, and counteract disinterest and fear in energy policy-related investments and contracts. Further policy implications have been formulated in the accompanying RECREATE policy brief on this narrative.

[10] The Eco-Innovation Observatory defines a system eco-innovation as „*a series of connected innovations that improve or create entirely new systems delivering specific functions with a reduced overall environmental impact*" (EIO, 2013a).

1.2 Understanding the Innovation System

The Innovation

"I have worked roughly 14 years for the biggest car leasing company in the world. And basically I bumped into solar energy, related to electric vehicles and leasing electric vehicles. And then the whole puzzle fell together because I thought, I know this model inside out—car leasing and hassle-free mobility—and solar panels have next to a great financial return also a great sustainable return. So the only thing that prevents mass adaptation of decentralized solar energy is hassle-free solar energy by removing the investment, hassle and risk barrier. And that is how we started with Solease."

(Pierre Vermeulen, Solease)

Innovations in the area of solar PV are usually associated with technical improvements. Facing a historically experienced learning rate of 22 %[11], it has made remarkable progress in reducing costs (IRENA, 2012); and historically, no other energy technology has shown such a high learning rate over such a long period of time (OECD/IEA, 2008). This has made solar PV to a mature, proven and competitive technology (see also section on "Future Market Potential").

Recent innovations in the solar PV area are rather of a financial and organisational than a technological nature. The reason lies in the technology learning curve driving the levelized costs of electricity of solar PV systems, which are competing against local electricity prices on respective markets (Breyer et al., 2009). This has made solar PV electricity competitive with electricity retrieved from the grid in various markets. It has reached so-called grid parity (see also section on "Current Market").

This narrative puts its spotlights on the gap that has grown between competitive solar PV technologies on the one hand and a lack of rooftop installations of solar PV systems on grid parity markets on the other hand (EPIA, 2014; Greenpeace and EPIA, 2011). This gap can be filled by a business model that changes the way in which solar PV technology is perceived and used by the end customer (residential homeowners, commercial or industrial customers[12]). For several reasons—like for example high upfront costs and difficulties in handling a solar PV system (see also following sections)—self-financing and owning a solar PV system is not always the preferred solution for every potential customer. Taking into account the number of available rooftops, the share of potential customers is quite large. This has paved the way for measures helping to overcome cost and handling barriers. The business model of selling solar services are such a measure: instead of selling the solar PV system to the end customer, it is first purchased by an intermediary company and then leased and placed at the disposal of the end customer who is able to use the electricity generated on his roof for a monthly fixed price. The product sold by the intermediary company is the access and the allowance to use solar energy being produced on the customer's roof, but not anymore the solar PV system itself. Since the intermediary company keeps the ownership of the system, not the customer but the company is responsible for additional services such as selection, installation, monitoring, repair etc. (see table below).

Due to these range of services, this narrative has been coined "Selling Solar Services". However, terms used in business practice are manifold and comprise for example: solar lease, solar power purchase agreement, rent model, fee-for-service, third party ownership etc. and in parts also energy contracting.

[11] Corresponding to 22 % price reduction for each doubling of cumulative volume.
[12] An average residential household has around 3 kWp on this roof, whereas the commercial customer has 250 kWp installed.

Selling solar services change the traditional business model of how solar PV is distributed. In order to better understand the mechanisms of this business model, the nine pillars that typically form the logics of a business model (Osterwalder et al., 2005) are discussed with regard to the solar service business model, see following table.

Table 1. Understanding the Business Model of Selling Solar Services-

Business model pillars of the Selling Solar Services-business model	
1. Product	The customer buys reliable supply of (solar) electricity. This includes the allowance to make use of the energy being produced by solar panels on his roof. Additional value adding services comprise as selection and planning of the appropriate system, financing, insurance, installation, monitoring, maintenance, repair, and removal.
2. Target customer	In principal, all rooftop owners are of interest. In practice, companies serve either residential and/or commercial customers. Due to unclear ownership structures and authorities to decide, buildings with more than one user are not yet included.
3. Distribution channel	The service providing company can use typical distribution channels such as online platforms, telephone hotlines or conventional selling points, including intermediary service providers (such as installers).
4. Relationship with customer	Due to the strong service-orientation, the relationship between the company and the customer can be characterized as very close. It begins with the planning of the system and ends after a couple of years with the removal or sale of the system.
5. Value configuration	The ownership of the solar PV assets is kept by the solar service providing company. It is responsible for further value adding services.
6. Core competence	The core competence is to offer those services that are in turn not core competence of the customer. Thereby the service company develops into a one-stop shop that offers a worry-free package.
7. Partner network	A large and well-functioning partner network is essential to the business model. It can comprise investors, manufacturers, insurers, organizers, installers, and site hosts.
8. Cost structure	Solar PV systems are typically characterized by high upfront investment costs. Since the value proposition is based on monthly customer fees after couple of years only, companies deciding for this business model will need to base their business activities on a high amount of equity capital or loan capital.
9. Revenue model	Revenue is generated by monthly fees.

Selling solar services competes with two alternative pathways: 1) the traditional energy supply via electricity from the grid and 2) the purchase of a solar PV system either via one-off-payments or bank loans. However, what is the reason that makes the solar services-model to a realistic purchase decision option compared with these two alternatives? Interviewing experts has revealed the following sales arguments:

- **Sales argument 1: Cost savings from the first day**
  In comparison with the traditional energy-from-the-grid option, the end customer saves costs. While costs for solar PV technology have fallen remarkably over the past years, the contrary trend is shown for conventional electricity prices for end-consumers. First, the intersection of these two trends has indicated cost neutral installations of solar PV. Today, solar service providers advertise themselves even with promised savings from day one on.

- **Sales argument 2: Self-consumption allows independency from energy market developments**
  Furthermore in comparison with the traditional option, the client can become independent from energy supply and energy price developments, at least in large parts. For example, in combination with

storage solutions, a 60 to 80 % self-supply of renewable energy would be possible[13]. (Geo-)political developments pointing into the direction of a prospectively unsecure energy supply may support the customer in deciding for an energy market-independent and self-sufficient energy supply.

- **Sales argument 3: Solar energy is clean and stems from a renewable source**
  Although electricity supply has been a low interest product for a long while, in times of climate change and the transformation of energy systems, the own energy supply and its sources is of increasing interest and is developing into an emotionally charged issue. For example, a survey among European citizens has indicated that people are more favourable to renewable energy, in particular solar energy than any other energy sources such as natural gas, coal, and nuclear energy, (European Commission, 2011). Thus, retrieving energy from a renewable source instead of a non-renewable fossil or nuclear energy-based source may represent a further reason, why customers decide for a solar service-option instead of the traditional grid option.

- **Sales argument 4: Financing distributes high upfront costs over a longer time period**
  Despite decreasing costs for solar PV systems making it a competitive option in comparison with grid electricity, the technology is characterized by high upfront costs[14]. While this might not be a barrier for all potential customers, it does indeed represent a hurdle for lower income households—or companies that need to invest their liquid assets otherwise, e.g. in new machines. For those customers, the leasing option is much more interesting than the buying option.

- **Sales argument 5: One-stop shop offering a worry-free package**
  When it comes to the competing option of simply self-financing the purchase of a solar PV system, the reasons named above are all still true. However, the main sales argument can be traced back to the circumstance that customers prefer a 'one-stop shop' that is offering a 'worry-free' and 'nothing-to-care-about' package. The reason behind can be found in the complex interrelations and legislation of the energy market, the wide variety of PV technology options, the missing knowledge of installing, repairing and removing a solar PV system. To put it simply, planning, installing, running and removing a PV system do not belong to the core competences of neither private homeowners nor commercial and industrial rooftop owners. Companies providing expert knowledge in these fields of uncertainty provide trust in the solar PV technology on the own roof. Solar service providing companies find their justification for existence mostly in exactly this argumentation.

Apart from this customer-related view towards solar eervices, this business model is particularly interesting from another perspective—the perspective of systemic eco-innovation fostering a carbon-free and circular economy. Selling solar services as a business model differs from both the traditional energy supply and the self-financed purchase of a solar PV system in many ways. Though both target customer and distribution channel only change marginally—if at all—all other elements of the so-called business model canvas change. While this business model could be referred to a radical innovation, because it leads to a new logic of how value is created (Lüdeke-Freund, 2014) and hence could be seen as radical business model innovation, however, it could be also interpreted as a simply new application of the already existing leasing idea model to another sector and product group.

Though not being radically new, what becomes clear from the following discussions of this innovation's environmental and social benefits and innovation system functions, is that it can be interpreted as 1) an eco-innovation that has 2) a systemic character. "*Systemic eco-innovations produce the most wide-ranging changes and can be defined as a series of connected changes improving or creating novel functional systems*

[13] Based on expert assessment.
[14] For example, the costs for an average residential rooftop system (around 15 panels with each 3 kWp) are estimated at about € 5,000 to € 8,000 (based on expert assessment).

leading to positive impacts on the environment", (EIO, 2013b). Selling solar services can lead to a reduction of natural resources used, as for instance included in solar PV modules, and decrease the release of harmful substances such as CO_2 emissions across the whole life cycle—defining its eco-innovation property[15]. Additionally, selling solar services can be seen as one of many jigsaw pieces in the whole transformation of the energy system, beginning at a point short where technological maturity and competitiveness of PV has been (mostly) realized—and before the point at which energy supply is completely renewable, decentralized and individually managed. Linking these both developments, or "*series of connected changes*", refers to its systemic character.

Current Market

> "*We are not afraid of the competition because we really think that we have developed a good product. However, the market is so small that it would be even helpful to have more competitors. Because this would help to make this business model and its mechanisms more known. Then, talks with potential end-customers would rather be about why for example the offer from DZ-4 is much better compared with the offer from another solar service provider than about the business model mechanisms in general.*"
>
> (Tobias Schütt, DZ-4)

Globally, in the last few years, competitiveness of solar PV technology has remarkably improved. This can be traced back to large cost reductions in module and system prices[16] (BSW Solar and Inter Solar, 2014): In most markets, prices for PV systems have divided by three and module prices have divided by five and it is assumed that in the future costs of electricity from PV in different parts of the world will converge[17] (OECD/IEA, 2014). As consequence of the past cost reductions, in some global markets it has already become more economical to self-consume PV electricity than buying it from the utility grid, because the levelized cost of electricity of decentralised solar PV systems is increasingly falling below the variable portion of retail electricity prices. According to a Deutsche Bank market analysis, "*[s]olar is currently competitive without subsidies in at least 19 markets globally and we expect more markets to reach grid parity in 2014 as system prices decline further*" (Deutsche Bank Markets Research, 2014)[18]. Seven of these 19 markets can be found in the EU, they comprise Germany (residential and industrial), Italy (residential and industrial), Spain (residential) and Greece (residential and industrial), see following figure. Regarding all EU countries, analyses from IPCC expect solar power reaching grid parity—and thus becoming competitive with grid electricity—by 2017[19].

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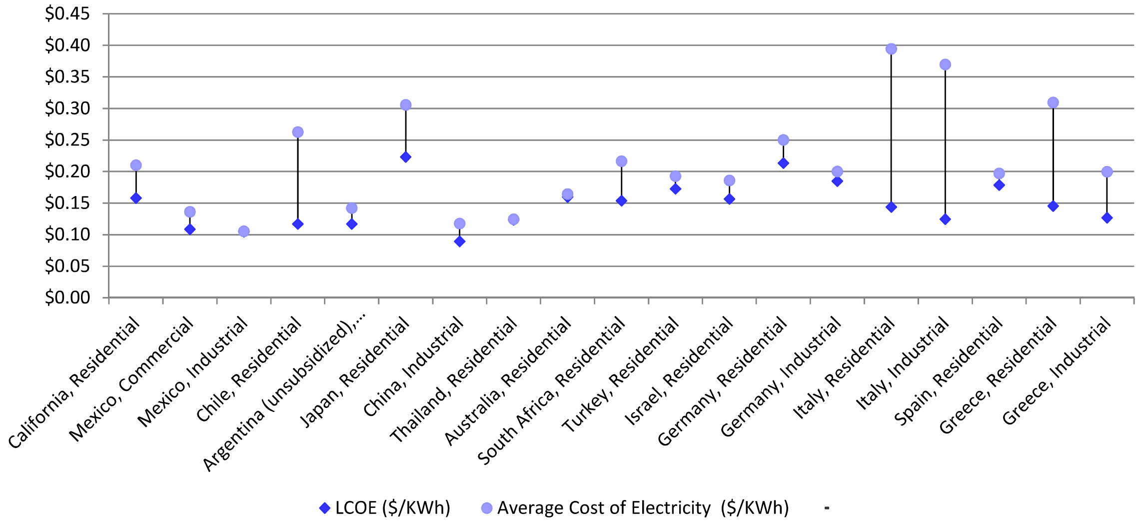
[15] Referring to the definition of eco-innovation according to the Eco-Innovation Observatory (EIO, 2010).
[16] For example, in the U.S., reported prices of residential and commercial PV systems (<5 MW and/or roof-mounted) have declined 6-7 % per year on average from 1998 to 2013—and by 12-15 % from 2012 to 2013 (depending on the system size)—and are expected to further decrease (Feldman et al., 2014).
[17] Average cost reductions will be 25 % by 2020, 45 % by 2030, and 65 % by 2050.
[18] Other sources that report on European grid parity markets comprise for example: (Deutsche Bank Markets Research, 2015), (Citi Research, 2014), (Frankel et al., 2014), (Breyer and Gerlach, 2013), and (IEA, 2013).
[19] http://www.euractiv.com/specialreport-solarpower/ipcc-author-solar-power-reach-gr-interview-505060 (published: 26.5.2011) (accessed: 21.11.2014)



Source: (Deutsche Bank Markets Research, 2014)

Figure 1. Markets at Grid Parity

With more than 80 GW total by the end of 2013, Europe has continued to operate more solar PV capacity than any other region in the world. However, the existing European solar PV market is quite heterogeneous and one can hardly speak of one solar market. It is stated that solar PV is still concentrated in just a few regions within Europe[20], and that there is still strong and almost untapped potential for solar PV growth in European countries (EPIA, 2014). The residential segment represents less than 5 % of the cumulative PV capacity in Slovakia, Spain, Bulgaria, Romania, and Slovenia, whereas it accounts for more than 50 % of the cumulative PV capacity in Denmark, Netherlands, Czech Republic and Belgium. Besides its unequal distribution among the Member States, untapped potential is said to consist in areas such as roofs and building surfaces, "*[f]or example, 40 % of the European Union's total electricity demand in 2020 could be met if all suitable roofs and facades were covered with solar panels*" (Greenpeace and EPIA, 2011)[21]. In a 2013 survey among EU-28 citizens[22], only 5 % of the respondents stated that they had installed equipment, such as solar panels generating renewable electricity, as an action to fight climate change (European Commission, 2013). However, analyses expect that utility-scale systems and rooftop systems will each have half of the future market (OECD/IEA, 2014).

[20] http://www.pv-power-plants.com/industry/europe-a-heterogeneous-pv-market/ (accessed: 18.11.2014)

[21] Based on data from Sunrise project (EPIA).

[22] The survey was conducted between the 23.11.2013 and the 2.12.2013. More than 27,000 respondents from different social and demographic groups were interviewed face- to-face at home in their mother tongue.

1.3 Estimation of the Investment Case

Investment Strategy

"We operate in a conservative industry called energy supply. Solar PV systems are sustainable decentralized power plants, which will last for 25 years or more. It is possible to generate a return on investment of up to 20 % per year."

(Pierre Vermeulen, Solease)

Costs for solar PV technology incur primarily upfront. This holds true also for selling solar services whose investment costs in the initial business phase account for the highest share of expenditures (remaining costs cover services such as insurance, installation, maintenance and repair)[23]. However, once built, solar PV generates electricity almost for free. Therefore, this business case is under discussion here.

Indeed, in 2014, one of the biggest categories of renewable energy investment worldwide was small-distributed capacity, largely rooftop solar, at US$ 73.5 billion, corresponding to a 34 % increase compared with the previous year (Bloomberg, 2015), see also following table. For example in the U.S., the residential solar PV market experienced more than 50 % growth, largely being attributed to the widespread availability and increasing diversity of financing solutions (recently also comprising direct ownership).

However, despite these trends, companies active in the market of solar services, either entering the market or further diffusing their activities, still report a lack of public and private financing (see also section on "Resources Mobilization" below). For example, DZ-4 has reported that the business year 2014 could have been more successful, if more investments were realized. And Solease pointed out that if they were still in their initial market phase with a lower track record, the problem of acquiring funding would be as difficult as back in 2011, when their business started.

Table 2. Global Investment in Small-Distributed Capacity in 2014

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
8.6	10.3	9.5	14.1	22.3	33.4	62.2	76.1	78.8	54.9	73.5

Source: (Bloomberg, 2015)
Note: All values in US$ billion

So why is it that retrieving funding from an investor is still difficult? Looking at it with investors' eyes, investing into a business model that sells solar services, means in effect investing into the physical assets of the service providing company—that is the solar PV systems being leased and installed on the customers' rooftops. This can be realized for example by means of a financial fund by which the solar PV up-front investments are covered and into which the contractual agreed payments are paid on a monthly basis. However, despite significantly decreasing prices for solar PV technology, the investment into solar services is very capital-intensive and thus the payback period can be considered as long.

For example, the costs for an average residential rooftop system (around 15 panels with each 3 kWp) are estimated at about € 5,000 to € 8,000[24]. Additionally, upfront costs comprise installations costs, too. When it comes to storage solutions, average costs are even higher. DZ-4 has reported investment costs of

[23] Based on expert assessment.
[24] Based on expert assessment.

roughly € 10,000 for solar PV systems without storage, and approximately € 20,000 for solar PV systems including a storage solution. Thus, pre-financing the solar PV assets for a group of 100 end-customers, which would be a realistic target for the first two business years of a solar service providing start-up, would require upfront investment costs of already around one million Euros without storage, and two million Euros including storage. It is the balance between capital expenditure (CAPEX) and operational expenditure (OPEX) that determines the Total Cost of Ownership (TCO) and thus the attractiveness for investors to participate in selling solar services. In the following section, elements that determine the unattractiveness and attractiveness of an investment into the capital-intensive solar service business are discussed:

1. **Why Selling Solar Services can be perceived as an unattractive investment option:**
   Selling Solar Services suffer from a rather high risk perception by investors, especially since all the biggest part of investments needs to be realized beforehand. Investments into solar services are not only quite high but also their financial return is presumably lower (e.g. when compared to an IT service model) and comes with delay, because it is designed for a period of at least ten years. Furthermore, the invested money is bound into fixed physical assets that cannot be easily converted into liquid resources, since their stay on the customers' roofs is contractually agreed. Interviewed solar service providers have reported that investors seeking for a promising investment option are scared off by the complex interrelations and rather unforeseeable political and economic developments that are usually associated with an investment into a business aiming to become active on the energy market. Interviews with representatives of possible investors have furthermore revealed that the current absence of a secondary market for once leased solar PV systems that would secure reacquisition of liquid assets (in case the company goes insolvent or the contract reaches its end), is a further possible reason that prevents financiers from an investment decision into solar services.

2. **Why Selling Solar Services can be perceived as an attractive investment option:**
   An investment being bound to an existing physical asset, in terms of a solar PV system, also brings advantages. For example, investing into selling solar services means to invest into existing fixed assets, thus in tangible commodities. Solar PV is a mature technology with a current life expectancy of roughly 20 to 30 years for installed systems and only a little need to repair in between. The risk profile of this investment can be considered low. Regardless of the fact that the service provider is successful or becomes insolvent, the solar PV systems themselves loose neither their functionality nor their value. It is even this long lifetime expectation that has prevented the development of a secondary market—an argument named by potential funders to explain why solar service investments are less convincing (see above). However, with the on-going further diffusion of solar PV technology, a reverse stream of solar PV systems and valuable waste as well as the development of respective secondary market including recycling structures can be expected in the next 10 to 20 years. Interviews with solar service providers have revealed that they see themselves as traditional and extremely conservative investment option, that is indeed high investment costs, but also a foreseeable and secure return on investment in a wide but given timeframe. And while upfront investment costs are very high, the operating costs—comprising for example costs for insurance, monitoring, maintenance, repairs if necessary—are modest. Therefore, investors know from the very beginning, when and to what amount they will receive their financial return. Additionally, the usual type of end-customer is a private homeowner whose creditworthiness is usually rated highly. A further argument for the solar service option is the diversification of risks in a portfolio when it comes to technical breakdowns—because in case a solar PV system breaks, only one customer is affected. This is in contrast to a centralized solar PV park where one breakdown would lead to a much larger supply failure affecting a bigger group of customers. However, the most convincing argument for investing into solar service businesses has been put forward by Solease: "*Try to find a European citizen who says, 'I am against sustainability, and I am also against saving or earning money'. You can't find them. It is a mass conversion concept.*" The business model of selling solar services can work financially and is therefore able to attract customers,

who, as a cherry on the cake, can also change to a more sustainable energy solution. With adjustments in the range between 10 to 30 %[25], the business model concept of selling solar services can be rolled out to other (European) markets, and is in this respect a mass conversion concept.

Table 3. Assessing Unattractiveness and Attractiveness of Investments into Selling Solar Services

Rather unattractive investment option	Rather attractive investment option
High upfront investment costs being bound to physical assets for a long period	Solar PV is mature technology with long life expectancy and little need to repair etc.
Moderate financial return distributed over a longer time span	Investment is a fixed asset, a system that does not loose functionality and value in case the company goes bankrupt
Energy market associated with complex interrelations and fast and unpredictable changes	Secondary market is about to develop in the next 10 to 20 years
Secondary market not yet existing	Conservative business model with a foreseeable return on investment after certain period of time
	Upfront costs are high but operating costs represent only a mere fraction
	Usual target group is private homeowners, with a usual low share of private bankruptcies
	Diversification of technical breakdown risks via the portfolio effect
	Model works financially and is sustainable, therefore attracting customers plus can be rolled out to more markets making it a mass conversion concept

The interviews performed with representatives of selling solar service start-ups have painted an interesting picture of successfully acquired sources of founding, respectively types of investors. It were not only the traditional funders such as banks, business angels or big players such as incumbent energy supply companies that decided to invest in solar services but rather innovative forms of funding and actors being active in the energy market and therefore equipped with a prerequisite to understand the mechanisms and chances of success of the business model. Amongst others, innovative sources of funds reported comprise:

1. **Venture Competition of Dutch Climate-KIC:**
   In 2012, Solease won the Dutch Climate KIC Venture Competition. This annually held competition aims to identify the ultimate clean tech starter company with the potential to lead the way in Europe with a product contributing to solving the climate problem. Furthermore, this programme helps in bringing the awarded commercial solution to market. Apart from coaching and further support, as a winner, Solease has received € 75,000 in grants in three stages. The company reported, that winning the Climate-KIC competition has been the breakthrough for Solease, "*in the beginning, the only one who helped us, was Climate-KIC*". Apart from the financial funding, Solease won not only its first customer via the Climate-KIC network but especially credibility, which is most important for a start-up company always fighting against a lack of reputation.

2. **Equity-based crowd-funding:**
   In addition to three conventional financing rounds with which DZ-4 has financed its first systems, it has also decided for the innovative form of finance acquisition via a crowd-funding round. More precisely, it used crowd-funding for a refinancing of already built systems. The concept is the following one: Not all citizens interested in solar PV are able to decide for a solar service option, for example because they live in an apartment building with an ambiguous situation for installing a solar PV system on their roof. Another chance for making them a part of the solar PV story is to make them to small-scale investors

[25] Based on expert assessment.

and profiteers of the transition towards an energy system based on renewables. In concrete terms, supporters deciding for an investment will receive a yearly interest rate of 4.5 % to 5 %, with an annual 10 % repayment of their loan. Additionally, they have a share in a 20 % distribution of profits, making the investment to a profit-participating loan. In summer 2014, interested investors had the chance to participate with at least € 250 and a maximum of € 10,000. Finally, within 11 days DZ-4 was able to receive € 180,000 of funding from 143 investors, with an average participation of € 1,259 per investor. With this investment round, DZ-4 was able to refinance roughly 40 % of its portfolio (corresponding to 28 systems, partly including storage solutions) at that time (around € 468,000)[26].

Future Market Potential

> *"I don't think we are a solar lease company. We are basically an energy company of the future. That is what we are. In Europe we are however clearly lagging behind the U.S. They are two steps ahead of us currently, we need to catch up. And we need to catch up fast."*
>
> (Pierre Vermeulen, Solease)

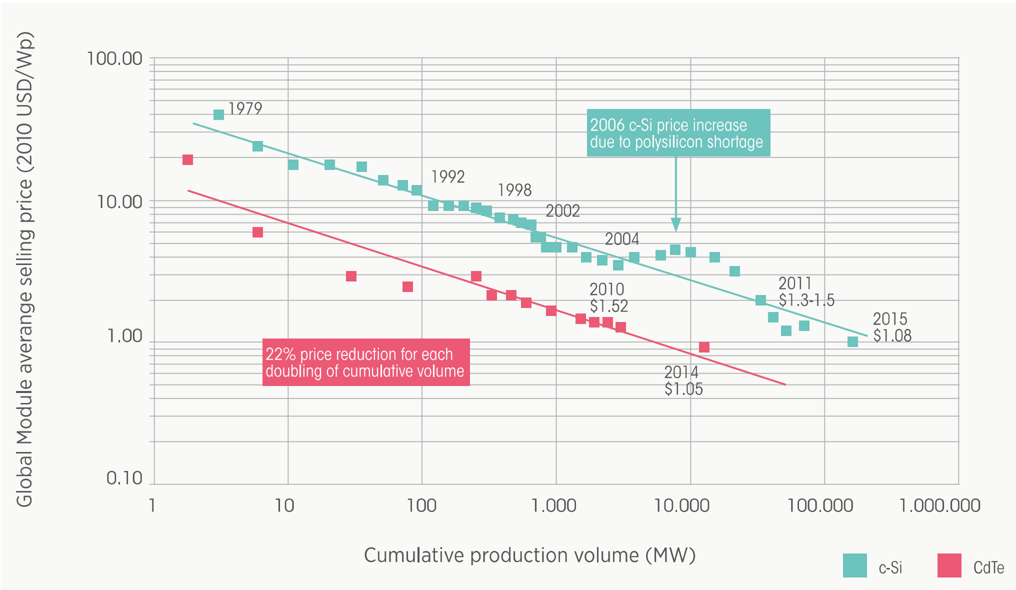
The future market potential for solar services is considerable. Evidence for this assessment stems from various developments—that in their interplay are expected to lead to a higher demand for rooftop-based solar services:

- **Technology learning curve, rising quality and large cost reductions:**
  Over the last decades, the learning rate, respectively, experience curve of solar PV has been on a stable 20 % level. That means that with each doubling of the cumulated module production, module prices have decreased by about 20 %. At the same time, quality has been improved. The cost reductions and quality improvements stem from economies of scale and technological improvements resulting from extensive research and development activities as well as continued support for solar PV market development ensuring the required experience and scale effects, (BSW Solar and Inter Solar, 2014; EPIA and Photovoltaic Technology Platform, 2010; IRENA, 2012; OECD/IEA, 2008, 2014). Further 40 % solar systems cost reduction for over the next 4 to 5 years are expected, due to declining solar module costs, gradual improvements of panel efficiencies, scale and competition, declining global financing and customer acquisition costs (Deutsche Bank Markets Research, 2015). The following figure depicts the global development of PV prices between 1979 and 2015.

- **Decreasing LCoE and increasing grid parity:**
  However, besides the increasing technology learning and large cost reductions for modules and systems, more relevant for the diffusion of the solar PV technology is its costs per kWh generated. It is reported that depending on the location, the annual output (being proportional to the annual irradiation) varies from 700-800 kWh/kWp in the Northern Scandinavian countries to more than 1500 kWh/kWp in the South of Spain and Italy, Greece and Turkey. Based on these outputs, PV electricity generation cost ranges from ~0.22 €/kWh in the North of Europe to ~0.12 €/kWh in the South (data from 2012) and is expected to significantly decrease with the range of 0.14 - 0.07 €/kWh in almost all of Europe by 2020, (EPIA and Photovoltaic Technology Platform, 2010). In comparison with the levelized cost of electricity from the utility grid, the levelized cost of solar electricity determines whether solar PV is economically attractive. As consequence of the past cost reductions, in some global markets it has already become more economical to self-consume PV electricity than buying it from the utility grid,

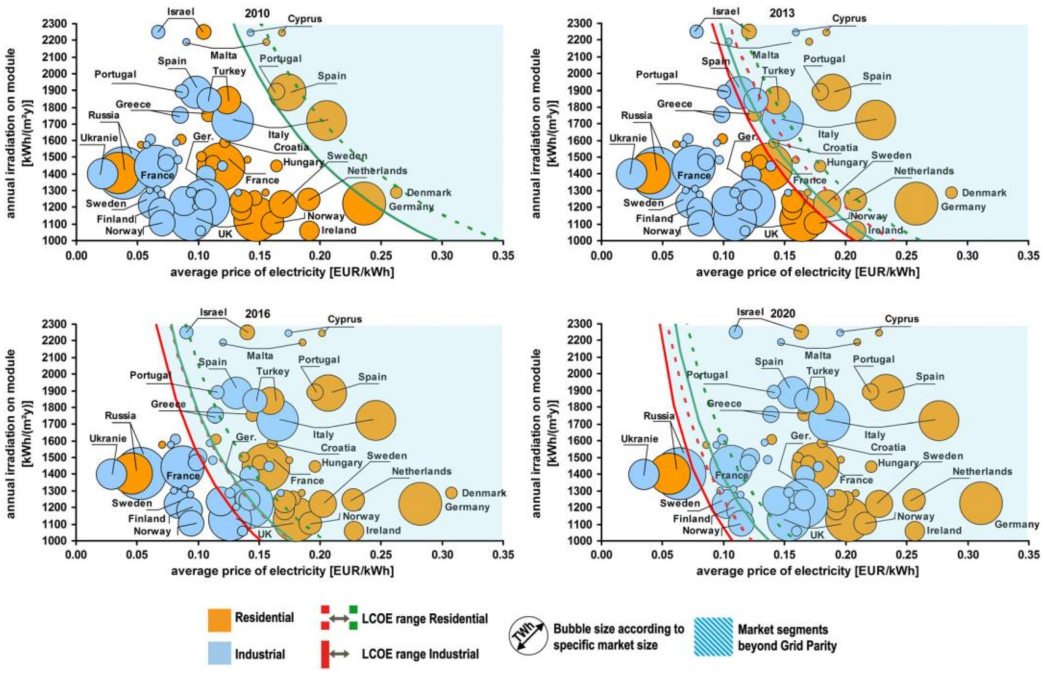
[26] https://www.econeers.de/investmentchancen/dz4

because the levelized costs of decentralized solar PV are increasingly falling below the variable portion of retail electricity prices. The following figure shows an analysis of grid parity on European markets for 2010, 2013, 2016 and 2020—it shows that all residential EU markets, will have reached grid parity in 2020.



Source: (IRENA, 2012) based on data from (EPIA and Photovoltaic Technology Platform, 2010; Liebreich, 2011)

Figure 2. The Global PV Module Price Learning Curve for C-SI Wafer-Based and CdTe Modules, 1979 to 2015

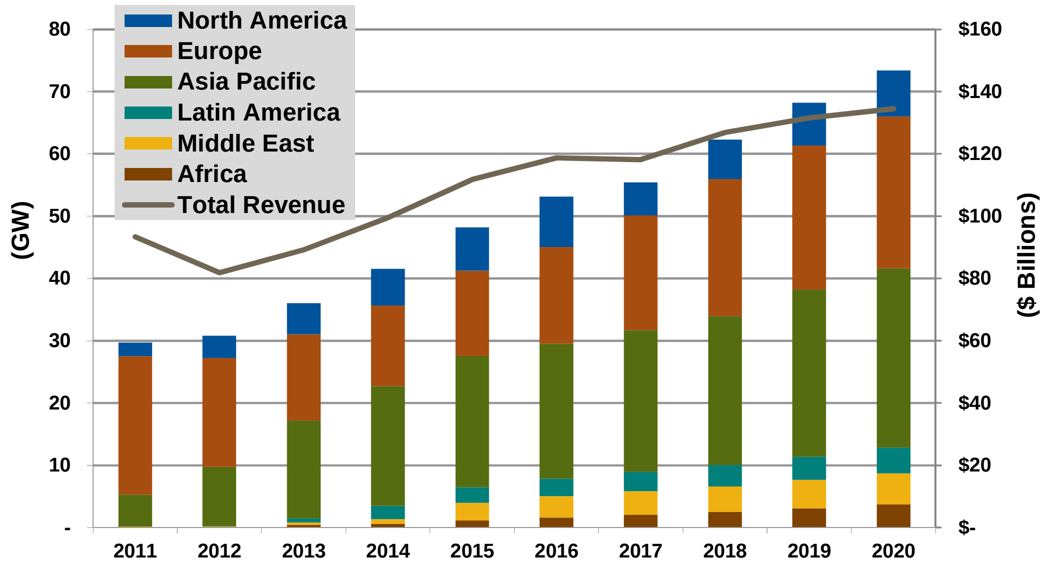


Source: (Breyer and Gerlach, 2013)

Note: European countries are rated by their population-weighted solar irradiation and electricity prices of the major market segments.

Figure 3. Grid-parity analysis for Europe in 2010 (top left), 2013 (top right), 2016 (bottom left) and 2020 (bottom right)

- **Increasing solar PV installations:**
  Taken together, large cost reductions, realization of grid parity in an increasing number of markets and the trend towards decentralized energy systems and self-consumption have the potential to lead to a wider diffusion of solar PV. For instance, in Europe, around 25 GW are expected to be installed in 2020 (in comparison, with 14 GW in 2015), to represent a global share of 34 %. Assuming that revenues per GW installed are equally distributed among the different world regions, solar PV installations in Europe could generate an annual revenue of around US$ 46 billion, in 2020 (facing a global revenue of US$ 134 billion), (Navigant Research, 2013). The following figure shows the annual solar PV installed capacity and revenue by region between 2011 and 2020.



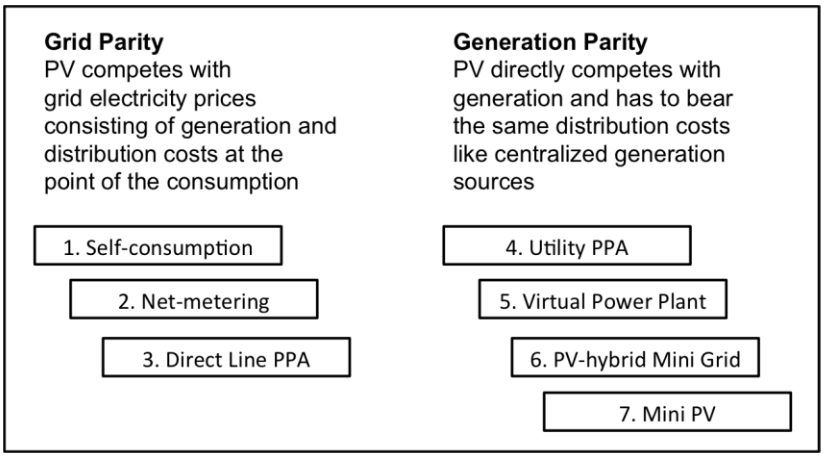
Source: (Navigant Research, 2013)

Figure 4. Annual Solar PV Installed Capacity and Revenue by Region (2011-2020)

In those solar markets that are characterized by a high distribution, these developments (and referring to the sales arguments discussed above) will open up a gap that allows for the rise of various new PV business models, for one possible overview see following figure. One of these new business models is selling solar services[27]. All interviews with already active market players have revealed that an increasing demand and growing market for solar services is expected. In five years, respondents see themselves even more on the solar service market.

Interviews have also shown that further developments and amendments of selling solar services could comprise the options of a changed product and changed target group: If not already included, the degree of sufficiency with self-produced solar energy and hence independency from the energy market could be enlarged by including storage solutions. Latter ones are able to provide up to 80 % of self-produced solar energy[28]. Also, if not already included, in addition to private end-customers (3 kWp), the target group could also include commercial customers (250 kWp) and vice versa. Additionally, the target group of multi-tenant properties could be tapped—however this is currently legally restricted and difficult to understand and realize.

[27] Selling Solar Services is not decidedly mentioned in the figure, since the latter one portraits only one of several possible structures. For another approach see for example (Frantzis et al., 2008).
[28] Based on expert assessment.



Source: Own illustration based on (BSW Solar and Inter Solar, 2014)
Note: 1. Self-consumption: PV system owner and electricity consumer is the same legal entity.
2. Net metering: PV generation that is not directly consumed on-site is fed into the grid and balanced by credits or by reversed metering. 3. Direct Line PPA: The PV system owner sells the electricity within the same building or via a direct line to a nearby consumer. 4. Utility PPA: Supply of PV electricity to a utility or the distribution grid operator is structured via a power purchase agreement (PPA) for a feed-in-tariff. 5. Virtual Power Plant: sale of PV electricity at the electricity exchange often via pooling of several PV plants. 6. PV-hybrid Mini Grid: Inclusion of grid infrastructure, other generation and storage to reliably supply residential, commercial or industrial demand. 7. Mini PV: Flexible use for a single purpose and without grid connections.

Figure 5. Solar PV Business Models

However, interviews have also shown that all solar service entrepreneurs are pursuing a vision that is beyond those rather incremental business model developments of slight product-service changes such as the inclusion of storage solutions or widening the target group by including commercial and industrial customers. Instead, solar services is not regarded as a standalone solution but is rather seen as an entry into a holistic home energy management including combined solutions for home and e-mobility, yet even comprising neighbourhood supply via local grids. Following future developments could be expected:

- **Different wording**
  Especially due to the market entrance of bigger energy companies being able to provide solar services on a completely different scale, solar services will loose their lease, respectively rent character. This will be reflected in different wording and labels. Thus, energy supply companies would less offer solar leasing or solar rent offers but—with respect to the wording of this narrative—"solar services". Then, for example, potential end-customers among themselves could ask each other "*Why don't you change your roof into an energy roof?*" instead of "*Why don't you put solar PV panels on your roof with a solar lease contract?*".

- **New building standards**
  Solar PV systems and storage solutions enable households or companies to be almost energy independent, 80 % of the energy needed stems from the sun, only the remaining 20 % need to be obtained from the utility grid. While presently only a share of buildings is equipped with these solutions, in the future they will belong to the standard facility of new buildings. Solar service companies could then already become a part of the building planning process.

- **Holistic energy solutions**
  The energy supply of the future will be an individually tailored, but holistic energy management. For example, solar PV energy stemming from the rooftop could be used to load, and yet to discharge e-cars. Also, the discharge of e-cars and feeding their energy back into the home energy cycle is conceivable ('vehicle-to-grid'). That requires an intelligent combination of solar PV and charging infrastructure. This market development is already driven by activities of Google and Apple. Solar

service companies of today could become less European counterpart but the more small-scale system integrators of tomorrow.

- **Digitalized managed neighbourhood energy supply in small grids**
  In the future, solar PV producers could be compensated for grid-stabilizing measures by feeding in their surplus self-produced energy into the grid. Another way of treating surplus energy is to share it with close residents within small-scale neighbourhood grids. For example, why shouldn't a furniture store sells its surplus energy to the catering booth on its parking place? All these solutions require an intelligent digitalized and standardizes energy management. This could be a role being filled out by solar service companies.

- **Crowd funding with shared responsibilities**
  New forms of financing, such as crowd funding, will further push the diffusion of solar PV and will continue to shift responsibilities of energy companies from energy supply to energy service companies. Different models are conceivable, for example, public participation funds could finance municipal decentralized solar PV projects. While a group of citizens finances and uses the solar energy, the energy company plans, organizes, installs, couples, maintenances, repairs the solar technology. Profit is shared among municipal community and company.

Referring to this vision, it becomes evident that the trend towards decentralized self-supply of energy of European citizens and companies is less a potential opportunity that incumbent energy companies could jump on—it is rather a crucial imperative for them to remain an integral part of the energy supply game. Decentralized energy production allowing the self-supply with renewable energy is a trend that cannot be turned back.

In addition to the effect the solar service model is expected to unfold with respect to the energy market, a further future market-related question is for which and how many other high-investment products this leasing business model can be applied and repeated? Areas coming into question could comprise houses, e-mobility infrastructure, very complex semiconductors and medical equipment.

Employment Effects

"But it's everything, it is installation, it is insurance, it is logistics. We are basically creating jobs in the EU, which cannot be outsourced... A system, which we put on the roof for a Dutch homeowner will be installed by a Dutch company. It will be Dutch and European job creation. This is what is also great about this."

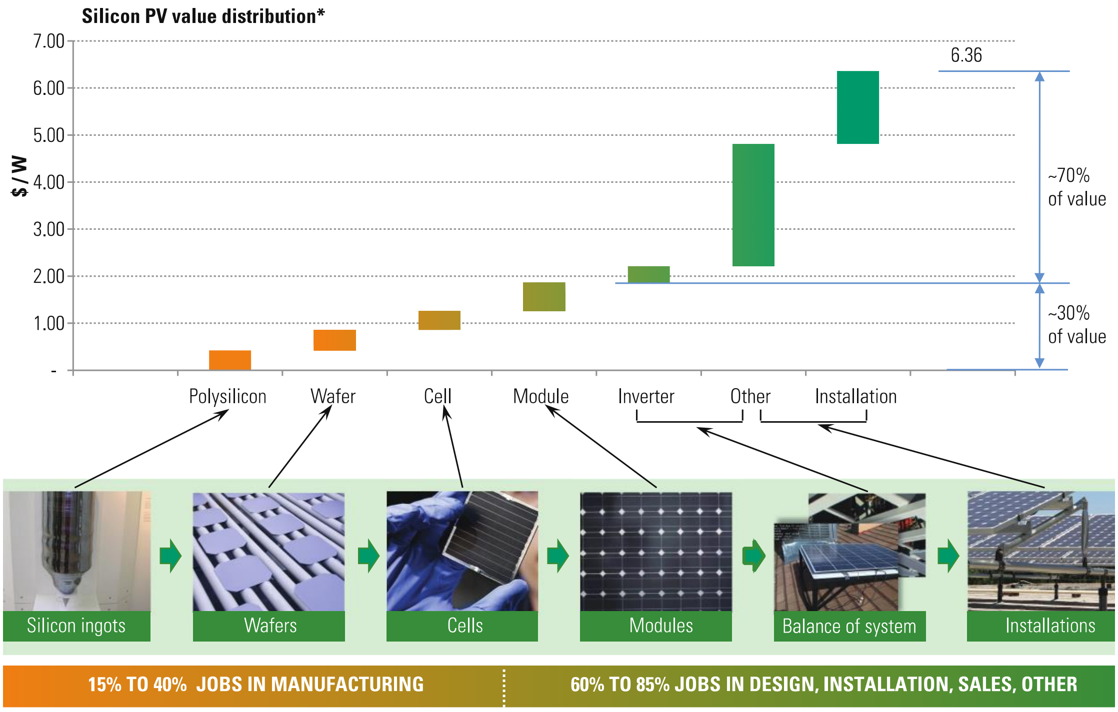
(Pierre Vermeulen, Solease)

The business model innovation of selling solar services has a decisive influence on employment within the solar value chain:

1. **Positive effect on net job creation in the solar chain:**
   First, the business model of solar services clearly aims at the diffusion of solar PV. Residential households or commercial buildings that are now obtaining their energy from the grid will switch to solar energy and thereby initiate respective activities in the solar PV manufacturing and service chain. The increased demand will therefore lead to a multiple of activities compared with the current level. In the current market phase of the solar services that is characterized by an increasing market share of already active companies but still a very small market, it is rather a shift of jobs between conventional

selling to leasing options. Meaning that for example the same workmen that have installed solar PV systems under an outright purchase contract are now installing solar PV systems under a leasing contract. Nevertheless, in the long run, the installers will have more orders simply because more people decide for a solar PV system in the frame of a service contract. Therefore, it can be assumed that solar services have the potential to induce a positive employment net effect.

2. **Large part of job creation in service activities and therefore in the EU:**
   Second, since this business model is decidedly not only technology-oriented but includes the provision of additional services for the time period of the lease contract, above all, it creates jobs in the service sector. Studies of the U.S. silicon PV value chain have observed that "*[i]n mature [solar] markets, value creation is also not concentrated on manufacturing*", (NRDC, 2012). In the U.S., about 30 % of the value along the silicon PV value chain is attributed to cells and modules, the remaining 70 % of value does lie downstream, comprising inverters, balance of the system, mounting, site preparation, labour, and other activities such as engineering, permitting, legal processes, financing, and distribution, see the following figure. Therefore—unlike as the manufacturing of solar PV that has moved from Europe (and the U.S.) to Asia, notably China and Taipei, especially because of their capability to make use of economies of scale in large new production facilities (OECD/IEA, 2014)—solar service create jobs locally, that is within the cities and other areas of the EU. It is about jobs that cannot be exported or lost to non-EU economies and thus have a direct employment and wealth effect on the EU.



*Based on unsubsidized value chain analysis of U.S. silicon PV market. Roughly similar value distribution for thin film technologies.

Source: GTM Research prepared for Solar Energy Industries Association (U.S.A), "U.S. Solar Energy Trade Assessment 2011: Trade Flows and Domestic Content for Solar Energy-Related Goods and Services in the United States."August 2011; European Photovoltaic Industry Association and Greenpeace, "Solar Generation: Solar Electricity for Over One Billion People and Two Million Jobs by 2020" Sept 2006; EPIA, Greenpeace. "Solar Generation 6: Solar Photovoltaic Electricity Empowering the World." 2011; Rutovitz, J. and Atherton, A., Institute for Sustainable Future, University of Technology Sydney, "Energy Sector Jobs to 2030: A Global Analysis" 2009; The Solar Foundation. "National Solar Jobs Census 2011." 2011.

Source: (NRDC, 2012)

Figure 6. Jobs and Value Created in Silicon PV Value Chains

Interviews with companies offering solar services have revealed anecdotal evidence for following job creation effects: Each of the companies has been active on the solar service market for around two years. During this time, each entrepreneurial entity (either a firm or a company's department) was able to create between five and eight jobs[29]. While this number of direct jobs seems to be low, it has to be taken into account that those companies understand themselves as lean companies and have outsourced a wide range of activities. Thus, the more interesting job creation of a business being active in solar services should be expected in the indirect sphere, or in the downstream part of the value chain. The interviews have revealed that for each of the direct jobs in the service-providing company itself, roughly 10 to 20 jobs are created indirectly in the area of downstream activities, such as insurance, logistics, installation, maintenance, monitoring and repair[30]. Solease also explains its plans for the coming five years: while a number of direct jobs should be enlarged to 50, the factor for indirect job creation could and should increase to 100—meaning that 5,000 jobs could be created indirectly by Solease if it has created 50 direct jobs.

However, these numbers hold only true for the downstream part. Studies have shown that the production of solar PV systems—no matter if distributed via outright purchase or leasing—creates additionally also jobs in the upstream manufacturing part in a range between 15 and 40 %, see also table below (NRDC, 2012). That would mean that in the Solease-scenario of future 50 direct and 500 indirect jobs, additional jobs in the upstream manufacturing part could comprise between 97 (15 %) and 366 (40 %) jobs.

Table 4. Distribution of Jobs Across the Solar Value Chain

<table>
<tr><th>Data source</th><th>Manufacturing</th><th>Installation</th><th>Sales</th><th>Other</th></tr>
<tr><td>(Greenpeace and EPIA, 2011):
(global average for 2010-2020)</td><td>25-40 %</td><td colspan="2">60-70 %</td><td>up to 5 %</td></tr>
<tr><td>(Rutovitz and Atherton, 2009):
(global average for 2008)</td><td>24 %</td><td colspan="3">76 %</td></tr>
<tr><td>(The Solar Foundation, 2011):
(U.S. average for 2010 to 2011)</td><td>15 %</td><td>55 %</td><td>26 %</td><td>4 %</td></tr>
</table>

Source: (NRDC, 2012)

From a macro perspective, "*[c]onsidering the expected growth in the [PV] industry, the job creation potential is considerable*", (European Photovoltaic Technology Platform, 2013). On average, 30 full-time equivalent (FTE) jobs are created for each MW of solar power modules produced and installed[31,32,33] (Greenpeace and EPIA, 2011). Based on these figures and in combination with the scenario for future market potential of solar PV (25 GW in 2020), the potential for future global annual job creation can be assessed: As outlined above, the scenario's assessment of the future solar PV development follows the assumption of different trends: Decreasing costs for solar PV systems and modules lead to grid parity on more markets, and open up new business model opportunities "*In distributed solar PV markets, innovative finance options are merging that will make the technology available to more homeowners*" (Navigant Research, 2013). Provided that European installations of new solar PV capacity will have reached more than 25 GW in 2020, this might generate more than 750,000 FTE jobs. This number of jobs solely takes into account research and development, production and installation—however it does not include losses in

[29] Not necessarily full time equivalent jobs, however close to that.
[30] Based on expert assessment.
[31] The European Photovoltaic Technology Platform states that every MW of PV power installed is creating around 50 jobs in production, installation, research and distribution activities (European Photovoltaic Technology Platform, 2013).
[32] However, taking into account discrepancies between countries, between companies and between technologies these numbers can be rather seen as a worldwide average rather than a precise European-focused estimate.
[33] The lever for employment takes into account the following part of the selling solar power-value chain: research centres, producers of silicon, wafers, cells, modules and other components, and also installers. Presumably[33], it does not include those jobs that are connected with distribution, operation and remanufacturing, nor indirectly created jobs and those jobs that are lost in the conventional energy industry

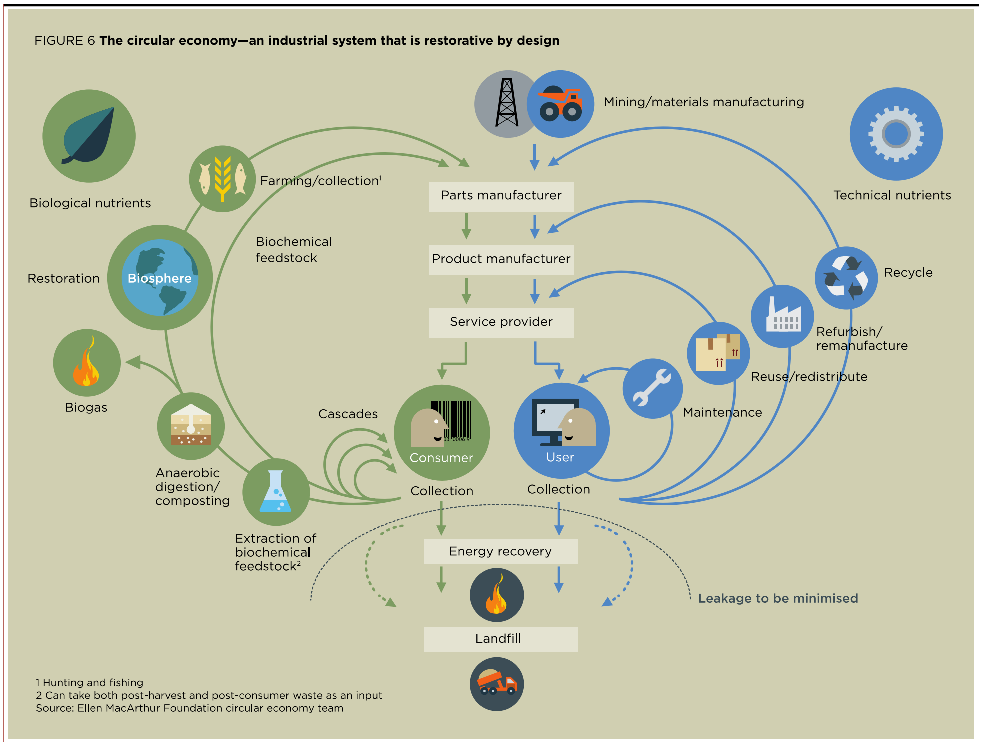
conventional energy sector, jobs in distribution, operation and remanufacturing and other multiplier effects of job creation.

Referring to the average distribution of jobs across the solar value chain presented in the table above (The Solar Foundation, 2011), these 750,000 jobs would cover 70 % of the solar chain part (15 % manufacturing, 55 % installation)—leaving another 26 % to sales and 4 % to other activities (corresponding to 321,000 jobs). That means that more than 1 million jobs[34] could be created in 2020 through a further diffusion of solar PV, made available via solar service business models. At the same time, only the minor part of jobs will be found in the solar service-providing company itself.

Environmental and Social Benefits

> *"If you want to create a real sustainable society and a circular economy, we have to move from an economic model based on outright purchase towards one based on lease and Total Cost of Ownership, because this is the only way where suppliers like us and manufacturers have an incentive to build a sustainable product."*
>
> (Pierre Vermeulen, Solease)

A diffusion of the solar services could support Europe's transition to a circular economy. As such is also contributes to the Europe 2020 goal of a sustainable and low-carbon Europe that is using its resources more efficiently. This also applies to the circular economy, which is defined as "*an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design*", (Ellen MacArthur Foundation, 2013).



Source: (Ellen MacArthur Foundation, 2013)

[34] Due to the combination of different sources, and thus different methodologies, a statement regaridng the type of job—being a FTE job or not—is hardly possible.

Figure 7. Mechanisms of a Circular Economy

Referring to this definition, selling solar services contributes to a transition towards a more circular economy through the following circular economy characteristics:

1. **Renewable energy basis:**
   It is evident that the uptake of the solar services contributes to the diffusion of solar PV, which in turn leads to a larger share of energy provision by renewable solar energy and a reduction of greenhouse gas emissions harmful to the climate. Greenhouse gas emissions (GHG) are responsible for global warming and climate change. Residential buildings running light, air-conditioning and equipment are responsible for large amounts of GHG emissions, if their power supply is not based on renewable energy sources. In the EU-28, residential buildings (and commercial and public services) were responsible for more than 400 million tonnes of CO_2 emissions in 2011 (The World Bank, 2014). Solar PV has a negligible environmental footprint, and producing electricity with solar PV does not emit any greenhouse gases (Greenpeace and EPIA, 2011). The 'energy payback'[35] time for solar PV systems is between 1.5 and 2.5 years (depending on the used system, technology and geographical location), (Fraunhofer ISE, 2012). Facing an assumed life expectancy of 30 years (and more), the net clean electricity consumption of a solar module is approximately between 92 and 95 %. Thus, replacing the conventional energy supply by self-generated solar power would reduce the emissions stemming from the residential sector. Targeting the reduction of GHG emissions produced by the residential sector would therefore represent an effective lever to realize the goal of a low-carbon economy based on renewable energies.
   All solar service companies interviewed are offering a solar power flat rate, meaning that the end customer pays a monthly fixed fee for the solar service. No matter if the customers make use of the energy produced on their roofs or not, they are paying the same price. What they do pay however, is the additionally obtained energy from the grid[36]. Therefore, in order to keep the paid price for additional grid energy as low as possible, there is a natural incentive for the customers to use as much as possible from the more cost-efficient and climate-friendly solar (flat rate) energy—and to reduce the share of additional grid-obtained energy as far as possible.

2. **Efficient (re)use of resources and prevention of waste:**
   The solar service model belongs to a group of business models that are typically associated with a needed transition of production and consumption patterns within a circular economy, such as result-oriented product-service systems, functional sales, leasing society. They all have in common that the use of a product (or the result of using a product) instead of its one-way consumption is sold. This is automatically combined with new ownership and cost incentive structures. Not the roof owner but the service providing company has and keeps the ownership of the solar PV system installed. As more or less life-long owner of the system, the service provider has the incentive to reduce their total costs of ownership (TCO), and therefore to create a cost optimum taking into account their costs of acquisition and also operating and disposal costs. Generally, aiming for integral cost reduction as such is not a surprising component of economic activities, and is well developed in the high-tech equipment sector. Product reliability and reparability are an integral element of the design process in that sector. In the case of solar services, the entrepreneur is interested in operating a system, which runs at optimal costs more or less frictionless for a lifetime of 25 to 35 years and is easy to maintain and repair[37]. This in turn

[35] The energy payback captures the idea that it also „takes energy to save energy“—mainly relating to the fact that energy (and associated with this also CO2 emissions) was input to the manufacturing process, too. It answers the question „How long does a PV system have to operate to recover the energy—and associated generation of pollution and CO_2—that went into making the system, in the first place?“ (The National Renewable Energy Laboratory, 2004).

[36] As long as solar PV panels on the roof are not combined with storage solutions in the cellar, a virtual self-sufficient energy consumption is not possible and needs to be supplemented by energy from the grid.

[37] According to expert assessment, with a couple of exceptions the available quality of solar PV technology in terms of modules is already on a high and homogeneous quality level. Conergy has stated, an incentive to produce qualitative and long-living parts is

requires a resource-efficient design of the PV system referring to three aspects: 1) because of the contract model a service provider does not have the incentive to sell as many panels as possible but instead an optimized (mostly lower) number of panels; 2) the use of reliable long-living parts and systems reduces the number and associated costs of repairs; 3) it entails an appropriate system design and right choice of materials enabling the effective and efficient remanufacturing of systems and recycling of system materials.

While the influence of a solar PV diffusion on the goals of a low carbon-economy is quite obvious, the connection between lease-based business models and environmental benefits of a circular economy in terms of efficient use and re-use of resources is depending on the concrete business model realization (Fischer et al., 2012; Tukker et al., 2006). Therefore, the interviews conducted especially targeted the questions if and how the solar service business model refers to the resource efficiency and waste aspect of circular economy goals:

2.1 Individual customer and roof-related planning of the system:

For example, respondents have confirmed that their incentive is not to sell as many solar PV panels as possible but instead the optimized number that can differ from end-customer to end-customer, no matter if in the B2B or in the B2C area. Therefore, they conduct a very extensive energy and rooftop check in each of the customers. Additionally, DZ-4 has reported that commissions paid to sales partners are not based on the size of the installed system anymore but on the number (and kind) of products sold.

2.2 Thinking in TCO terms leads to use of reliable long-living parts and systems:

When it comes to the long-living parts, the interview with Conergy, the worldwide operating downstream solar company and manufacturer of solar PV modules, has not confirmed the existence of different incentives between an outright purchase model on the one hand, and a lease-based service model on the other hand. However, incentives might exist for manufacturers producing equipment with a moderate to bad quality. According to interviews with solar service start-up entrepreneurs, the PV technology supply side comprises not only high quality products, for example regarding inverters and storage solution. It are these companies, on which a solar lease model could have an effect. Solease explains it like this: "*In an outright purchase model, there is no inherent incentive to put quality panels on the roof*." While, however, in a lease situation, the incentive structure is different. The solar service provider is the one that reacts to the customer wish and controls thereby the whole value chain. The customer is mainly interested in a reliable supply of (enough) electricity and how much they have to pay for that. That means in turn that the service provider will choose this brand of solar PV panels that is characterized by the lowest total costs of ownership (TCO). For example, all respondents confirm to act as cost-efficient and quality optimizing as possible. Since their costs are influenced by the parts' error rate they aim to use reliable long-living parts and systems**.** RWE puts it like that, "*no matter at which point of lifecycle the technology currently is, we continuously observe the market regarding innovation, quality and costs. It cannot be the case that we need to go to the customer and repair their systems every three weeks.*" Trianel amends, "*when you are responsible for such a small part system for a period of 18 years, you really need to make sure that this operates failure-free*". DZ-4 has mentioned a further aspect into the game: Solar service providers have an insurance that becomes effective in case solar PV systems break. Since also the insurance has a strong interest in keeping their costs low, both parties have contractually agreed a standard of quality ensuring that only high-quality components are allowed for use. This quality standard is a list of concrete modules and power inverters. At the same time, installers need to meet certain criteria—all fulfilling the purpose of

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already represented by comparatively long periods of guarantee —12 years are Conergy's warranty time for solar PV modules. Referring to the whole sector, 10 years for PV modules and 5 years for inverters are already standard. The aim is to produce in a way "that the end-customer is not able to play the "warranty" card.

preventing the case of repair work, costs and resources.

2.3 Thinking in TCO terms enables the effective and efficient remanufacturing of systems and recycling of system materials:

Regarding parts and materials that are easily and therefore cost-efficiently to recycle, Solease has confirmed that it is again the TCO mechanism that sets the incentive for a sustainable and therefore cost-efficient behaviour. The TCO may become lower when the solar PV panels can be easier and better remanufactured and parts and materials (such as glass, ferrous and non-ferrous metals, certain semiconductor materials and junction boxes and cables) recycled. According to Solease, "*lower TCO are always linked with a sustainable product—and vice versa*". In this way, the Selling Solar Services model has a very positive influence on job creation in the remanufacturing and repairing sectors, thus minimizing waste and preserving value at a higher value than in a linear purchasing model. This combination of job creation and value preservation forms the basis under the broad support for the circular economy.

1.4 Innovation System Functioning

Function 1. Entrepreneurial Activities (EA)

The idea of not selling a solar PV system but offering hassle-free solar services instead is new. According to expert assessments, this concept finds itself in the rollout phase since the beginning of 2015. The years before it was accompanied first by disbelief from investors and conventional energy companies and later by scepticism that this model would ever “learn to fly”. First market activities have roughly started in 2012, and pioneer market players were mainly start-ups. However, those were continuously and actively observed by old-established energy market participants. For example in the German market, DZ-4 has been the first company offering solar services to private customers in 2012, and in 2012 the incumbent energy supply company RWE has been first mover in the German commercial and industrial customer market. Meanwhile the idea has spread, according to expert assessment, 15 to 20 % of German utility companies have included solar services in their product range already. Nevertheless, the market is still at its very beginnings and has not yet developed its potential size at all. Potential end-customers are usually not aware of the existence of a solar service offer, let alone the mechanisms of the service package. Therefore, active companies are rather “busy” with explaining their business model in general instead of explaining, why and how their business model is different and “better” than the ones offered by their competitors. Although main mechanisms of the solar service business models from the entrepreneurs interviewed are similar, there are also differences. The PV system is installed by the service-providing or a partner company, the ownership does not pass on to the rooftop owners, who are however allowed to use the energy. Customers do pay a monthly fee, and are compensated for surplus and not used energy. Differences do exist regarding certain business model building blocks, such as contract duration and cancellation periods, amount of monthly fee, price of additional energy supply, inclusion of storage solutions, target group etc. Besides the interviewed respondents stemming from companies being active on the solar service-market, other companies active on the European market do comprise for instance the French Upsolar and the Dutch Zonline:

- Since 2013, Upsolar, a leading international provider of solar PV modules, runs a “Pass Locasolaire” program that enables homeowners across France to earn additional income by leasing the space on their rooftops for solar electric systems. During the first year of operation it offers participating homeowners up to € 500 for rooftop rental, followed by a yearly payment equal to 15 % of the generated power’s value. While rooftop lease programs have been a key part of growing the residential solar market in other regions, this model has been slower to catch on in France**.** Drawing on its experience developing high-quality modules and the relationships it has built with top installers in France, Upsolar is the first module manufacturer to offer French homeowners this alternative financing model[38].

- Starting in 2011, Zonline has been offering residential rooftop solar power systems to Dutch homeowners via a fixed-rate pricing model. Zonline’s customers agree to pay a fixed rate for the electricity generated for 20 years, while the installation is for free. In 2011, Sungevity, a key player in the residential solar power U.S. market became a joint venture partner of Zonline by taking an equity stage in Zonline in order to demonstrate replicability of their business model in emerging grid parity markets[39]. Although "not being the sunniest place in Europe", the Dutch market is of special interest

[38] http://www.businesswire.com/news/home/20131119006921/en/Upsolar-Brings-Rooftop-Leasing-Program-French-Market (published: 20.11.2013), (accessed: 1.12.2014)
[39] http://www.bloomberg.com/news/2011-11-18/zonline-s-netherlands-rooftop-solar-model-emulates-u-s-leases.html (published: 18.11.2011) (accessed: 18.11.2014)

for the U.S. investor, because it has high electricity rates but low solar subsidies—the Netherlands "*is therefore a great testing ground for our model in an unsubsidized roll-out*"[40]. In 2014, Sungevity has converted its stake in Zonline to full ownership, rebranding the company as Sungevity Netherlands (http://www.sungevity.nl/)[41]. Additionally, it declared partnership with utility company E.ON Benelux under which Sungevity offers its solar power services to E.ON's base of customers. It is expected that this partnership will expand to other European countries in the near future.[42]

Box 1. Evidence Base for Function 1 "Entrepreneurial Activities" (EA)

Solease is a Dutch start-up that has been founded in 2011. Solease is selling hassle- and risk-free solar energy and aims to "*remove all barriers that people have and to make sure that they switch to decentralized production as soon as possible, because it makes sustainable sense, it makes financial sense, it is actually a total no-brainer. You'll be completely crazy not to do it*". Within its business model, Solease purchases the solar system, installs it and takes care of maintenance, repairs and insurance. In addition, it provides additional value added services like system monitoring, reporting and energy saving measures. The initial focus was on private customers (3 kWp on the roof), offering solar energy from 14 panels for a monthly fee of € 55. From the first day, customers are able to reduce their energy bill by about 10 to 15 %. The contract duration is in principle 15 years but still flexible. Each month the customer can handover the system to a new homeowner, buy the system or give it back to Solease. The exit options are each performed at cost price, in order to demonstrate to the customer that Solease is not generating profits in case the lease contract is terminated earlier. Recently, due to the SDE+ subsidy Solease has started to offer its services also for commercial customers (250 kWp on the roof), because each project, "*which is in the money*" is something where Solease wants to offer its solar service package.

One of the main aspects why **DZ-4** has decided to develop a solar lease-based business model was the conclusion that potential customers would be able to save energy costs. DZ-4 understands its service package as a "one-stop shop" because DZ-4 takes care of all hassles accompanying the operation of a solar PV system, such as equipment selection, procurement, installation, operation, monitoring, maintenance, insurance and removal. DZ-4 became active in 2011, which was the point at which storage solutions, offering the customer a better supply quote of self-produced renewable energy, have become less expensive and it was to be expected that further cost reductions would follow. In this respect, DZ-4 differs from the other discussed business models since it contains not only the solar service that makes it possible to deliver solar energy not only by day but also by night. Target group are residential homeowners that can choose between two tariffs—with or without storage solutions. In the latter option, the additional energy provided is certified eco-power from the grid. Generally, customers pay a fixed monthly fee that is dependent from the option they choose (with storage solutions being around 20 to 30 % higher) but also from their annual energy consumption. Additionally, they also pay for the additional electricity consumed from the grid. At the same time, they also receive a monthly compensation for energy fed into the grid corresponding to the EEG rules. The contract duration is at least 10 years—afterwards, the system can be bought, further leased or returned to DZ-4, respectively, DZ-4 is then renting the roof. Finally, after up to 25 years, the system is either bought or simply removed.

Trianel is a European municipal utility cooperation that aims for a collective realization of projects, which would not be possible to stem if the municipal utilities acted alone. Therewith, Trianel is active solely on the B2B market. Amongst others it develops white label products and business models that can be easily adopted by its partner utilities. One solution developed back in 2012 and now provided is "Energiedach" that gives utilities assistance regarding the deployment of solar services via rooftop-based PV systems including and storage solutions. Meanwhile, "Energiedach" has evolved into the lead product of Trianel's energy contracting white label options that are three in number. 35 of the Trianel partners are working with the "Energiedach" product. While Trianel's direct customers are local utilities (in Germany, the Netherlands, Austria and Switzerland), the end-user target

[40] http://www.sungevity.nl/sungevity-nieuws/internationaal/Sungevity%20starts%20parntership%20with%20Zonline (published: 12.11.2011) (accessed: 1.12.2014)
[41] http://www.sungevity.com/news/release_2014_06_04.php (published: 4.6.2014) (accessed: 1.12.2014)
[42] http://www.reneweconomy.com.au/2014/sungevity-teams-with-germanys-e-on-to-scale-residential-solar-59205 (published: 5.6.2014) (accessed: 18.11.2014)

group comprises as well residential rooftop as commercial rooftop owners. The solar service provided includes planning, financing, installation, maintenance and repair of the solar technology solutions. The "Energiedach" solution mainly focuses on the financing and distribution activities, while other activities such as insurance, procurement, logistics, installation and maintenance etc. are offered to the end-customer but are however outsourced to other value chain members, such as the engineering, procurement, and construction (EPC) service provider Conergy. The contract duration is 18 years, during which the end-customer pays a fixed monthly fee.

In 2012, **RWE** has developed its solar service-product "RWE Photovoltaic Pachtmodell". The target group to which the service is sold is the commercial end-customer that is usually facing upfront investment costs in a larger order of magnitude, supporting them to invest in more business core process-related assets and activities. The solar service offered includes customer-related planning and design of the system, financing, installation, monitoring, and repair, cleaning and maintenance of the system is the responsibility of the customer. RWE also offers the energy from the grid the customer needs to obtain in case that the rooftop energy produced is not sufficient. Additionally, the customer can decide for a contracting option that analyses and optimizes lighting performance. Storage service is not yet included since the needed size for B2B storage solutions is too big compared with the size of currently available qualitative and reliable storage technology. Nevertheless, a combination with storage solutions is assessed as ideal, especially for those companies actively in the day and without shift operation. Due to the diversity of offered services, RWE partners with a variety of companies of the upstream and downstream value chain, such as EPC service provider like Conergy. Contract duration are 18 years, after that time the contract can be prolonged, or the system is purchased by the customer or removed by RWE. During the contract period the end-customer pays a monthly fixed fee.

Conergy is a worldwide operating downstream solar company, specialized in the design, financing, building and operation of high performance solar systems for homes, businesses and utility-scale power. It cooperates with Trianel in the B2C market and with RWE in the B2B market. Despite that Conergy is still active in the outright purchase market, Conergy's role in its solar service cooperations is to realize the solar service from a technical point of view. While Trianel (and utilities) and RWE do offer the business model concept and are responsible for "soft" activities like customer acquisition and sales activities, Conergy designs the PV systems, manages and plans the system installation, however, again in cooperation with local craftsmen. In short, Conergy is responsible for the engineering part and manages the installation network. Though not active on the sales part, Conergy reports about a rising customer interest in the mechanism of the solar service business model.

Function 2. Knowledge Development (KDev)

On part of the entrepreneurs, the development of knowledge regarding the setup, mechanisms and contractual set of agreements of the Selling Solar Services-business model has been different from respondent to respondent. In large parts, the successful US models have served as a blueprint. Backed by tax equity, solar has become mainstream in the U.S.—with "Corporate America" being on board[43]. Within only a couple of years, starting with pioneer activities in 2007[44] and taking off in 2012, "*third-party financing of solar PV has become the predominant business model in some of the largest residential markets in the U.S.*"[45]. For example, California has seen a sustained growth in new residential solar PV installations, from which 75 % were leased in 2012 (as opposed to 7 % leased in 2007), (Hobbs et al.,

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[43] http://www.baltimoresun.com/business/bs-bz-businesses-going-solar-20131020-story.html#page=1 (published: 20.10.2013), (accessed 18.11.2014)

[44] Pioneering companies comprise SunRun, SolarCityCorporation, SunPower, Sungevity, RealGoodsSolar, SunEdison and ClearPowerFinance. They all have a unique business model. They differentiate themselves for example by post-installation services such as system monitoring, customer back-end experience, distribution channels, capital structure etc. http://www.greentechmedia.com/articles/read/can-you-name-all-the-residential-solar-lease-providers (published: 26.3.2013), (accessed: 18.11.2014)

[45] http://www.greentechmedia.com/research/report/u.s.-residential-solar-pv-financing (published: 11.2.2013), (accessed: 18.11.2014)

2013)[46]. Taking the country as a whole, in 2013, 66 % of residential solar was realized by third-party-ownership business concepts (42 % in 2011), outpacing the overall U.S. market (41 %)[47]. According to a research report, it is expected that this share will peak in 2014 at 68 % and exceed 1 GW for the first time (and then fall[48] to 63 % by 2018)[49]. Analysts see several reasons to believe that the "gold rush" in the U.S. American solar sector will even continue—amongst others, the availability of the residential leasing option offered by highly profitable solar leasing companies is supposed to act as significant growth catalyst will let the second solar PV "gold rush" begin (Deutsche Bank Markets Research, 2014). Best practices from the U.S. are noticeably gaining foothold in other countries, such as European countries, however also in Australia and Canada.

Most respondents have confirmed that U.S. business models have served as a blueprint for their business model development. However, models have not just copied one-to-one but were analysed and reconfigured in consideration of the specific market conditions. Apart from the U.S. models being a best practice blueprint, it has become evident that especially start-up entrepreneurs have had a past in at least related business areas such as the leasing of cars, or even within the solar lease business itself like in the U.S., that helped them to implement the concept of solar services. For early moving bigger energy companies, the knowledge development process has started with the realization that the energy market is changing towards decentralized self-consumption energy models. In cooperation with a variety of partners, changing the traditional structure and distribution of work of the traditional solar value chain, common solar service knowledge has been jointly developed. Another form of knowledge development of bigger utility companies comprised direct high-level talks with the solar lease start-ups but also mystery shopping at the pioneer firms in order to gain insights into the innovative set of contractual agreements. Generally, the level of knowledge development can be considered as sufficient. According to expert assessment, with individual adjustments in the range between 10 to 30 %[50], the business model concept of Selling Solar Services can be rolled out to other (European) markets, and is in this respect a mass conversion concept.

Box 2. Evidence Base for function 2 "Knowledge Development" (KDev)

Before starting with **Solease**, founder Pierre Vermeulen has worked 14 years long for the largest car leasing company in the world. Learning how to think in (car) leasing terms and structures, such as being orientated towards total costs of ownership, has paved the way for developing an own business based on leasing mechanisms, however being focused on solar energy as main object of interest. At the time the idea came up, own market analyses had revealed that there were already companies doing that—in the United States. Although they were still at their very beginning, the U.S. models served as "*a great inspiration*" and it became clear that "*this business model can work and that this model does add value*". The fine-tuning of Solease's business model principles was then shaped by several visits to successful Silicon Valley-based solar leasing companies "*to talk to all of them*". Besides the fact that due to differences between the American and the European / Dutch energy market, a one-to-one copy of business model mechanisms would not be possible anyway, Solease sees itself as a hybrid model that combines the best characteristics from the US based companies into one globally competitive model.

According to **DZ-4** founder Tobias Schütt, who was working for the Conergy group in the U.S. at the time when SolarCity and Sunrun started their activities, the success of the local solar lease businesses has triggered the idea to consider the introduction of the solar lease business model to the German market. In this respect, the U.S. models

[46] However, California is a particular case since it has a history of leadership and energy and climate policy, for example, in the last quarter of 2010, it was able to capture 50 % of global venture capital funding for clean-tech (Mandell and Kelsey, 2011).
[47] http://www.greentechmedia.com/research/report/u.s.-residential-solar-financing-2014-2018
(published 24.6.2014), (accessed: 18.11.2014)
[48] Due to further declining PV system costs and a higher level of availability of solar loans.
[49] http://www.greentechmedia.com/articles/read/Market-Share-for-Leasing-Residential-Solar-to-Peak-in-2014
(published: 23.6.2014) (accessed: 18.11.2014)
[50] Based on expert assessment.

have served as an inspiration; however, from the very beginning it was clear that a German model has to be different from the American approach. For example, while the U.S. models are based on a net metering mechanism, the German market is based on feed-in-tariffs that do not allow using the grid as a buffer for the self-produced energy, unlike the U.S. models, at least from an accounting perspective. In addition to the blueprint from overseas, having Jigar Shah, the founder of SunEdison, and Hanns-Ferdinand Müller, former CEO of RWE Vertrieb AG, in the DZ-4 company advisory board has been in another regard helpful for the business concept refinement. Nevertheless, from the first idea back in 2010 it took DZ-4 roughly two man-years to develop and launch their model on the market. While DZ-4 developed its solar service-knowledge via its own pathway, it registered several mystery shopping requests of bigger energy supply companies—at least at the time as the set of contractual agreements was still unique to the Germany energy market.

Regarding the **Trianel** product, US models were not known and have not served as a blueprint. Rather, the initial situation for the solar service business concept was the idea to develop a business model that serves the trend of increasingly desired energy self-consumption but is still economically attractive to the end-user without being based on subsidies right from the start. At the same time it was goal to develop standardized and digitalized business model processes that could be easily repeated by Trianel customers stemming from the B2B area. As a factor of success for its own business model but also for its customers' business models, Trianel has recognized that sales activities need to be standardized and digitalized on a very high level. Potential entry points identified comprise especially interfaces with partners, such as insurers, system providers, logisticians, installers and workmen. Referring again to the US models, while they have not served as a role model during the initial development phase of the Trianel product, meanwhile they are of big interest and have been for example used as inspiration especially for marketing and customer acquisition methods.

RWE has decided for its business model of solar services because of structural changes on the energy market that both required and allowed new customer solutions. It has been observed that decentralized energy supply allowing self-consumption and energy cost reduction is a trend that needs to be addressed by respective products and services. RWE has recognized this is as "*this is the market and sooner or later every entrepreneur will decide for a solar lease service until 2020*". Since RWE is one of the biggest energy companies on the German market, it developed already knowledge and partnerships during its traditional energy activities. However, with the rise of decentralized PV energy solutions, RWE needed to engage stronger in strategic partnerships, especially in the technological sphere with partners such as Conergy. For example in order to develop knowledge enabling RWE to measure and monitor its installed PV systems. The existence and success of the US models were acknowledged, however, they did not directly influence the RWE product-service development.

As an EPC service provider, **Conergy** itself does not offer the solar lease model. Nevertheless, it is active on the solar PV market since 1998. In cooperation with its partners, Conergy has been dealing with solar service activity development since 2001. Knowledge particularly regarding solar services has been developed during the on-going solar service activities, for example leading to completely new fields of product offering and work such as the design of pre-assembled PV systems, the management of a broad installation network and communication with public utilities and energy suppliers. A further effect is a new quality of cooperation each between Conergy, its end-customers, and its installers. While the first ones have significantly longer contract and encountering period, the latter ones are completely giving up their sales activities by receiving the already inspected and planned customer order.

Function 3. Knowledge Diffusion through Networks (KDiff)

In several respects, a further diffusion of knowledge created is highly necessary. Independently from the particular solar service-option, there seems to be a lack of information regarding solar PV technology in general. For example from an investor perspective, solar PV is not attractive, since it is still perceived as an expensive technology that has not yet reached competitiveness (Bazilian et al., 2013). Another lack of knowledge example has been formulated by the co-founder and CEO of one of the largest U.S. solar lease companies, aiming for a replication of the scalable Sungevity business model in European markets. He referred to numerous studies showing that selected European markets are already at grid parity, however only a few people would be aware of that[51]. From a customer perspective, solar PV installed on residential rooftops is not of interest, because of the belief that there is not enough sun and because of the perception that solar PV requires high upfront costs. Apart from a certain gap of knowledge on the part of investors and customers, interviews have revealed that start-up entrepreneurs offering solar services are especially reliant on a continuous information exchange between them and their value chain partners. The biggest challenge for entrepreneurs offering a new business model that contains radically new elements, as solar services do through the changed ownership-structures, lies in winning public attention and confidence from investors and customers. This is also connected with the pre-conditional challenge of being perceived as an existing investment, and / or service option at all.

Hence, events and networks are crucial in producing attention and the occasion of talking to potentially relevant stakeholders. At the emergence of solar service-business models, different events such as workshops and conferences have speeded the knowledge diffusion and supported the creation of value networks. Following examples can be noted:

- "E-world energy & water" is the European leading fair regarding the energy and water industry. Most of its visitors are participating in purchasing and procurement in their respective industries, comprising amongst others energy supply companies, service providers and industry.
- "Climate KIC Venture Competition" events are taking place within the EIT organized "Climate KIC". They provide the opportunity to enlarge the level of awareness especially of innovative start-ups.
- The "Cleantech Forum Europe" traditionally has widely noted solar entrepreneurs. In entrepreneur showcases it brings together investors, corporate executives, potential customers and partners and further decision-makers.

Box 3. Evidence Base for Function 3 "Knowledge Diffusion" (KDiff)

When starting with its business idea, **Solease** has talked to all the big energy companies in the Netherlands because of the belief that only sharing will make an idea happen. Cooperation and mutual support by partners is essential for developing an idea to a successful market product. Nevertheless, at the time Solease was starting its business in 2011, discussing the idea of solar leasing with the incumbent energy companies was too early: "*So we talked to all of them and then we concluded to ourselves, there is no point talking to them now. They are not organized to pick up this opportunity. So, we left it at that*". However in the last months most utilities active in The Netherlands have been in contact again with Solease as now they do see the added value a long-term solar lease could bring. What did help Solease at the time was winning the Dutch edition of the Climate-KIC Venture Competition in 2012. Besides financial sponsorship, Solease has received public attention—making the company and its business idea more credible, and known. Recently, Solease announced a cooperation agreement with Nuon, the Dutch subsidiary of Vattenfall.

Before **DZ-4** was officially founded in 2011, its founder has visited several trade fairs, e.g. the "E-World Energy & Water" in order to discuss the basic idea of solar leasing in Germany with other experts and relevant market players. During that time, initial talks have taken place also with the incumbent energy companies. Back in 2010, the idea was perceived as unrealistic, yet even too imaginative, while in every further year the idea became more realistic. Later, three of the four big German energy players were interested in bilateral talks in order to understand the business model concept. Finally, this has resulted in the previously announced cooperation between DZ-4 and EnBW. Cooperating with a big player is helpful insofar as it provides the start-up with an access to end-customers that is not necessarily possible to get as standalone player. Furthermore, cooperating with an important market participant helps to "educate" the customer. This refers to the fact that the DZ-4 business model is still so new to

[51] http://cleantechnica.com/2014/07/25/talk-sungevity-ceo-andrew-birch/
(published: 25.7.2014), (accessed: 18.11.2014)

the German market and its participants that acquisition talks with potential customers are rather about the business model mechanisms in general than about why for example the offer of DZ-4 is much better than of another solar service provider from the same market. Apart from addressing investors, having a social network that helped to make the solar service concept more known has been evaluated as very valuable by DZ-4. Yet even DZ-4 understands itself as a network company since it cooperates with a variety of 50 partners in distribution, supply and installation.

In the case of **Trianel**, business-model enabling knowledge diffusion has taken place at the trade fair "E-World Energy & Water". An exchange of visions regarding future energy market structures between decision-makers has led to a cooperation project aiming for the development of a white label selling solar service-concept, respectively a concept that can be repeated and applied by various utilities. Trianel rates the regular exchange with partners as very important. However, instead of focusing to a large extent on external fairs and conferences, Trianel itself has built up its own network "Neue Technologien". It consists of 120 partner utilities and includes 16 annual technology and trend-related events, regarding decentralized power generation, e-mobility, energy efficiency and smart metering. These meetings offer the possibility for experience exchange and knowledge diffusion, for example regarding technical problems, customer acquisition, website design etc.

RWE is active player of the German energy market. As such, it is regularly represented on knowledge diffusion events such as respective fairs, conferences, exhibitions etc. Despite its potential influence on these events, it still sees a substantial need in further knowledge diffusion in terms of information about the energy market and as well business model mechanisms towards the end-customer: "*If you lease a solar PV system you will save money from the day one*".

Due to its value chain constellation and its function as an EPC service provider, **Conergy** has not been in the definite urge of both, generating and diffusing particular Selling Solar Services-knowledge.

Function 4. Guidance of the Search (GoS)

Although not directly been tailored to the development of solar services, various political measures have paved the way for the expansion of this business model. Solar services have begun at a stage where political measures supported the diffusion of renewable energies in general. This entails research and development measures with regard to the PV technology itself and includes market incentives such as feed-in-tariffs. It also comprises government actions such as deployment targets for renewables, and solar PV in particular. This kind of support, market incentives and deployment targets, are currently the main drivers of solar PV. They have led to an exponential development of solar PV in the last decade and will continue to do so for markets in which solar PV is not competitive yet (Greenpeace and EPIA, 2011).

When it comes to the diffusion of Selling Solar Services, interviews with market players have revealed that guiding political measures are hardly perceived as a proactive guidance. However, misguiding legal measures have been definitely noticed and reported. Thus, respondents have mainly pointed at those political developments that have the potential to extremely harm the deployment of the solar service-model. For example, in the German Renewables Act, the fee on self-consumed solar energy from the own rooftop sets an incentive that is completely contradictory with the goal of expanding renewable energies. Before in 2014 this fee was decided for systems above 10 kWp in the end, its pre-discussion included also a fee on small-scale PV systems before. Since the benefit of this household fee would have been compensated by the costs of its realization, this discussion can be seen as representative for contradictory signals from energy policy, in this case stemming from the German energy ministry. Generally, it can be stated, that energy market policy throughout the EU is perceived as complex, inconsistent and too short sighted. However, independently from the respective market, entrepreneurs developing a business model need above all trust and confidence in the stability of long-term framework conditions. Thus, expressed in exaggerated terms, non-favourable but long-term policies ensuring a reliable business development framework are assessed more important than favourable but short-term policies.

Box 4. Evidence Base for Function 4 "Guidance of the Search" (GoS)

One of the biggest challenges reported by **Solease** is that the lifespan of governmental institutions and their strategic goals and regulatory measures to achieve these goals are around two to four years. From the perspective of a young company that is working in the extremely dynamic energy market, it is very difficult to plan and to operate with only a two to four years horizon and at the same time being dependent on the legislation that can change rapidly after that time span. "*It is not about subsidizing, it is about knowing what is going to happen in the next 30 years*". What the market needs—and what policy makers would be able to provide is long-term policies. Because if policies change into the adverse direction, financial investors are frightened off, end customers are unsettled—and a company with a financially and sustainable healthy idea can become unnecessarily insolvent. Nevertheless, due to regulatory measures in terms of the recently launched SDE+ subsidy, Solease has started to offer its services also to commercial customers.

DZ-4 has reported that in connection with the last EEG amendment in 2014, it was not clear whether their business model will be able to further exist or if it will be affected by a reformulation targeting the consumption of self-produced electricity. Since especially grid operators have considered the topic of self-consumption critical, one possible option discussed was the taxation of self-produced energy that would lead to another load distribution. While a realization of this option would have represented a serious threat to the DZ-4 and any other business model empowering private persons to consume self-produced electricity, finally, an exception for solar PV systems being below 10 kWp was included. Facing the fact that the technical realization of this option would have cost more than any possible tax revenues, this option has been interpreted as an attack on those new business models.

Trianel reported that extremely high legal expertise has been required to develop and run the solar service-business model. The energy market mechanisms in Germany are assessed as very complex. For example, it is only a fine line between the German concepts of "Leasing" and "Pacht". "Leasing" fulfills the financing function, whereas "Pacht" rather fulfills the service function. "Leasing" requires an expensive license, and offering too many services in the "Pacht" concept however could prevent the EEG-regulated compensation of the end-customer for renewable energy produced. This complex constellation leads to caution on the part of potential service providers. Additionally, the 2014 discussion about the taxation of self-produced energy has been perceived as a strong barrier for the business model of solar services, especially regarding commercial and industrial customers, but also for the general model of the increasing self-sufficiency. Policy expectations regarding a stronger integration of solar PV into the market are hardly to combine with policy measures aiming at the taxation of solar PV energy produced.

One of the decisive factors for **RWE** to run its solar service-business model was the understanding that energy end-customers are increasingly burdened with taxes, duties, cost allocations and grid user fees, and thus rising electricity costs. Offering a decentralized self-consumption energy supply model would represent a competitive alternative and remove the burden from its customers. Electricity prices in Germany include amongst others EEG allocation that has been introduced by the German Renewable Energy Act in order to promote the expansion of renewable energies. At the same time, the EEG allocation allows a compensation for surplus electricity fed into the grid.

Rising prices for conventionally generated electricity and compensation for renewable energy generated, both being determined by legal measures have indirectly guided the RWE's search for its solar service-business model.

Conergy reports about the recently introduced compensation for self-produced solar energy in the German market. From a psychological view, it is difficult to explain to the end-customer why they need to pay a fee for renewable energy. Additionally, the solar service-product becomes even more bulky and complex than it needs to be and therewith further increases the perceived complexity being already on a high level.

Function 5. Market Formation (MF)

While the story in solar power was about hardware and panels earlier, its recent story has been about finance[52]. The push towards a greater utilization of selling solar power-services and creating a respective market is guided mostly by financial incentives—this holds true for all the affected groups, for investors, customers, and the service-providers themselves. Due to the increasing competitiveness of solar PV technology, such as modules and recently starting also storage solutions, grid parity has been reached in a couple of selected world markets, and further are expected to follow. Thus, because solar PV has become competitive with the conventionally produced energy from the grid while offering further advantages such as independency from the energy market, purchasing arguments and therewith, the conditions for the market diffusion of Selling Solar Services are given. While the majority of investors, customers and traditional energy companies have not yet realized and understood the mechanisms of solar service offers, first moving solar service start-up entrepreneurs have realized this opportunity at the most possible early stage. Now following companies such as public utilities or bigger energy supply companies are deciding for the solar service model because of its forward-looking and mandatory character. Or putting it differently, the future lies in self-consumption of rooftop decentralized produced energy. Solar lease services are just the entrance into a new energy age, in which solar PV belongs to the standard building equipment, rooftop energy supplies homes and e-cars, is sold or exchanged with neighbours through little local grids and where citizens do jointly engage for solar service neighbourhood projects. Forced by market developments, energy supply companies of today have no other chance than shifting their business from conventional energy assets to distributed energy solutions if they want to stay an energy company in the future.

Box 5. Evidence Base for Function 5 "Market Formation" (MF)

In comparison with the U.S. market, the Dutch market for solar services has been described by **Solease** as more challenging. Not only that the sun is shining more in California but the financial case of U.S. companies has been much better from their very start because of the solar investment tax credit that gives a 30 % tax credit[53] to the service providing company for solar systems on residential and commercial properties. Although such a financial incentive has not been given in the Netherlands, he sees the tighter Dutch market conditions as a blessing in disguise. "*Here you have to squeeze out inefficiencies and everything to make it profitable. So, it is much harder for us now but in the long run this can prove to be beneficial. The financial business case is a bit worse here than it is in California, therefore we have to come up with a leaner and meaner company.*" Implemented in 2012, the Dutch SDE+ has started to subsidize renewable energy producers. Solar PV is supported if it exceeds a capacity of 15 kWp (private producers of renewable energy do not come into consideration). Due to SDE+, solar leasing has become viable also for big projects. Recently, Solease has started to be active in this commercial market as well. Its aim is to reduce the share of projects, which are awarded but in the end not built (estimated at 40 %). The reason for that installation gap is mostly lack of financing but also the anticipated hassle and risks. This is exactly the point where Solease aims to come into play to add value with their solar lease concept.

Providing the customer with the possibility of a maximized self-supply with renewable energy belongs to the core beliefs of the **DZ-4** concept. However, because the German market is not based on a net metering concept that would allow using the grid as a buffer for the surplus daytime solar energy it was clear that the DZ-4 business model will have to be based on integrated storage solutions. Therefore, DZ-4 has waited with its first market activities until the point at which prices of storage solutions have started to decrease. Although at that time the integration of storage into the business model concept has not been economical, from 2011 on it could be expected that prices would continue to fall and that a storage market was about to develop. Indications for this development were seen

[52] Quoting Andrew Birch (CEO of Sungevity), http://reneweconomy.com.au/2014/sungevity-teams-with-germanys-e-on-to-scale-residential-solar-59205 (published: 5.6.2014), (accessed: 18.11.2014)

[53] Corresponding to a dollar-for-dollar reduction in the income taxes that a company claiming the credit would pay the government.

in an upcoming market incentive programme for storage solutions. Also the fact that big manufacturers such as Panasonic and Sanyo started to be active in that field was crucial for the decision to get the business model started.

Trianel reported that it is a truism, that "*public utilities do only trust public utilities*". That means that once the process is on track, public utilities are convinced not only by the success of other public utilities but also by the amount of utilities having adopted their business model. Such a movement incentivizes public utilities to develop their products according to the role model public utility. Apart from the knowledge diffusion amongst solar service providers, Trianel describes the knowledge diffusion amongst potential end-customers as rather selective. For example, customers in certain regions are informed about the existence of the solar service option at least, whereas this is not the case for other regions. However, end-customers are perceived as rather uninformed about mechanisms of the energy market, for example the German renewable energy act (EEG). Currently pro-active and hence better-informed end-customers are those with a high solvency that are interested in getting solar services because of supply reasons.

RWE has been already offering contracting solutions before it expanded its product range by solar services. Since contracting and energy service provision is related, RWE already had experience in the business model in the broadest sense already and has been already part of the market. Final momentum for RWE to start its B2B solar service market activities has been the realization of grid parity, thus the point at which the PV panel quality has risen and the solar PV production costs reached a point below the costs for conventional energy. From that point on, RWE offered its solar service product as a first market mover and "bet" with commercial end-customers: "*My purchase price plus return on investment against your current price of electricity still allows you to achieve savings*". RWE is not yet active in the B2C area, however, it continuously observes the market and the competitors being active. Nevertheless, facing the complexity of the energy market in general, developing a solar service B2C mass concept is assessed as difficult. Usually, the business model mechanisms but also the energy market mechanisms need to be explained to the customer that is often uninformed and disinterested in the topic.

Regardless of the solar service evolution, for many years **Conergy** has been already active on the solar PV market as a manufacturer of PV systems and as an EPC service provider. Conergy is aware of ongoing changes in the energy market such as rising customer demand for decentralized energy supply and solar PV. Increasing electricity prices have led to popularity of leased solar PV systems because those offer savings compared with conventional energy supply. Nevertheless, offering these solar services on the market is very complex and challenging. Therefore, Conergy has preferred a business model constellation based on cooperation with companies like RWE and Trianel that already do have an established access to customers and enjoy customer confidence.

Function 6. Resources Mobilization (RM)

One of the reasons why end customers decide against the classic outright purchase option is financing (see also collection of sales argument in the section above). Rooftop owners decide for the leasing option because they shy away the high upfront costs, and commercial customers because they need to invest their liquid assets into the core activities of their business. It is thus logically main element of the solar providing service-business model to pre-finance all installed solar PV systems. However, that makes solar services to a very capital-intensive business model—which in turn may deter large-scale investors to become part of the solar leasing business. Therefore, resources mobilization is a central challenge to the Selling Solar Services-business model. Conducted interviews have revealed, for start-up companies, mobilizing financial resources was—and still is—a very high market entrance challenge. It has been consistently reported that traditional investors such as banks assess potential investments into solar services as very critical. Reasons for that may lie in the perception that this business model is too small-scale and too extensive from a temporal perspective. Also, the mechanisms and advantages of the solar services-business model in comparison with classic outright purchase models (with or without consumer credit) is not always perfectly understood. Additionally, respondents have outlined that investments into energy market-related innovations are always treated with special, perhaps even excessive caution, due to the complex and dynamic mechanisms and unexpected, yet contradictory, legal measures supporting the expansion of renewable energies. Thus, the interviewed start-up entrepreneurs have drawn their first money from rather non-classic investors such as venture competitions and crowd funding campaigns. However, in parts, also traditional investors, such as business angels, supported solar service-entrepreneurs have played a role. Nevertheless, those had been already familiar with the solar PV market and thus had a better access to assess the investment-related opportunities and risks. Thus, an understanding of the business model in the particular market surrounding is of crucial importance.

Box 6. Evidence Base for Function 6 "Resources Mobilization" (RM)

Solease sees itself as a connector between the financial industry and the end customers. Investors are not equipped for financing small-scale solar PV solutions distributed over a group of many customers. "*What they can do is, let's say, investing a million. So what we are doing is, we are just aggregating this million [in terms of customers] and then getting it financed. And because of these numbers we also have better purchasing conditions in all areas of what we provide, covering for example insurance and hardware*". At the same time, especially in the initial phase of Solease, it has been difficult to attract investors "*We talked to all different kinds of investors, but they all wanted to see a company with actual clients*". In the end, the Climate KIC programme helped to get these first paying customers and as a result investors have come on board since. However, what was much more of a greater value than the actual grant, was reputation and credibility being generated by winning that competition and successfully going through the three stages of the acceleration program. With this credibility, Solease was able to attract clients and investors like for example UMC Utrecht, and Rabobank. "*Getting to the first million of investments, that is the most difficult and this has been really a hard road which has been made easier by Climate KIC.*" To paint the picture, it took Solease between three and four years to get the first half a million Euro—and nowadays it is able to get another four million Euro within three to six months. *"The biggest market imperfection that needs to be solved is to help companies to get to that first million."* Recently, Solease was able to receive a € 4 million funding from three different energy funds, Overijssel, Limburg and Utrecht.

By the middle of 2015, **DZ-4** has gone through four different equity financing rounds. The first three have been business angels, of which two are companies that already stem from the solar market themselves. Those have understood the business model idea and its mechanisms quite easily. This has not necessarily been the case when DZ-4 held dialogues with other financial investors and venture capital companies that were not linked with the solar or energy market. Retrospectively, those that financed DZ-4 in its very beginnings somehow had a link with the solar market and knew the U.S. models. In addition to the classic financing rounds, DZ-4 has also conducted an equity-based crowd-funding (see also section on "Investment Strategy" see above). Within 11 days DZ-4 collected € 180,000 from 143 investors. Due to this financing round, DZ-4 could refinance roughly 40 % of its portfolio (corresponding to 28 systems, partly including storage solutions) at that time. Regarding financial support decidedly from R&D funds, DZ-4 reported that their intensive search for an appropriate kick starting support ended unsuccessfully. The observation was rather that while technology and patent-based start-ups receive funding from technology-oriented funds, and IT-based start-ups receive funding from a service-oriented fund—the funding of a non-IT but service and non-patents owning but still technology-based start-up is extremely difficult. Acquiring research and development funding for business model innovations does not comply with current R&D guidelines, especially those from the EU. Currently, service-oriented business model concepts that are based on ideas, intelligence and on people fail to find and convince investors.

Trianel itself does not implement the solar services-business concept, it develops and provides the business model blueprint, respectively while label for it. As such, it is not confronted with mobilization of resources.

As a traditional market player and energy supplier, **RWE** has a minor issue in resources mobilization than investing its resources in the right strategy and assets.

Conergy is not responsible for the financing part in its solar service-construct. However, it traces investors' sluggishness back to the circumstance that the business model is presumably perceived as very small-scale. Nevertheless, especially the fact that many people are monthly paying into a fund substantially reduced the risk of failure—in technical and monetary terms.

Function 7. Creation of Legitimacy (CoL)

All respondents expect an increasing market development in the next months and years. Therefore, all interviewed entrepreneurs still see themselves on the solar service market in the future—even more than ever before. Currently, the market is still in its beginnings. Participants interviewed specified the beginning of the solar service role out phase approximately with the end of 2014 and beginning of 2015. While the first players have been rather entrepreneurial start-ups than incumbent energy supply players, this picture is about to change. Meanwhile, public utilities and big energy supply companies have started to offer solar services, or are cooperating with the first movers. Interviews have revealed that it is both, expected and wished, that more and bigger energy players do become part of the solar service game. Participating in the solar service market is less a question of "How big is the slice of the cake?", because according to respondents the market is big enough, but rather "How can the market be developed as fast as possible?" Referring to statements from the smaller start-ups, big players are needed to further explain the rules of the game, respectively the mechanisms of the business model. For example, information needs of present potential customers do rather comprise questions regarding the business model in general and less regarding the advantage of this particular solar service offer in comparison to a competitive one. A big player can use completely different canals, resources, and synergies to explain the business model and to actively address customers. Thus, activities of the solar service start-up pioneers have been very important in clearer drawing the picture of the decentralized energy market of the future, however now also bigger players are needed to further diffuse the idea and develop the market. However, the other way around, if the incumbent energy supply companies still want to be the energy supply companies of tomorrow, they need to adapt themselves to the trend of decentralized self-consumption with cheaper and renewable energies. Thus, developing the solar service market by the bigger players has no "doing a favour" character but is a crucial precondition for their survival on the market.

Box 7. Evidence Base for Function 7 "Creation of Legitimacy" (CoL)

Solease is now at a point at which it has overcome initial barriers such as financing and clients. Their problem is not their current market share, their problem is that the market in general is still very small, because people have not yet realized how interesting it is to lease solar panels. People in the Netherlands and the EU do not yet know that they can actually lease solar panels. This holds not only true for potential end customers but also for investors and collaboration partners. For example, while Solease had talked to the bigger energy utilities at the beginning of its activities with the result that the incumbent parties did not fully grasp the opportunities of offering solar services. However, Solease was contacted again by the energy companies at the beginning of 2015 and talks about potential cooperation took place. The arguing of Solease for a successful collaboration is as follows: "*The model of solar lease fits much better with the energy companies than the outright purchase model, because what they do is to supply energy and they send a monthly bill for it. What we do is, we supply energy and we send a monthly bill for it. The only difference is, they used to do it with centralized non-sustainable assets and we're doing it now with decentralized sustainable assets*". The change of interest could be explained with the simple fact that every customer who is deciding for solar services and against energy from the grid is "*gone from the electricity market for good and will never come back*". A customer that has once retrieved self-produced solar energy from the roof is very probably not going back to fossil-based and centrally provided energy after the solar service contract has expired. Instead, the customer will put new more sustainable technology on his roof. In turn, not the bigger energy companies are competitors to solar service businesses—it is the other way around because companies like Solease do take the customers from the market of the incumbent energy companies as it currently is, completely. The "*bull game*" with clients changing between the big energy companies and then back, has changed.

In 2010, first activities of **DZ-4** have been accompanied by disbelief and skepticism expressed by the incumbent energy companies. However, the DZ-4 steps on the market have been constantly observed by existing players, for example in terms of mystery shopping in order to have a glance at the contractual aspects of solar leasing, which at the time of 2012 were very innovative for an energy company on the German market. Even if with caution, energy companies have been constantly interested in the DZ-4 idea. This has also been reflected in a range of negotiation talks that DZ-4 had conducted with a range of energy supply companies. Finally, the cooperation with EnBW, the third biggest energy utility on the German market, starting in 2015, is therefore only a logical consequence of earlier contact attempts and discussion rounds between the solar lease start-up and incumbent energy players. DZ-4 has stressed that they chose EnBW as a cooperation partner because of their convincing concept of an open innovation culture that is a company-owned innovation campus developing new business ideas in a start-up manner and bringing them to the market as fast as possible. Therefore, the headline "*learning from the small business groups*"[54], describing the DZ-4 and EnBW cooperation captures the on-going transition process on the German energy market quite to the point.

Trianel has decided for the development of solar services because it has recognized the trend of increasingly demanded self-consumption on the part of private but also commercial and industrial end-customers. This trend is assessed as irreversible, and therefore energy suppliers of today need to adopt their business models accordingly if they want to remain part of the energy supply market. However, Trianel's future vision of the energy market goes beyond a simple diffusion of its current "EnergieDach" product. It rather includes combined solar PV system and storage solutions for a home and e-mobility solutions. In this respect, it is more than necessary to develop such a business model—because otherwise incumbent energy suppliers would face a serious problem.

As an incumbent energy market player, **RWE** has recognized the challenge to leave the traditional quality business, in terms of electricity orders and invite to tenders. In the long run, no energy supply company would be still able to earn as much revenue as needed for covering all costs. RWE has decided for solar services because of the belief that the market is already there and because it wants to help the customers organizing their "*67 % of self-consumption obtained from their own rooftop*". Nevertheless, the solar service model is assessed to extremely require explaining. Potential customers are scared off by a lack of knowledge, fear, solar PV as a non-core business, and unpredictable developments in the energy market. Policymakers and entrepreneurs need to act in concert in order to put this model on the right track and to put the idea across that "*there is only one solution—you need to become a decentralized power producer*".

Conergy assesses that the solar service market will grow increasingly. One important driver for this development are less the start-up companies but especially the big energy supply companies, because those have completely different opportunities in addressing and informing the potential target group, for example, simply by adding a respective information flyer to the yearly invoice letter. However, because the concept of solar services is difficult to grasp and to communicate, informing the customer about the existence and functions of this business model is highly necessary.

Summary: Drivers and Barriers

Analysing the seven interrelated Innovation System Functions (ISF) typically results in insights with respect to drivers and barriers of the specific innovation, (Suurs and Roelofs, 2014) . This section summarizes the main drivers and main barriers from the pre-discussed Innovation System Functions and their relation to a further diffusion of "Selling Solar Services". Based on the information provided in the preceding sections, the levels of ISF fulfilment is shortly discussed and is hence based on the author's own assessment. The fulfilment is scored by means of a five-point scale (1 – very weakly developed, 2 – weakly developed, 3 – developed, 4 – strongly developed, 5 – very strongly developed), see also following figure.

[54] http://green.wiwo.de/von-den-kleinen-lernen-versorger-enbw-steigt-bei-solar-start-up-dz-4-ein/

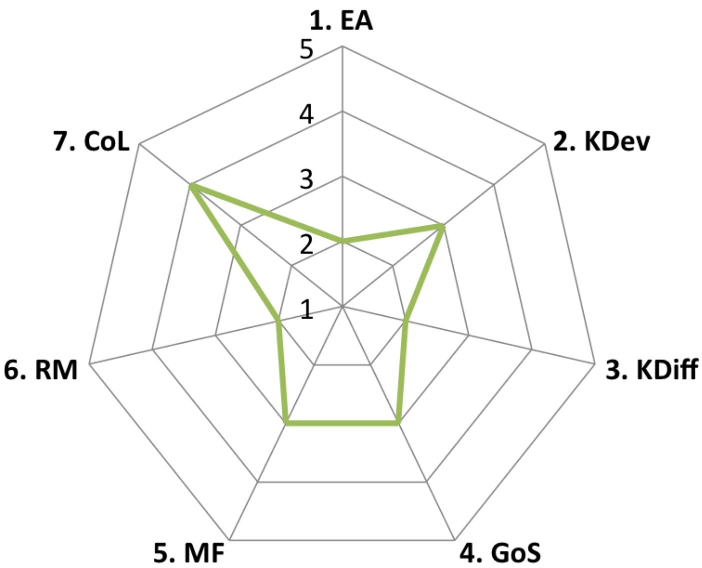

Figure 8. Fulfilment of Innovation System Functions: Selling Solar Services

- **1. EA**: Due to already existing entrepreneurial start-up activities whose success has shown that the solar lease model is competitive and able to assert itself on the market, first market followers in terms of incumbent energy companies have launched own market activities. Market activities of further competitors are explicitly desired. In the future, all asked respondents see themselves on the solar lease market more than ever. Current share of active companies in developing markets is assessed to be around 20 %, this trend is likely to accelerate. Nevertheless, evidence for entrepreneurial solar service activities has not been found for all EU countries. All in all, this ISF is rated with “2”.

- **2. KDev**: The success of US companies has set the foundation and inspiration for the development of solar service offers in the EU. While it is clear that US business models cannot be transferred one-to-one to the EU market, domestic entrepreneurs can pick best working mechanisms from the blueprint US models. Due to expert assessment, solar lease business model is a mass conversion-capable concept, the market-needed adjustments is approximately 10 to 30 %. All in all, this ISF is rated with “3”.

- **3. KDiff**: With a view to a lack of knowledge on the part of investors and customers, a further diffusion of developed business model knowledge and experiences through networks is of high importance. Investors need to understand the mechanisms of the business model, and customers need to know that solar service offers actually exist. Apart from that, respondents have highlighted the networking character of their companies—most of activities are outsourced, the solar service value chain comprises various partner companies fulfilling many different functions. A standardized and digitalized process management enabling partners to efficiently communicate through their network is highly important. All in all, this ISF is rated with “2”.

- **4. GoS**: The rise of Selling Solar Services is the product of various way-paving regulatory measures with regard to innovation system of renewable energies and solar PV in particular. With regard to the diffusion of the service model, with few exceptions, no specific regulatory measures have been named that had supported and would support the entrepreneurial activities. However, regulatory measures, such as planned taxes on self-consumption being contradictory to the transition towards a low-carbon economy have been criticized. All in all, this ISF is rated with “3”[55].

[55] This assessment differs from the first narrative version („4“ in earlier version). Is has been corrected due to insights provided by expert interviews.

- **5. MF**: With the development of solar services, above all, the recent story of solar PV has taken place in the financial sphere. Solar services have reached readiness in markets with grid parity; while this is the case for selected residential and commercial markets already by now, the majority of EU markets will follow in the coming years until 2020. While the real market is still small, experts assess that at least the market opportunity for solar services is already there and more market participants are decidedly wished in order to develop needed market structures. Further market formation is seen as inevitable development towards a decentralized self-supply-oriented energy market future that will lie also beyond solar services. Incumbent energy supply companies that do not engage themselves in this or related business models will miss an important chance. All in all, this ISF is rated with "3".

- **6. RM**: The mobilization of resources is one of the essential success factors for solar service start-ups. While entrepreneurs who were able to take this first hurdle via innovative financing sources have reported about an improved financing situation, they still tell that still more market diffusion would be possible if more investors were won. They also report that the financing situation for start-ups would be still as critical as in the time when they were in their own initial business phase. Regarding public funds, they describe a funding gap for innovative technology-based service companies. Regarding private funds, a lack of knowledge and of understanding is reported. All in all, this ISF is rated with "2".

- **7. CoL:** Selling Solar Services are in a phase in which they are starting to reach the point of legitimacy. The initial market phase has been characterized by entrepreneurial start-ups activities, being actively observed by sceptical and disbelieving incumbent energy companies. Meanwhile, public utilities and big energy supply companies have started to offer solar services, too, or are increasingly cooperating with the first movers. Interviewed respondents unanimously report that energy companies of today need to adapt themselves to the trend of decentralized self-consumption in order to survive on the market of tomorrow. All in all, this ISF is rated with "4".

In the following, barriers and drivers are discussed in thematic clusters crosscutting the seven ISF.

- **Financing: Lack of financing (barrier) vs. supporting technology-based service companies (driver)**
  Selling Solar Services is very capital intensive. The business model is based upon the circumstance that the technology is pre-financed by the solar lease company. Additionally, standardization and digitalization are needed, also requiring a certain amount of investment. However, interviews with market players of the solar service market have revealed that financing was and still is the main entrance challenge for entrepreneurial start-ups in their initial phase. While for companies that have asserted themselves now for around two to three years on the market the situation has become easier, the same companies assess that it would be still difficult, if they were a start-up trying to gain a foothold on the solar service market now. Reasons for this are manifold, and need to be distinguished between regarding private and public investors. To put it simple, private investors usually prefer investment options of a manageable size leading to a return on investment within a reasonable period of time. However, the very capital-intensive model of Selling Solar Services is very small scale and a rather classic investment option in terms of a modest but secure ROI being generated in the long term. Acquiring financial support from public funding has been described as difficult, too. One reason named comprises the circumstance that it is often perceived as very complex, time-consuming and requires too much business-related but sensitive information. A further problem described is connected with the "nature" of the Selling Solar Services business model: While there are be public funds available for service-companies that are mainly IT-based and for companies with technological innovations, a service-based company building on a mature technology, like a solar service firm does, falls into a gap between these two main funding sources and goes away empty-handed.

- **Reputation: Lack of trust (barrier) vs. confidence-building competition and awards (driver)**
  The lack of reputation is at least just as crucial as the financing barrier. One of the most important preconditions for being successful on a certain market is trust and confidence of investors, value chain members, and customers. For the solar lease start-up the situation is at least doubly difficult—they need to convince not only with their own company ability but also with the general business model capability to succeed on the market. For example, respondents have reported that the incumbent energy companies have reacted with strong disbelief and skepticism that this model would ever "learn to fly", while they are now increasingly integrating this model in their own activities. If companies being active on the market can hardly judge if an energy-related business model innovation will succeed or loose, how can even customers, considering that electricity is generally a low-interest product, assess if they want to give their trust and money to a new firm with a new product-service and a new approach of ownership and responsibility? Since the market of interest is the energy market, which is generally perceived as complex and inscrutable, the barrier does not become less challenging. What helps is reputation building. For example, it has been reported that participating in and winning of venture competitions have led to an enormous confidence building on the part of potential partners and customers. This has created a "trust license", which confirms that that the service-providing company and it product are credible.

- **Knowledge: Lack of knowledge (barrier) vs. improving awareness and level of information (driver)**
  Another, even more simple reason for a lack of financing and lack of reputation lies within a lack of knowledge and insight into the energy market and its mechanisms and legislation. Thus, apart from the "trust problem" that comes into the game, when investors and customers are actively confronting themselves with this option, in a first step they need to know that this option actually exists. Or to put it differently: A lot of stakeholders simply do not know (a) that they can either support or do solar leasing, (b) how this model works and (c) how the existing models do actually differ from each other. In this respect, more competitors that offered solar services would help to make the business model more known. A publicly accessible platform explaining the model and comparing different offer options is assessed as helpful, too.

- **Access to customers: Manual customer acquisition (barrier) vs. organized customer projects (driver)**
  Connected with the lack of reputation is the problem that new companies have to develop their access to the end-customers completely different compared with the customer acquisition process of an incumbent energy company, which could easily reach its customers by sending out information materials in addition to its yearly invoice or monthly advertisement letters. From the perspective of a start-up, a sponsored demonstration project with a certain amount of customers would be helpful in

- **Interest: Disinterest and fear (barrier) vs. understanding the model and its background (driver)**
  Generally, electricity is generally a "low-involvement product" or "low interest product" being perceived and treated without emotion. While this is about to change slightly for example due to proceeding climate change, political crises linked with energy dependency etc., the majority is rather unwilling to deal with the topic of their own energy supply. However, currently, Selling Solar Services is still in such a development mode that it extremely requires explaining. Potential customers are scared off because they simply do and cannot know better. Solar PV does not belong to their core competences; the energy market and energy market policy is complex and hardly predictable. Furthermore, leasing is combined with new ownership regulations—but people do not like change and typically, people do not even lease their cars. Thus, electricity supply and energy supply innovations are product, which is hard to sale. Because of this, it is of importance to inform, explain and create customer experience. The customer needs to understand the cost mechanisms of the offered product-service very well. At the same time customers need to understand energy market mechanisms and trends towards decentralized energy production.

- **Energy policy: Complex and hardly predictable (barrier) vs. continuous long-term (driver)**
  While several policy strands have supported the innovation system of solar PV technology, being a prerequisite for the Selling Solar Services business model, respondents have not reported about particular Selling Solar Services-oriented policy measures. Nevertheless, generally the energy policy framework is characterized by short-term and unforeseeable changes that might turn a circumstance into its diametrically opposed direction "overnight" and therefore perceived as very critical. Investors and entrepreneurs need stable conditions in order to develop robust business models. Hence, the challenge is to link short-term election-determined policy cycles with long-term entrepreneur perspectives. In addition, the legal framework is perceived as very complex, which is unnecessarily leading to a lack of understanding and thus low involvement and disinterest on the part of needed potential investors and customers.

1.5 Further Evidence on the Innovation System

n/a

1.6 Policy Implications

"*Policy makers may support systemic innovation by supporting the innovation system functions of one or more Technological Innovation Systems*", (Suurs and Roelofs, 2014). Therefore, the preceding section on innovation driving and preventing functions serve as basis for the formulation of the following policy recommendations.

One of the main market entrance and barrier for start-ups in their initial market phase reported was—and still is—the lack of financing—regarding as well private as public financing sources. Hence, policy recommendations derived from this evidence-based narrative aim at the improvement of the funding situation of solar service start-ups:

- Criticism regarding public funding sources comprises that available funds do mostly exclude innovative technology-based service innovations, as long as they are not IT-focused (service perspective) or patent-oriented (technology perspective). Selling Solar Services is such a technology-based service business, however without a focus on IT. It is also technology based, however, without new patent registration but the use of a mature technology. Thus, Selling Solar Service business models (and probably also other service innovations) fall through that funding gap. **Therefore, policy recommendations contain a new, amended definition of funding service-based or technology-based innovations in addition to the funding of either IT-service or patent-technology concepts**. Positive emphasis has been put on a venture competition that has awarded a solar lease start-up firstly with funding, and secondly with reputation and a "trust license". Both have enormously kick-started the start-up and helped it to gain a foothold in the market. Having realized a certain size, it is now much easier for this start-up to acquire further capital—it even plans to roll out its business model to further markets. **Following from that, appreciated and helpful structures of funding could be realized either with a fixed kick-starting funding amount, or with a funding related to the first ten customers, or in a more structured way with (relating to the cited Climate KIC competition) three financing stages, supported by coaching and support**. Further expressed policy recommendations comprise a mental switch towards more courageous and economical thinking: "*Take a part of your budget and test it out on the market, because this is what entrepreneurs do.*" In order to make the market bigger, **research and development policy should also invest into the market itself, either into developing or developed service concepts, which again for their part are driving research and development activities from that**. In this way, research and development support could result in a market leverage effect, through which one Euro spent in market activities is able to create a bigger effect on innovation than if it would be spent into for example research on solar service concepts. This also includes a sustainable perspective. A leasing company has to operate TCO-driven and thus it has many incentives to act more sustainable (in comparison with linear purchase options). Since this company creates its value chain and chooses its partners according to TCO aspects and therewith sustainability-related incentives, it unfolds a sustainable effect at best, too.

- Funding from classic private investors fails because of several reasons: They comprise a lack of understanding and missing interest driven by the general perception that energy market investments are too complex and risky due to unforeseeable short-term "overnight" policy changes. Additionally, while Selling Solar Services is a rather classic investment option characterized by a high capital intensity and a long-term but foreseeable rate of return, private investors do prefer investments with a short-term ROI and overlook potential investment opportunities. Private investors such as banks do assess investment options from a very conservative viewpoint. For example, as long as solar service company cannot robustly demonstrate that a solar PV system installed has a value different from zero in case an end-customer is insolvent, the bank assesses the value of the PV system with zero and decides against a funding. What is absurd from an entrepreneurial perspective is however low-risk day-to-day business of classic funders. **This situation might be loosened by information and dissemination campaigns enlightening various stakeholders such as investors about the trends of the energy market and of the opportunities connected with the solar service business concept.** Simple communication in the form of information material, conferences, show cases, exhibitions, presentations, fairs, panels, competitions with prizes and awards, but also pilot and demonstration regions and integration of key disseminators is recommended. Another means would comprise the establishment and running, or support of respective networks addressing for examples investors and other value chain partners because this helped to make the idea more known.

While funding and the information of potential investors represents only one side of the medal, the communication towards potential end customers is also of crucial importance. While selected customers are very well informed about their energy supply options, not all customers show interest in energy-related questions, yet even do not even know that the offer of solar services does already exists. Interviews have shown that solar service companies are rather active with explaining the general mechanisms of the business model than explaining why their model is better than the competitive one. **Thus, what is needed in order to diffuse solar services on the demand side of the market is—as for the investors—simple information and dissemination campaigns**. **What is assessed as additionally helpful is the arrangement and implementation of competitions, leading to prices and awards, or the introduction of standards labels, which, all in all provide the solar service company with a certain reputation and a "license to trust".** Solar service start-ups reported that reputation and reliability are at least as important as a proper funding. Research and development policy could support that with respective information instruments as aforementioned. **Another option might consist in a publicly accessible platform to compare solar service pricing data.** This could facilitate a competitive solar service market environment and also enable more robust research and analysis of trends.

Besides the recommendations to improve funding and information instruments, a rather general but important policy recommendation in regulatory terms is to create an innovation environment with stable settings. **This means that entrepreneurs need reliable, in terms of continuous and long-term, political and hence also economical framework conditions in order to develop a business idea, gain foothold and survive on the market**. Especially energy policy is perceived as complex, and contradictory and is also connected with the image that it can change overnight. While this is discouraging certain market players to become active at all, it poses a challenge to those that take the risk. For example, surprisingly decided taxes on self-produced and consumed solar PV electricity in an environment that has largely supported the diffusion of renewable energies can easily destruct business models focussing on self-consumption that are firstly very capital-intensive and calculate their ROI with a time horizon of 15 to 20 years and secondly have been developed and carefully balanced on given circumstances, including subsidies and taxes for renewables, electricity prices for conventional energy sources, credit costs etc.

An interesting side note, not necessarily important for particularly solar service policy recommendations but for other products and technologies having an effect on the environment, is that solar PV modules are mostly characterized by a comparably long durability. This is due to industry standard product warranties comprising up to ten or more years. Evidence taken from the interview with a module manufacturer reveals that no matter if leasing or outright purchase—due to the long warranty standard, they have already the incentive to produce long-living and error-free modules. **Hence, long guarantees appear to be a proper instrument to prolong the durability of products**.

The question is, to which other products and technologies besides solar PV technology including systems and storage solutions, a transfer of warranty periods but especially the transfer of lease options, respectively hassle-free service offers is recommended to be repeated. It is conceivable that this is transferred to other very high investment products, as for example houses, e-mobility equipment, very complex semiconductors or even medical equipment but presumably also further options are plausible and likely and need to be analysed. **It therefore follows the research question to which and how many other products the model of solar services could be applied to. In order to better assess the environmental effects of solar services, and in particular its implications for the realization of a circular economy, further research suggestions comprise both, a detailed TCO analysis and life cycle assessment for outright purchase models on the one hand and service models on the other hand**. Evidence found and discussed in this narrative support the assessment of solar services contributing to a circular economy, however detailed analyses would enable to quantify the environmental effects and to paint a better picture of solar services as a systemic eco-innovation and their effect on a circular economy.

References

- Bazilian, M., Onyeji, I., Liebreich, M., MacGill, I., Chase, J., Shah, J., Gielen, D., Arent, D., Landfear, D., and Zhengrong, S. (2013). Re-considering the economics of photovoltaic power. Renew. Energy 53, 329–338.
- Bloomberg (2015). Global Trends in Renewable Energy Investment 2015 (Frankfurt am Main).
- Breyer, C., and Gerlach, A. (2013). Global overview on grid-parity. Prog. Photovolt. Res. Appl. *21*, 121–136.
- Breyer, C., Gerlach, A., Mueller, J., Behacker, J., and Milner, A. (2009). Grid parity analysis for EU and US regions and market segments - Dynamics of grid-parity and dependence on solar irradiance, local eelctricity prices and PV progress ratio. (Hamburg),.
- BSW Solar, and Inter Solar (2014). PV Investor Guide: New business models for photovoltaics in international markets.
- Citi Research (2014). Energy 2020: The Revolution will not be Televised as Disruptors Multiply (Citigroup).
- Deutsche Bank Markets Research (2014). 2014 Outlook: Let the Second Gold Rush Begin.
- Deutsche Bank Markets Research (2015). F.I.T.T. for investors: Crossing the Chasm (Deutsche Bank).
- EIO (2010). Methodological report (Brussels: Eco-Innovation Observatory, Financed by the European Commission, DG Environment).
- EIO (2013a). Europe in transition: Paving the way to a green economy through eco-innovation. Annual Report 2012. Eco-Innovation Observatory. Funded by the European Commission, DG Environment (Brussels: Financed by the European Commission, DG Environment).
- EIO (2013b). EIO Thematic Report: A systemic perspective on eco-innovation (Brussels: Eco-Innovation Observatory, Financed by the European Commission, DG Environment).
- Ellen MacArthur Foundation (2013). Towards the circular economy: Economic and business rationale for an accelerated transition.
- EPIA (2014). Global Market Outlook for Photovoltaics 2014-2018.
- EPIA, and Photovoltaic Technology Platform (2010). Solar Europe Industry Initiative (SEII). Draft Summary Implementation Plan 2010-2012.
- European Commission (2011). Public Awareness and Acceptance of CO2 Capture and Storage (Brussels: Conducted by TNS Opinion & Social at the request of Directorate-General for Energy).
- European Commission (2013). Climate Change (Brussels: Conducted by TNS Opinion & Social at the request of the European Commission, Directorate-General for Climate Action (DG CLIMA)).
- European Photovoltaic Technology Platform (2013). Photovoltaic Fact Sheets: The Status of the PV industry.
- Feldman, D., Barbose, G., Margolis, R., James, T., Weaver, S., Dargouth, N., Fu, R., Davidson, C., Booth, S., and Wiser, R. (2014). Photovoltaic System Pricing Trends: Histroical, Recent, and Near-Term Projections (SunShot U.S: Department of Energy).
- Fischer, S., Steger, S., Jordan, N.D., O’Brien, M., and Schepelmann, P. (2012). Leasing Society (Brussels: European Parliament, Directorate General for Internal Policies, Policy Department A: Economic and Scientific Policy).
- Frankel, D., Ostrowski, K., and Pinner, D. (2014). The disruptive potential of solar power.
- Frantzis, L., Graham, S., Katofsky, R., and Sawyer, H. (2008). Photovoltaics Business Models (National Renewable Energy Laboratory).
- Fraunhofer ISE (2012). Photovoltaics Report.
- Greenpeace, and EPIA (2011). Solar Generation 6, Solar Photovoltaic Electricity Empowering the World.
- Hobbs, A., Benami, E., Varadarajan, U., and Pierpont, B. (2013). Improving Solar Policy: Lessons from the solar leasing boom in California (Climate Policy Initiative).
- IEA (2013). Renewable Energy, Medium-Term Market Report 2013. Market Trends and Projections to 2018 (International Energy Agency).
- IRENA (2012). Renewable Energy Technologies: Cost Analysis Series. Solar Photovoltaics (International Renewable Energy Agency).
- Liebreich, M. (2011). Bloomberg New Energy Finance Summit: Keynote Presentation (London).
- Lüdeke-Freund, F. (2014). Innovation und Evolution von Geschäftsmodellen dargestellt am Beispiel BP Solar. In Kompendium Geschäftsmodell-Innovation, D.R.A. Schallmo, ed. (Wiesbaden: Springer Fachmedien Wiesbaden), pp. 257–281.
- Mandell, J., and Kelsey, N. (2011). California - State Case Analysis. In Green Growth: From Religion to Reality. 7 Case Studies on Ambitious Strategies to Shape Green Growth, (The Berkeley Roundtable on the International

Economy),.
- Navigant Research (2013). Executive Summary: Solar PV Market Forecasts. Installed Capacity, System Prices, and Revenue for Distributed and Non-Distributed Solar PV.
- NRDC (2012). Laying the Foundation for a Bright Future Assessing Progress Under Phase 1 of India's National Solar Mission.
- OECD/IEA (2008). Energy Technology Perspectives 2008. Scenarios and Strategies to 2050 (Paris).
- OECD/IEA (2014). Technology Roadmap: Solar Photovoltaic Energy (Paris: International Energy Agency).
- Osterwalder, A., Pigneur, Y., and Tucci, C.L. (2005). Clarifying business models: Origins, present, and future of the concept. Commun. Assoc. Inf. Syst. 1–40.
- Rutovitz, J., and Atherton, A. (2009). Energy Sector Jobs to 2030: A Global Analysis (Sydney: Institute for Sustainable Futures, University of Technology).
- Suurs, R., and Roelofs, E. (2014). Systemic Innovation: Concepts and tools for strengthening National and European eco-policies (Delft: TNO).
- The National Renewable Energy Laboratory (2004). What is the energy payback for PV? (U.S. Department of Energy).
- The Solar Foundation, (2011). National Solar Jobs Census 2011.
- The World Bank (2014). World Development Indicators.
- Tukker, A., Berg, C. van den, and Tischner, U. (2006). Product-services: a specific value proposition. New Bus. Old Eur. Prod.-Serv. Dev. Compet. Sustain. - Sheff. Greenleaf ISBN 9781874719922 - 2006 P 22-34.

Annex 1. Interview Questionnaire

1. What is your business model? [5 min]
   a. Explaining the "Company" business model
   b. The US as a business model blue print?
   c. Role of incumbent energy companies

a. **How does your current business model look like?**
Wie würden Sie Ihr gegenwärtiges Geschäftsmodell beschreiben?
[Degree of importance: 3/rather low]

- Product
- Target group
- Distribution channel
- Relationship
- Value configuration
- Core competence
- Partner network
- Cost structure

b. **To what extent have US models been serving as a "blue print"? Where do you see a difference?**
Inwiefern haben die erfolgreichen US-Unternehmen als "Blaupause" gedient? Wo liegen Unterschiede?
[Degree of importance: 1/very high]

c. **How would you characterize the past role of incumbent energy supply companies? Why haven't they been adopting this business model on their own?**
Wie könnte man die bisherige Rolle der alteingesessenen Energieunternehmen beschreiben? Warum hat(te) man dort (noch) nicht dieselbe Geschäftsidee?
[Degree of importance: 1/very high]

2. Is your business sustainable? [5 min]
   a. Systemic eco-innovation and circular economy
   b. Level of importance and awareness
   c. Incentives for resource-efficient behaviour

a. **Would you call your business model a "systemic eco-innovation that contributes to a circular economy"?**
Könnte man das Geschäftsmodell als systemische Öko-Innovation, die zur Realisierung einer Kreislaufwirtschaft beiträgt, beschreiben?
[Degree of importance: 2/high]

"... systemic eco-innovation towards a circular economy is a transformation of complete consumption and production patterns of systems, which decreases their resource requirements along their life cycle. This cannot be achieved by technological change only, but requires systemic innovation of guiding visions and core beliefs, behavioural changes, infrastructure as well as production technologies, which help to improve the cyclic properties of production and consumption patterns..."

b. **Have sustainability thoughts (systemic eco-innovation / circular economy) affected your business model choice?**
Inwiefern haben bei der Geschäftsmodell-Wahl Nachhaltigkeitsgedanken eine Rolle gespielt?
[Degree of importance: 2/high]

c. **Do changed ownership structures and running costs incentivize acting in resource-efficiency terms?**
Haben die veränderten Eigentumsstrukturen sowie laufende Kosten einen Einfluss auf ressourceneffizientes Handeln?
[Degree of importance: 1/very high]

3. "Let's get down to business..." [15 min]
    a. Customer perspective
    b. "Company" perspective
    c. Market perspective

a. What do customers have to pay?
Was müssen Kunden bezahlen?
[Degree of importance: **3/rather low**]

b. How does entrepreneurial perspective look like?
Wie sieht das Geschäftsmodell aus der unternehmerischen Perspektive aus?
[Degree of importance: **1/very high**]

- Founded in?
- Legal form?
- How many direct jobs in 2014?
- How many indirect / induced jobs in 2014?

- How expensive is one average customer (upfront investment costs)?
- How expensive is one average customer (running costs)?
- How would you characterize your typical costs?
  / "Once built solar PV generates electricity almost for free"→ Would you agree?

- How many systems were installed in 2014?
  / How many customers?
  How much annual turnover is created by one average customer?
- How long is average payback period of one customer?

- Which financial public support do you receive that single customers wouldn't receive?
- Which financial pressure do you have to bear that single customers wouldn't have to bear?

c. How does your current market look like?
Wie sieht die aktuelle Marktsituation aus?
[Degree of importance: **1/very high**]

- Tendency of customer demand?
- Competitive situation?
- Role of incumbent energy supply companies?
- Financing enthusiasm of investors?

4. What is your "bridging the valley of death"-story? [15 min]
    a. Financing the investment
    b. Drivers and barriers
    c. Role of research & development policy

a. How would you describe your investment strategy?
Wie würden Sie Ihre Investitionsstrategie beschreiben?
[Degree of importance: **1/very high**]

- How would you characterize your typical investor?
- How many investment rounds were needed?
- Were investors rather

b. How would you describe the phase from the "idea to the market"?
Wie würden Sie die Phase zwischen Ideenfindung und Marktrealisierung beschreiben?
[Degree of importance: **1/very high**]

- During that time, what was especially helpful (drivers)?
  —referring to role of legislation, energy market , consumers / society, technology
- What was especially hindering (bottlenecks)?
  —referring to role of legislation, energy market , consumers / society, technology

c. How would you describe the past role of research & development policy?
Welche Rolle hat dabei Forschungs- und Entwicklungspolitik gespielt?
[Degree of importance: **1/very high**]

5. What future vision do you have? [10 min]
   a. Future goals
   b. "Company" business model of the future
   c. Market of the future

a. What future goals / company vision do you have?
Welche Zukunftsvision verfolgen Sie für Ihr Unternehmen?
[Degree of importance: **1/very high**]

b. Referring to your business model, which of the pillars will have changed in which way?
Bezugnehmend auf Ihr Geschäftsmodell, welche Bausteine könnten sich zukünftig wie geändert haben?
[Degree of importance: **2/high**]

- Product
- Target group
- Distribution channel
- Relationship
- Value configuration
- Core competence
- Partner network
- Cost structure

c. How does your market of the future look like?
Wie schätzen Sie Ihren zukünftigen Markt ein?
[Degree of importance: **1/very high**]

- Tendency of customer demand?
- Competitive situation?
- Role of incumbent energy supply companies?

6. Role of research & innovation policy [5 min]

a. How could policy – in particular research & innovation policy – help?
Wie könnte Forschungs- und Innovationspolitik zukünftig helfen?
[Degree of importance: **1/very high**]

- If you were able to formulate a wish list to policy makers, how could this look like?
- Particularly with regard to EU R&D policy?

2 Ethanol from Residues and Wastes

Author(s):
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Changes based on request of European Commission:
The following descriptions build on a previous narrative version, developed in December 2014 and published in March 2015[56]. It has been amended and refined due to the specific request of DG Research and Innovation to

(a) Developing the insight into the financial strengths and weaknesses of the technology
(b) Specifying barriers and drivers for a further diffusion of the analysed innovation
(c) Formulating more detailed policy recommendations.

In order to fulfil this request, a techno-economic assessment has been incorporated into the narrative. This section contains production cost estimates, a cash flow model, comparison of production costs with other fuel alternatives, as well as an assessment of business and policy risks. The parameterization for the production cost and cash flow models was fine-tuned in discussion with industry stakeholders. Further policy discussion with a total of four stakeholders from the ethanol industry in Finland and Sweden were used to improve the comments on policy in the narrative. Following stakeholders were available for an extensive telephone interview:

- ST1 Biofuels Oy (Finland)[57,58]
- A large biofuel producer (Sweden)[59]

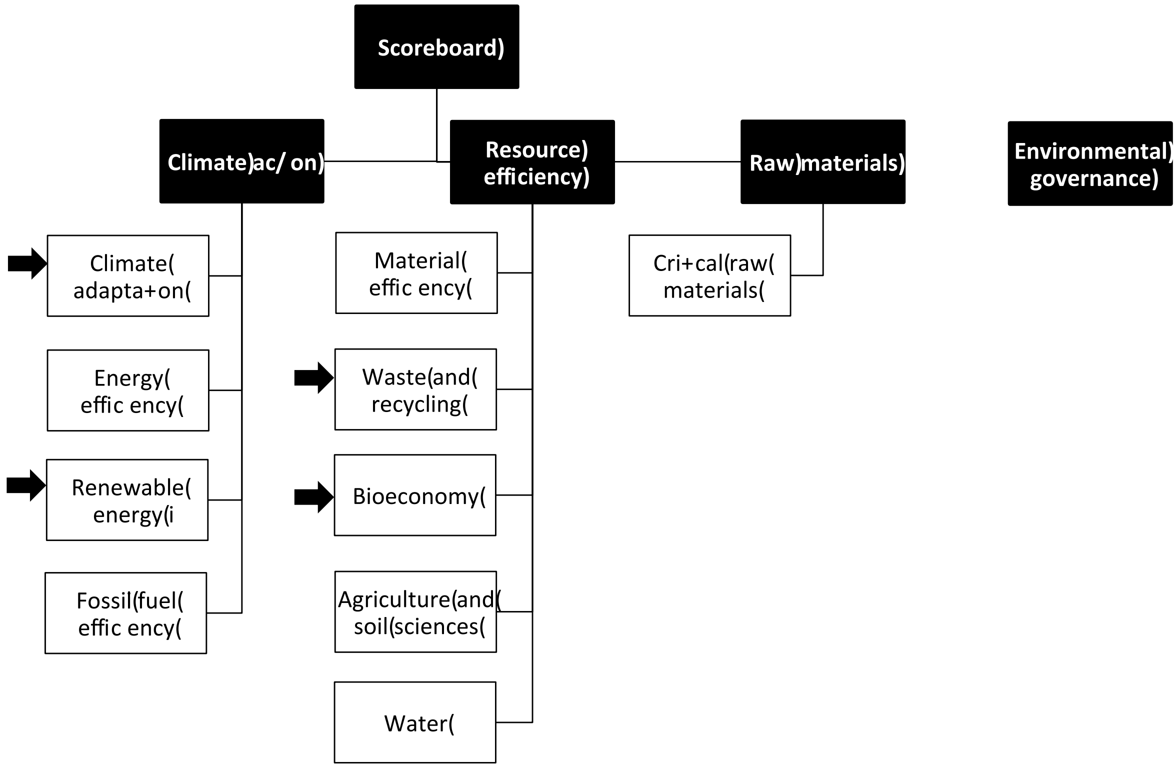
Additionally, interviews were amended by short exchange with

- f3 Centre, Swedish research and industry platform for renewable transport fuels (Sweden)[60]

The interview findings have been incorporated into the additional techno-economic assessment section, and updated versions of the sections on innovation system functioning and policy implications. Findings have also been presented and discussed in a session on "Waste-based ethanol" at the 2nd RECREATE Strategic Workshop.

[56] http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.1-SEI_final_clean_0.pdf
[57] Managing Director
[58] Head of Business Development
[59] Former employee
[60] Manager

Links with RECREATE Scoreboard:



Climate)ac/ on:)
Waste(based(biofuels(offer(significantly(reduced(GHG(mi+ga+on(poten+al(compared(with(both(fossil(fuels(and(cropL based(biofuels(

Resource)efficiency:)
Waste(based(biofuels(offer(a(high(value(applica+on(of(waste(and(residue(streams(

Note: Links are marked with an arrow.

2.1 The Narrative

The possibility to derive liquid fuels from residue and waste streams has a number of important benefits. Lifecycle carbon dioxide emissions are far lower than for fuels from fossil sources or crop based biofuels. It offers high value utilization of low value waste streams, improving revenue for the industries that produce and process these residue streams. Because waste based fuel production can be a localized industry, it may provide employment and reduce energy import dependency for any of the EU member countries. Bioethanol may be synthesized from a large variety of residue and waste streams. Broadly speaking, these fall into two categories, of sugar or starch rich waste streams, or cellulosic material. The former is much more easily fermentable, and required processing technologies are far more matured. The latter is much more difficult to process but the potential feedstock resource base is of a far larger volume, and available at lower cost. Pilot and (commercial) demonstration plants are springing up across Europe, but production volumes currently remain in the order of several to several dozen Ml per plant, totalling only a few per cent in total EU bioethanol consumption.

The economic potential for this fuel production system is substantial. The EU production potential, as determined by the maximum feedstock resource base, exceeds likely EU biofuel demand through 2030. Full utilization of this resource base could potentially create a turnover in the order of M€ 10,000-65,000, and create some 50,000-200,000 jobs in feedstock collection and fuel processing. Techno-economic analysis of a model project (5 Ml/a; using bread and bakery waste for feedstock) suggests a gross production cost of 530 €/m^3 of pure ethanol, and 459 €/m^3 when accounting for the value of co-products. Assuming average lifetime revenue of 600 €/m^3, including a 50 €/m^3 in 'green premium' for double-counting of waste-based fuels, this would generate an internal rate of return (IRR) of approximately 7.7%, and have a payback period of around 9 years.

Key business concerns are feedstock supply security, the volatility of feedstock prices, and remaining lack of clarity on double-counting for food/feed wastes under the new 'ILUC'-proposal on sustainability standards for biofuels. The synthesis of ethanol based on other wastes, including forestry industry wastes, crop residues, and biological fractions of household waste remains under technical development, with a number of plants, in between demonstration and commercial scale, across Europe.

Key barriers to unlocking this potential are remaining research and demonstration needs for developing cost-competitive ligno-cellulosic ethanol production processes, lack of clarity on financial stimulus and further competition with first generation biofuels, and lacking stimulus for the development of high ethanol blend markets and fuelling infrastructure. Guidelines on State aid for environmental protection and energy justifiably aim at limiting market distortions, but leaves very little room for individual member states to provide fiscal stimulus at a level likely to induce high penetration scenarios.

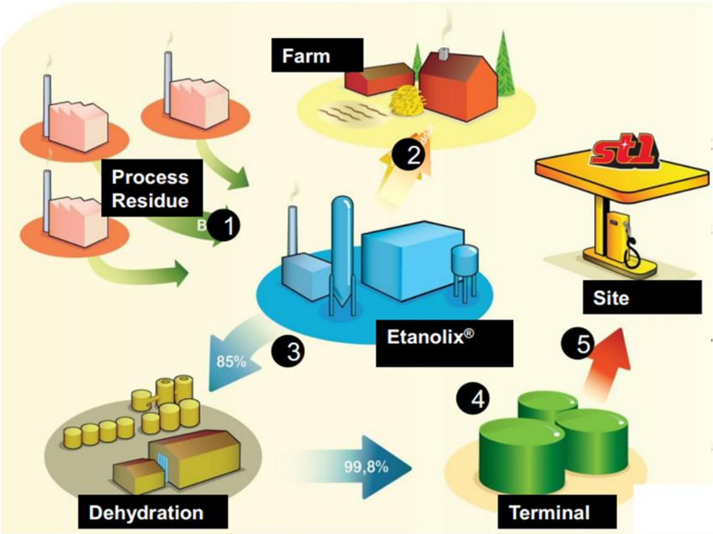
2.2 Understanding the Innovation System

The Innovation

Ethanol and other alcohols have been considered as a transport fuel since some of the earliest engine designs, but have long had niche applications only as a racing fuel. Recent global interest in ethanol as a motor fuel is driven by the possibility to derive ethanol from renewable biomass, reducing fossil fuel dependency and environmental impacts. Ethanol is produced either through fermentation of sugar or starch (first generation), or through the hydrolysis and subsequent fermentation of lignocellulose, the basic structural components that makes up the bulk of plant dry matter (second generation bio-ethanol). Global fuel ethanol production stood at approximately 70.3 Mt, or about 2,075 PJ in 2013, equivalent to circa 4,2% of global transport energy use [1, 2]. Main production and consumption markets were the US and Brazil, at circa 57 and 27% of global production, respectively, followed by the EU, at circa 5.9% [1]. The bulk of current bio-ethanol production is from sugar or starch rich food crops, mostly corn in the US, sugar cane in Brazil, and a mix of wheat, sugar beets, barley and corn in the EU [3].

Crop-based bio-ethanol has proven somewhat controversial due to concerns about energy balances, life cycle CO_2 emissions and competition with food production. In order to address these concerns bio-ethanol can be derived from waste – either by capturing industrial/municipal waste streams or by using waste fractions of crops (so-called lingo-cellulosic biomass). The latter technique is still in a relatively early stage of development, but ethanol can be refined from a number of industrial and municipal wastes and residues at scale today. This approach not only addresses climate and renewable energy goals, but is aligned with the circular economy agenda, by capturing additional value from the circulation of biogenic materials and promoting eco-industrial networks.

This narrative will examine the market potential for waste-based bioethanol production by using St1 as a reference case. This company is an oil refinery and fuel distribution group active in Finland, Sweden, and Norway, which has diversified to ethanol production and distribution starting from 2006. The production process chosen by St1 is based on biological waste streams. These are collected at smaller scale sites for conversion to ethanol to minimize bulk feedstock resource transport, and allow better utilization of process waste heat. Dehydration, storage, blending and distribution to fuel stations occur from a central processing plant (Figure 9). St1 utilizes three distinct processing technologies for three different feedstocks. First, for the use of waste streams rich in sugar and starch, from breweries and beverage industries, bakeries, potato processing, confectionary industry etc., with the Etanolix® concept. Secondly, for the use of biological fractions of municipal solid waste, with the Bionolix® concept. Third, for the use of forestry industry wastes (saw dust, wood chips, waste wood) and straw, with the Cellunolix® concept. This is the most advanced concept, utilizing lignocellulosic biomass.



1. Process residue and/or wastes are sourced from nearby industries
2. Residues from ethanol production are used as animal feed, fertilizer or solid biomass fuel
3. 85% pure ethanol is centrally collected for dehydration in Hamina
4. Storage and blending with gasoline
5. Distribution to over 1,200 fuel stations in Scandinavia

Source: taken from St1 website, captions edited by authors

Figure 9. Etanolix—Dispersed Ethanol Production Concept

Current Market

The market size for biofuels has largely depended on EU directives, which have mandated minimum levels of consumption to be attained by each Member State. The original biofuel directive of May 2003 set targets of 2% by 2005 and 5.75% by 2010. This directive was replaced in 2009 by one that set a 10% target for 2020 [4]. Although this target was attained, consumption has slightly dropped off since, see also section 2.3 later in this narrative.

Consumption of biofuels in 2014 stood at 14.0 Mtoe, or 4.91% of a total of 285 Mtoe for road transport fuel consumption. The latest biofuel directive, however, allows for 'double-counting' of biofuels produced from wastes. The 4.91% is counted as physical volume. The content of 'double-counted' waste-based fuels is estimated at 1.80 Mtoe in 2014, versus 12.2 Mtoe of crop based biofuels [5]. Correcting for double-counting, biofuel consumption is at 5.54% of all road transport fuel.

The 14.0 Mtoe is made up of circa 79% biodiesel, 19% bio-ethanol, and 2% biogas and others. The waste-based fraction is nearly entirely biodiesel alternatives, produced from used cooking oil and animal fats [5].

2.3 Estimation of the Investment Case

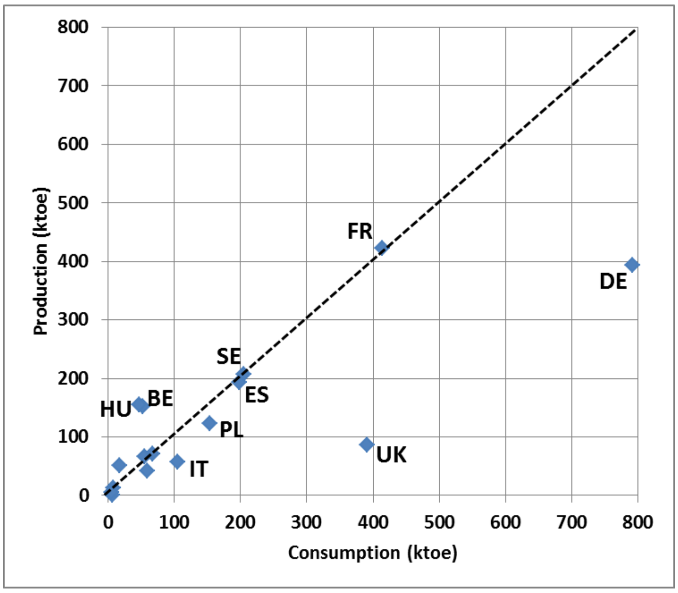
Investment Strategy

The investment required for the suggested production capacity is very significant. The most recent financial data are from facilities in between demonstration and commercial size (several to several dozen Ml). These have typically required investments of circa 1 M€ per Ml of annual production capacity [14]. It is difficult to extrapolate investment requirements, as current projects are still relatively small compared to expected commercial scale plants (approximately 100 Ml and over), and it is uncertain by how much production costs could be reduced trough scaling and process efficiency improvements. Different processing technologies, for the utilization of different feedstocks, are bound to have varying capital requirements as well. The suggested investment volume in the following table should therefore be considered very rough estimates, and likely on the high end of actually required investment.

Table 5. EU Waste Based Bio-Ethanol Cumulative Investment Requirement through 2030 (M€)

Scenario	2020	2030
Low demand (M€)	4,831	20,933
High demand (M€)	16,103	32,205
Maximum feedstock supply (M€)	65,000	65,000

An important consideration when evaluating numbers on investment, revenue and jobs created through economic activity surrounding waste based biofuels, is the degree to which this activity occurs locally. The EU produces circa 71% of the ethanol consumed for fuel production (for all biofuels this is even 80%) [8]. This relatively strong relationship between production and consumption continues even on the national level within the EU-28 (Figure 10). For waste based fuels production, this relationship should be considered to be even stronger as most wastes are far less easily transported over long distances than food crop feedstocks or fuel products.



Source: [8]. Dashed line indicates a 1:1 ratio of consumption:production.

Figure 10. EU-28 Consumption and Production of Fuel Ethanol

Future Market Potential

Current EU policy for 2020 is a 20% share of renewables for all energy, with a 10% contribution of renewables in all transport energy consumption. The suggested target for 2030 is a 30% share of renewables for all energy, currently with no specification of a target for transport fuels [6]. We will assume a 20% contribution in transport fuels.

Policy further has two measures to stimulate waste-based biofuels. First, the EU's fuel quality directive has capped the use of 'land based biofuels' (essentially biofuels produce from food crops), to a maximum contribution of 7 % of all transport energy [7]. Consumption of land based biofuels above this cap cannot be counted towards mandated biofuel targets. Second, fuels derived from waste resources are allowed to be double-counted towards meeting targets.

In the remainder of the text on future markets, we make a distinction between 'low' and 'high' demand scenarios. In the low demand scenario, we assume that crop based biofuels will remain competitive, and therefore to supply the suggested 7% maximum. Competitiveness of crop-based biofuels may also change with the development of technologies and policy (increasing support for advanced biofuels). In the 'high' demand scenario, we therefore assume that all biofuel demand will be fulfilled with advanced biofuels. Lastly, we also report the maximum domestic (EU) production potential, assuming that all available biomass feedstocks is utilized. This scenario is included primarily to indicate whether 'low' and/or 'high' demand scenarios are technically possible, and should not be considered a likely outcome.

We also need to make an assumption on the division between gasoline and diesel alternatives. The current market, which is highly dominated by crop-based biofuels, has a share of circa 80% biodiesel and 20% bioethanol [8, 9]. There are no real reasons to assume that this divide would also hold for non-crop based biofuels, and we will simply assume a 50/50% market split for diesel versus gasoline alternatives.
Taking all these issues into account, we will use market development scenarios in the remainder of the tables in this section as reported in following table.

Table 6. EU Renewable Fuel Demand Potential through 2030 (Mtoe)

	2020		2030	
Scenario	**Low demand**	**High demand**	**Low demand**	**High demand**
Total biofuels	10%	10%	20%	20%
Land based biofuels	7%	0%	7%	0%
Waste based biofuels	3%	10%	13%	20%
Accounting for double-counting	1.5%	5%	6.5%	10%
Gasoline vs diesel alternatives split (50%)	0.75%	2.5%	3.25%	5%
Total fuel demand (Mtoe)	360	360	350	350
Waste based ethanol demand (Mtoe)	2.7	9.0	11.4	17.5

Estimates of available feedstock for the production of waste-based ethanol vary strongly, e.g., with assumptions on factions of waste that can be utilized. A study that reviewed a list of assessments, and taking into consideration only those waste streams that are sustainably harvestable and not used for competing recycling purposes estimated the production potential at 36 Mtoe, or about 10% of all current EU transport fuel energy consumption [10]. Using all these resources would yield a maximum level of production of waste based ethanol of 65,000 Ml, far more than the demand estimated to be created by policy targets, see Table 7. The high demand scenario will require strong incentives from policy making, in order to improve the competitiveness between advanced biofuels and crop-based biofuels. The maximum feedstock supply scenario would even require competitiveness with fossil fuels.

Table 7. EU Waste Based Bio-Ethanol Demand Potential through 2030 (Ml)

Scenario	2020	2030
Low demand (Ml)	4,831	20,933
High demand (Ml)	16,103	32,205
Maximum feedstock supply (Ml)	65,000	65,000

Source: [6, 11]

The EU market currently accounts for circa 6% of global fuel ethanol consumption. Additional production in the EU should not be expected to be able to rely on export markets. The EU is currently a net importer of bio-fuels, with strong competition from US corn based ethanol and Brazilian sugar can base ethanol [1]. The average bulk purchase price of bio-ethanol in the EU was €0.55 per litre in 2011 [12]; the long term expected average is approximately €0.65 per litre [13]. Resulting turnover potential is presented in Table 8. In addition to his market, EU firms could potentially develop export markets for waste based ethanol production technologies. The size of this market is far more difficult to estimate in turnover volume.

Table 8. EU Waste Based Bio-Ethanol Turnover Potential through 2030 (M€)

Scenario	2020	2030
Low demand (M€)	3,140	13,606
High demand (M€)	10,467	20,933
Maximum feedstock supply (M€)	42,250	42,250

Employment Effects

One of the benefits of waste-based fuel production is that feedstock collection and fuel conversion tend to be highly localized and therefore provide local employment opportunities.
St1 Biofuels Oy, with a current production of circa 13 Ml of ethanol, has some 80 employees, involved in operating, but also designing and construction of bioethanol plants. As one of the latest developments in Finland, in autumn 2014, the North European Bio Tech Oy (NEB) has made an investment decision concerning the construction of a bioethanol plant in Kajaani, based on the St1 Cellunolix concept, with a capacity of circa 10 Ml annually. During product development, planning and construction, the project will generate about 200 person-years of employment. Once in operation, the plant will employ 15–20 people directly, and about 15 people indirectly. We assume these numbers will not evolve much in the future. Feedstock collection remains labour intensive, and the inherent smaller scale of localized waste to fuel production facilities leaves little potential for labour efficiency gains, too. At circa 3 employees per Ml of fuel production, we arrive at an estimate of up to 195,000 jobs if all feedstock is utilized, and several 10,000's in lower demand scenarios; see Table 9.

These numbers are focused on the employment at the production facilities. Export markets for knowledge and turn-key business should be expected to result in additional job potential, although not at comparable scales of that required in fuel production.

Table 9. EU Waste to Ethanol Job Potential through 2030

Scenario	2020	2030
Low demand (FTE)	14,493	62,799
High demand (FTE)	48,309	96,615
Maximum feedstock supply (FTE)	195,000	195,000

Environmental and Social Benefits

Here we compare well-to-wheel fossil energy use of waste based ethanol with wheat based ethanol and regular gasoline. These are circa 35 MJ/100 km for waste-based ethanol, 100 MJ/100 km for wheat based ethanol and 165 MJ/100 km for gasoline [15, 16]. The latter assumes 7% engine efficiency improvements through 2020, as is used in baseline scenarios by the European Commissions' Joint Research Centre, Institute for Energy and Transport [15]. Energy savings at production levels reported in previous section results in energy total energy savings as reported in Table 10. The 1,405 PJ of energy saved, in the case of maximum feedstock use, is equivalent to 9,3% of all current EU transport energy use.

Table 10. EU Waste to Ethanol Energy Savings through 2030

Scenario	2020			2030		
	Ml	Savings compared with Wheat ethanol	Savings compared with Gasoline	Ml	Savings compared with Wheat ethanol	Savings compared with Gasoline
Low demand	4,831	86	104	20,933	373	452
High demand	16,103	287	348	32,205	574	696
Maximum feedstock supply	65,000	1,159	1,405	65,000	1,159	1,405

Note: PetaJoule

Greenhouse gas emissions savings are very comparable in size to the energy reductions reported in the previous section. Well-to-wheel emissions are circa 30 g CO_2-eq/km for waste-based ethanol, 100 g CO_2-eq/km for wheat based ethanol and 132 g CO_2-eq/km for gasoline [15, 16]. In the scenario of 65,000 Ml of waste based ethanol, GHG emission savings would be equal to 110 Mt CO_2-eq when compared with gasoline, and 75.5 Mt CO_2-eq when compared with wheat based ethanol. This is equal to circa 9.3 or 6.4% of all GHG emissions from transport in the EU [8].

The estimated GHG savings, however, strongly depend on assumptions and system boundaries, e.g., what would have been the alternative fate of the waste streams, and what type of energy is used in ethanol and enzyme production [16-20].

65,000 Ml of waste based ethanol would replace 36.3 Mtoe or 43,300 Ml of gasoline, or 175 Mt of wheat.

Emission of NO_x, particulate matter and benzene are lower from ethanol powered vehicles, but acetaldehyde emissions are higher when compared to gasoline powered vehicles. Overall effects on local air quality and human health of fuel ethanol use has been estimated to lead to only marginal improvements compared with gasoline powered vehicles [21, 22].

2.4 Innovation System Functioning

Function 1. Entrepreneurial Activities (EA)

The case surrounding ST1's activities in bio-ethanol from waste production has seen substantial and sufficient build-up of entrepreneurial activities. The supply of biomass feedstock is guaranteed by integration of small-scale, localized production facilities at food industry production facilities, or through cooperation with waste collection firms (SITA and Kiertokapula). Another ethanol production facility is integrated into an enzyme production plant of Dupont. Further chain management is simplified by the fact that ethanol production, dehydration and distribution is all carried out by St1 itself. Lastly, the choice to supply ethanol as low blends into gasoline enables their utilization by gasoline powered vehicles without modification, preventing the need of inclusion of any further downstream actors. St1, does, however, also supply high level blends (E85) at a number of Swedish fuel stations, which has a considerable fleet of flex-fuel vehicles [58]. The current entrepreneurial activities centre around the utilization of food industry process residues and MSW, with four operational production facilities for the former, and one for the latter [59]. A production facility based on the Cellunolix principle, utilizing saw dust, is under construction in Kajaani, Finland, and due to start production in 2016 [60]. Current production capacity of the St1 plants is circa 13 million litre of ethanol annually, or 10.3 kt/yr. Expansion plans initially existed for another nine production facilities by 2020, and a total capacity of 237 kt/yr [61]. Currently, however, St1 is rethinking the optimal scale of the refineries utilizing bread, bakery and brewery waste. The original roll-out in 1.2 Ml/a plans may have led to less than optimal Capex and Opex, and St1 would now focus on 5 Ml+ plants. This would limit roll-out to one each in a city of approximately 500.000 people and up, according to an St1 representative.

There are also further demonstration and commercial activities for the production of ethanol from waste streams by other firms. Lantmännen agroetanol in Sweden is also producing ethanol from bread and bakery waste. Their solution is to feed these waste into an existing wheat based bioethanol refinery, rather than having a dedicated waste-based refinery, however. In Norway, Borregaard has a facility for 15. Kt/yr from wood wastes. In Sweden, the Svensk Etanolkemi AB, or SEKAB, has been running a cellulosic ethanol pilot plant in Örnsköldsvik since 2004, with a production capacity of circa 11.9 kt/yr. In Spain, Imecal is running a MSW to ethanol plant in the PERSEO project near Valencia, with a production capacity of circa 14.3 kt/yr. In Denmark, DONG energy runs a R&D center and 4.5 kt/yr production facility in Kalundborg for ethanol from straw and stover [14]. Outside the EU, there are several dozen pilot and commercial demonstration plants for cellulosic ethanol in the US and Canada, as well as a small number in China [62]. A summary of different entrepreneurial activities by St1 and other firms is provided in Table 11. Note that these activities refer to waste-based ethanol. For more information on production capacities of crop based ethanol and other waste based fuel types, please see [54].

Table 11. Entrepreneurial Activity Surrounding Waste-Based Ethanol

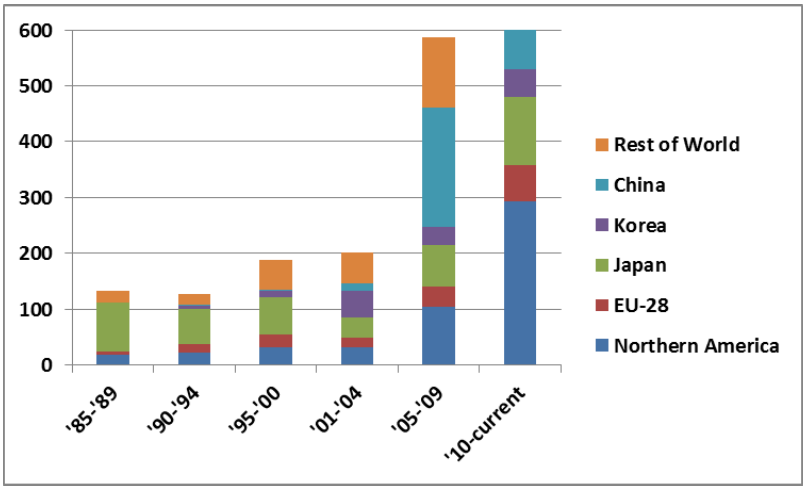
Type	Plants	Start yr	Tech status	Competitors
Etanolix **Bread waste**	5 (+3)	2007	Ready for roll-out Commercially viable with right policy stimulus	1 in Sweden
Bionolix **Biowaste**	1	2010	Continued testing Conversion remains substandard	?
Cellunolix **Forestry waste**	1	2016	Production pending Test-bed Plant scale (10Ml) below commercial size Enzymes costly; few suppliers	~10+ pilots (<5Ml) 6 commercial demo (10-50 Ml)

Source: interviews with industry representatives, [54, 63]

Function 2. Knowledge Development (KDev)

The production of ethanol via fermentation is a very well matured technology and knowledge development can therefore be judged to be very strong. This is true both for processes using sugar or starch rich food crops as well as for sugar or starch rich industry residues, as are used in St1's Ethanolix concept. Patenting numbers for these technologies would therefore not reveal much.

This is different for ethanol derived from lignocellulosic components of biomass. Although applied in a number of production facilities around the globe, as explained in the previous section, these currently do remain to be (commercial) demonstration projects [14], and cost reducing process technologies remain an important factor in the profitability of these types of production facilities [64]. Global patenting activity reveals that knowledge development has been rapidly building up since circa the latter half of last decade, see following figure. This figure also illustrates that EU activity remains far behind on that in the US, and Japan. Development of low cost, efficient enzymes or other technological pathways for the breakdown of cellulose and hemicellulose to easily fermentable sugars remain a key barrier to cost-competitiveness of the production of ethanol from this most abundant feedstock [64]. St1 has eight patents, granted between 2005 and 2010 [65].



Source: Esp@cenet [65],
Note: Keywords used: 'cellulos* AND ethanol' in abstract or title. Note that Chinese patent numbers are known to be inflated [66]; numbers for '10-current were 795 patent applications for China, 244 for Rest of World.

Figure 11. Patent Applications Relating to Cellulosic Ethanol Production

Function 3. Knowledge Diffusion through Networks (KDiff)

Although many universities in the Nordic countries are strongly positioned in (bio-chemical) processing of lignocellulosic materials, documents on the St1-project indicate that most R&D was performed in collaboration between VTT (Finland's Technical Research Centre) and St1's in-house R&D department [61, 67]. It has been suggested that this was due to the relatively strong focus on process engineering and experiences on learning by doing from the initial pilot plants [61].

There are further a number of firms with diverse industrial backgrounds that are developing projects, which may contribute to the innovation system build-up with specific sectoral knowledge. This include actors from the oil industry, the fermentation industry, the sugar industry, and wider biochemical process industries, including e.g., St1, Shell, Novozymes, Cargill, DuPont, POET and DSM [68, 69]. Although there are a number of platforms aimed at disseminating knowledge about biofuels in general (e.g., European biofuels technology platform, IEA Task 39), we could not immediately identify platforms specific to cellulosic ethanol.

St1 has provided study tours to their plants to societal groups, in an effort to improve societal knowledge about the production potential of ethanol from waste streams [61]. This may be of crucial importance seen their critical stance against 'unsustainable land-based biofuels' [70].

Function 4. Guidance of the Search (GoS)

The push towards a greater utilization of low-carbon fuels is guided mostly by the European biofuels directive. Directive 2009/28/EC targets to a minimum 10% share of renewable transport fuel use in every Member State in 2020, up from a 5.75% target in 2010. The directive further 'aims to ensure the use of sustainable biofuels only, which generate a clear and net GHG saving without negative impact on biodiversity and land use' [4]. Specific attention has been given to 'advanced' or second generation biofuels. Fuels derived from wastes and residues are allowed to be counted double towards reaching the 10% target, whilst first generation biofuels (derived from sugar or starch) are capped at 7% [71]. Further competition between both different first and second generation fuels is left to market forces.

The recent 'iluc' directive has finally provided the cap on land based fuels and indications on how emissions from indirect land use change would be incorporated into biofuel GHG accounting. This debate, however, has taken considerable time to be settled; discussion started approximately 2009 and the new directive is currently ready to be published into the Official Journal of the European Union [7].
Furthermore, there have been considerable adjustments during the discussion process. An initial cap on land-based fuels of 5% was suggested by the EC. This was subsequently changed to 6% by the European parliament, and ended up as a 7% cap in the final text [72]. Rules on double-counting, too, have been subject to change. An original proposal suggested double-counting for more simply processed wastes such as fats and oils, and quadruple counting of more recalcitrant feedstocks such as cellulosic materials ('advanced biofuels'). The final text grouped all of these, and applies double-counting to all [72]. The final text does set a separate target for the advanced biofuels, however. This target is a 0.5% indicative (non-binding) target, adjusted downwards from a binding 1.25% target in earlier proposals [72]. Lastly, it has long not been clear how the 'iluc' component in lifecycle GHG emissions, the core of the new proposal, would be dealt with; the final text adopted requires reporting of these emissions, but does not require these to be included when comparing a biofuels GHG emission with threshold values.
The lack of clarity of what future biofuel policy would look like has deterred investors form building new production capacity. The result has been virtually no growth in biofuel consumption between 2009 and 2014 (Figure 12). Although the debate has now finally been settled, clarity remains lacking on post-2020

targets, which are going to be needed soon to provide any long term prospect for investment made in following years.
For bread and bakery wastes in particular, the adopted text remains open to interpretation in its reference to these feedstocks: these may be double counted if these are 'not fit for use in the food or feed chain'. It is not specified whether this refers to technically fit (i.e. possible to use as feed) or economically fit (i.e., whether it would be utilized as feed in absence of other demand). This lack of clarity has made it difficult for St1 to convince investors in other EU countries to license their technology, according to a company spokesperson.

Of particular relevance to post-2020 targets is the support for high blend fuel markets and infrastructure. Ethanol at low blends can be utilized in gasoline-powered vehicles without any modifications. At current levels of ambitions, however, low blend fuels are not likely to be sufficient even for medium term targets (10% in 2020). Current EU legislation allows for a 5% ethanol blend (by volume) in standard gasoline, with only three countries (France, Germany and Finland) allowing 10% blends [73]. Legislation for 10% blends has been discussed in a larger number of countries but is yet to be effected. A key argument is the potential for damage to fuel systems and engines, voiced by a powerful lobby from fossil fuel, automobile and food industries. The same issue is discussed in the US, although the debate there concerns the step from 10 to 15 % blends [74]. High blend ethanol fuels will require changes to fuelling infrastructure and vehicle fleets. The number of fuelling stations offering E85 stood at approximately 4,000 in 2012, largely concentrated in Sweden and the UK [75].
The post-2020 targets are bound to be a step up from the 10% target for 2020, implying that high blend markets become an absolute necessity. Current stimulus by member states restricts policies that would enable such markets to be formed, however. This line of argument is presented in section 2.5.6, and we will not repeat it here.

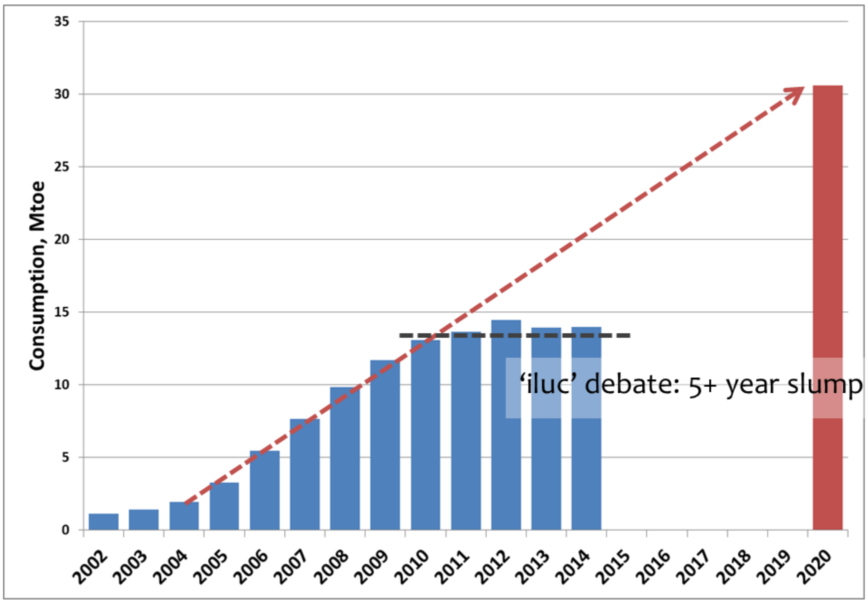
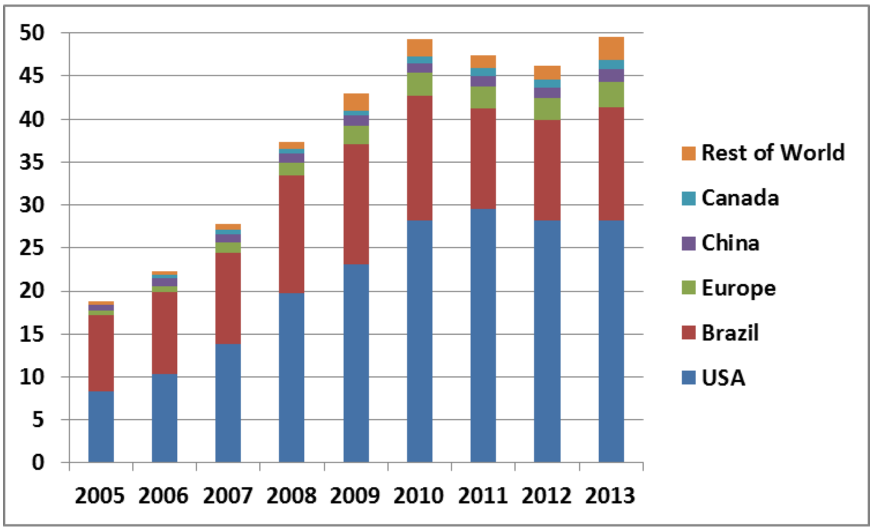


Figure 12. EU Biofuel Market Development Under Policy Uncertainty

Function 5. Market Formation (MF)

Global fuel ethanol consumption (including both crop and waste based ethanol) has more than doubled over the last decade, whilst EU consumption has even increased six-fold since 2005, see following figure. Despite this rapid growth, the EU clearly still lags behind the US and Brazil in volume of fuel ethanol production and consumption. The bulk of ethanol production here is crop based, i.e., from corn in the US and sugar cane in Brazil. Ethanol production, as a share of all road transport fuel consumption stood at 17,4% in Brazil and 5,8% in the US, versus 0,83% in the EU (2011 values).



Source: [76]; conversion factors: 1 Mtoe=41.87 PJ=1.41 Mt ethanol=1,719 million litre ethanol.

Figure 13. World Fuel Ethanol Production (Mtoe), including Crop and Waste Based Ethanol

Fuel ethanol production is to a very large extent used for domestic consumption. Brazil consumes circa 80% of domestic ethanol production [77]. The US has shifted between slight net imports and exports over the last few years [78]. The EU produces circa 71% of the ethanol consumed for fuel production (for all biofuels this is even 80%) [8]. This relatively strong relationship between production and consumption continues even on the national level within the EU-28 (Figure 10).

Despite significant research and demonstration efforts into ethanol from diverse wastes and residue streams, approximately 80% of EU production is still derived from cereals [39]. Currently, cereal based ethanol producers are already suffering from competition with US imports, with a number of projects reducing outputs or even mothballed altogether [79]. The future outlook for waste and cellulosic based ethanol is further likely to be impacted by the removal of beet sugar production quota and corn syrup import restrictions under the Common Agricultural Policy in 2017 [35].

An industry representative argued for expanded trade in mandates between parties obligated to blend biofuels. Currently, only a few countries allow this, but with no international trading taking place. The argument for an expanded, e.g., EU wide system is that 1) parties with an obligation would find markets where biofuels obligations could most easily or least costly be fulfilled, and 2) that such a market would create a price point for mandate credits. Such a price point would provide investors with far better perspectives, as it would commodify the biofuel mandates and provide easy access to EU-wide price trends, in the same way that we currently have time series with trends and real-time price tickers for carbon credits. Such a system, however, would require equal application of double-counting rules and other criteria throughout all European markets, and the current situation is far from that.

Function 6. Resources Mobilization (RM)

The development of several pilot and demonstration plants points to considerable mobilization of resources. The St1 project for waste based ethanol production in Gothenburg was budgeted at €10 million, with €1,7 million contribution form the EU [23]. Although we could not find investment details on earlier production facilities, the output of this plant is circa 5 Ml annually, or about 3 to 5 times as much as earlier projects. Other, relatively larger scale projects, have had relatively lower costs, at about €1 million per Ml of

production capacity. The Borregaard plant in Norway (18 Ml) is estimated to have cost €16,4 million, with about €7,3 million in public support. The much earlier SEKAB project in Örnsköldsvik (15 Ml) also cost circa €16,4 million, but received circa €15,2 million in public support [14].
St1's wood based cellulosic ethanol plant in Kajaani (10 Ml) is significantly more expensive, at an overall investment of EUR 40 million, of which 30% is covered by an investment subsidy granted by the Ministry of Employment and the Economy [60].
These projects are of a size that they are in between pilot plants (up to several ML) and typical commercial sizes (approximately 100 ML+). This is exactly where the typical 'valley of death' in the innovation chain occurs; as government funding for basic research is no longer applicable nor sufficient, whilst private investors are not yet sufficiently convinced to spend many 10s to a 100+ million euro in developing a first-of-its-kind large scale refinery. EU guidelines on state aid limit investment aid to projects generally not exceeding €15 million in aid, and up to 50% of total project investment cost [46].

In terms of feedstock sourcing, there seem relatively little issues for the suggested technological pathways. Waste streams from industrial processes and MSW are abundant, cheap, and of sufficient quality. Areas with many projects may suffer from competition over locally available feedstocks, however, so care should be taken in planning. This appears to be the case in particular for food-wastes. For cellulosic based production processes, feedstock volumes are very abundant, although also highly variable in quality, e.g., saw dust versus crop wastes.

Function 7. Creation of Legitimacy (CoL)

Waste based ethanol has a number of characteristics that correspond with societal and political goals. In terms of environmental emissions, it has very strongly reduced carbon emissions compared to both gasoline and crop based ethanol. Effects on air quality are marginal (see also the section on 'Environmental and Social Benefit' under 'Estimation of the Investment Case'.
Further, strong legitimation is derived from the fact that ethanol is produced locally, increasing local revenues and job opportunities, and decreasing dependence on foreign oil imports and price volatility.

Summary: Drivers and Barriers

Analysing the seven interrelated Innovation System Functions (ISF) typically results in insights with respect to drivers and barriers of the specific innovation, (Suurs and Roelofs, 2014) . This section summarizes the main drivers and main barriers from the pre-discussed Innovation System Functions and their relation to a further diffusion of "Ethanol from Residues and Wastes". Based on the information provided in the preceding sections, the levels of ISF fulfilment is shortly discussed and is hence based on the author's own assessment. The fulfilment is scored by means of a five-point scale (1 – very weakly developed, 2 – weakly developed, 3 – developed, 4 – strongly developed, 5 – very strongly developed), see also following figure.

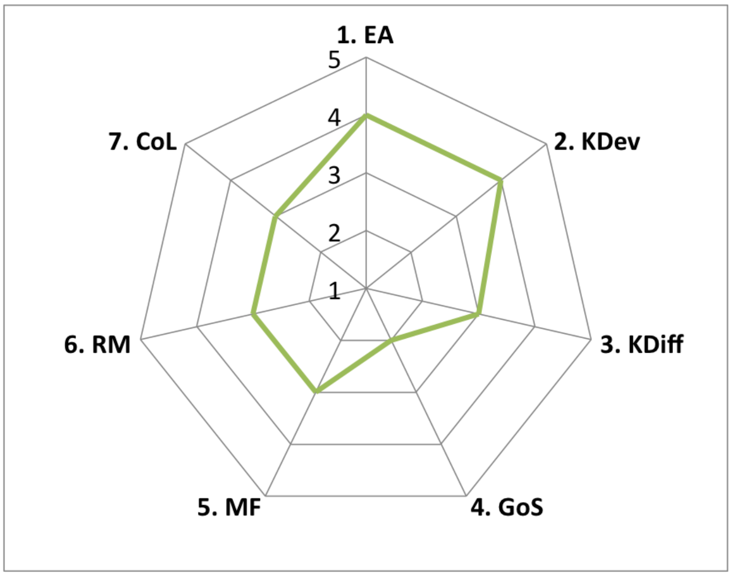


Figure 14. Fulfilment of Innovation System Functions: Bioethanol from Residues and Wastes

Key drivers are:

- Very strong knowledge base for easily fermentable waste fractions;
- The very strong reductions in GHG emissions compared with both gasoline and crop based ethanol;
- Potential for employment and revenue growth from domestic fuel production

Key barriers are:

- Remaining research and demonstration needs for developing cost-competitive ligno-cellulosic ethanol production processes;
- Difficulties in developing scaled up advanced biofuel refineries when private investors are hesitant whilst government participation is limited;
- Remaining lack of clarity on financial stimulus and further competition with first generation biofuels;
- Lacking stimulus for the development of high ethanol blend fuelling infrastructure;
- Limited commodification (and trading possibilities) of blending mandate credits; investors lack price signals for the value of their waste-based biofuels in particular

2.5 Further Evidence on the Innovation System

2.5.1 *Techno-Economic Assessment*

Here we describe the economics of a model project plant for the synthesis of waste based ethanol, utilizing bread and bakery wastes. We consider costs and revenues, risks and other business considerations, and compare with alternative biofuels and conventional fuels.

2.5.2 *Model Project Description*

The model project is made to closely resemble St1's ethanol production facility in Göteborg, Sweden, which started production of ethanol in June of 2015. The plant primarily utilizes waste from bakeries and bread products past its sell-by-date, collected from retailers. Similar plants in other locations use waste streams from mills or breweries. Collection from retailers is done by bakeries, other intermediaries, or set up by St1 specifically for the purpose of use in the Etanolix plants. The plant in Göteborg has a production capacity of circa 5 million litres per annum. Process flows for the model project are presented in Table 12.

Table 12. Model Project: Process Flows

Process flow	Annual volume	Unit
Inputs		
Bakery waste	10,800	t
Bread returned from retailers	7,400	t
Steam	10,000	MWh
Electricity	2,000	MWh
Water	44,000	t
Yeast and enzymes	55	t
Other chemicals	160	t
Outputs		
Ethanol (100%)	5,000	m^3
Stillage	4,750	t (dry solids)
Waste water	6,500	t
Bread packaging waste	270	t

2.5.3 *Financial Parameters and Cash Flow ModelRresults*

A list of key financial parameters is presented in Table 13. The values used in this overview were decided on after triangulation of data derived from a literature overview and data provided by ST1 biofuels.
The investment cost were provided by St1. The plant in Göteborg was co-financed with a subsidy from the EU's 'LIFE' programme, which makes financial details on both grant and total project budgets publicly available [23]. The budget reported in these documents was 4.5 M€, but this did not account for substantial cost benefits from integration into the refinery where the plant is sited. A stand-alone plant would cost approximately 10 M€, according to St1 representatives.

Feedstock cost are an average of two components. Unsold bread returned from retailers has a negative cost of approximately -30 €/t. This is a discounted fee compared to generic waste collection fees charged by the waste collector, incentivizing retailers to separate waste streams. The other feedstock component, bakery waste, is collected from larger scale industries that have alternative potential uses for these wastes (mostly animal feed). The range of costs of between 60 and 150 €/t is taken from a recent report from an EU funded research project on the synthesis of different biobased chemicals using bread wastes [24]. ST1 representatives reported a current cost for bakery waste of approximately 90 €/t.

Cost for electricity are those for a 'mid-sized industrial premise' as reported in a report by a Swedish government service [25]. Approximate cost for steam/heat are derived from an study on the synthesis of wheat ethanol in Sweden [26].

The types, annual volume, and cost of chemicals, yeast and enzymes used are derived from a report that focuses on the synthesis of ethanol using wheat [26], a process which should be similar enough to one using bread waste. The report distinguishes values for small, medium and large scale operations. We used values for medium scale plants, corrected for inflation. The value of the co-product, stillage (which can be used as an input for animal feed), varies a lot, as it is coupled to prices in grain markets. We use an approximate average of prices reported in a number of resources [25, 27-30].

Using the values as reported in Table 13, we arrive at an estimated production cost of €530 per m^3 of 100% ethanol, or €459 when accounting for the co-product value (see Figure 15). The feedstock cost is one of the key considerations in a business case for biofuels is, firstly because these are a considerable portion of total production cost (see Figure 15), and secondly because of the high volatility in feedstock prices (more in section 2.5.4). Note also that this cost is exclusive of fuel excise or carbon taxes. The treatment of biofuels versus fossil fuels in fuel taxation varies considerably across EU member states, with anywhere between no to full exemption from such taxes.

Expected revenue from ethanol is difficult to pinpoint, moving between approximately €450 to €600 in recent years, with an average of circa €650/m^3 expected in the longer term [13]. This large range is connected to volatility in agricultural product markets. The bulk of global ethanol production is currently still based on grains and sugar crops. We use values as reported in the medium term outlook from the DG Agriculture and Rural Development [13]. Further, we assume a 'green premium' of approximately 50 €/m^3. Fuels derived from wastes and residues can be double-counted towards obligations required from fuel distributors, and may therefore be considered a more cost-efficient way to attain blending quota. Such quota, as well as double-counting, are dependent on Member State policy choices, however. St1 indicated a 'green premium' of up to 100 €/m^3 exists, in markets where such double counting is applied, and always dependent on individual contracts between fuel supplier and distributor. We use a 50 €/m^3 green premium as a conservative estimate, accounting for the uncertainty in monetizing this green premium.
Using the values as reported here, this project would generate an internal rate of return of approximately 7.7%, with a payback period of around 9 years. There are, however, a number of risks regarding feedstock cost and supply security, as well as risks regarding revenue, from uncertain demand levels, competition with alternative biofuels, and policy stimulus, dealt with in the following sections.

Table 13. Main Parameters Used in Cash Flow Model

Parameter	Unit	Value	Notes
Capital expenditure			
Investment	€	10,000,000	a
Share equity vs. loan	%	30 vs. 70	
Payback period of loan	Years	15	b
Technical lifetime	Years	15	b
Interest rate	%	6.0	
O&M			
Personnel	FTE	5	a
Feedstock, average	€/t	42	c
Bread returned from retailers	€/t	-30	a
Bakery waste	€/t	60-150	c
Share of return bread vs. bakery waste	%	40 vs. 60	a
Chemicals	€/m^3 ethanol	4.5	d
Enzymes	€/m^3 ethanol	13.1	d
Yeast	€/m^3 ethanol	0.0	d, e
Water	€/t	1.2	f
Electricity	€/MWh	48.6	g
Steam	€/MWh	15.6	d
Packaging material (waste)	€/t	27.8	h
Maintenance	€/a	250,000	i
Revenue			
Ethanol	€/m^3	550	j
Ethanol double counting 'green premium'	€/m^3	50	k
Co-product (stillage)	€/t dry solids	75	l
Corporate income tax	%	22	m
Result			
IRR	%	7.7	
Payback Period	Years	9	

Note: a) this was difficult to estimate as the Goteborg plant strongly benefits from integration into a refinery plant; b) values used as in [27], which will be used to compare different biofuels in the following sections; c) average is calculated as 40% return bread at -30 €/t, and 60% bakery waste at 90 €/t; source: interview with St1 and [24]; d) source: [26]; e) yeast assumed to be produced on-site; f) this fee includes supply and wastewater components, source: [31]; g) source: [25]; h) source: [32]; i) assumed at 2.5% of investment per annum; j) source: [13]; k) St1 indicated a green premium of up to 100 €/t is possible, in markets where double-counting is applied. This is the case in Finland but not in Sweden; l) source: average as reported in [25, 27-30]; m) source: [33].

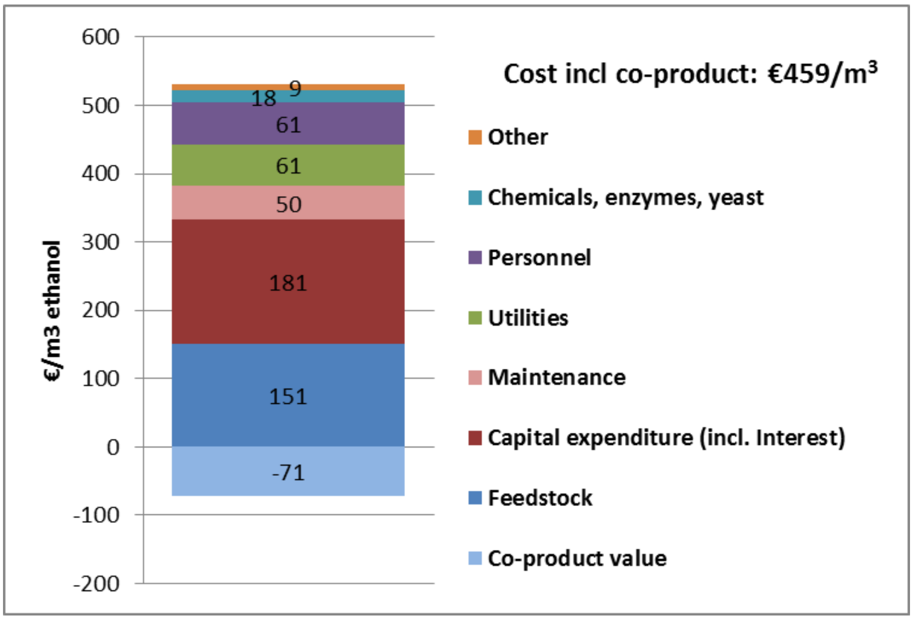
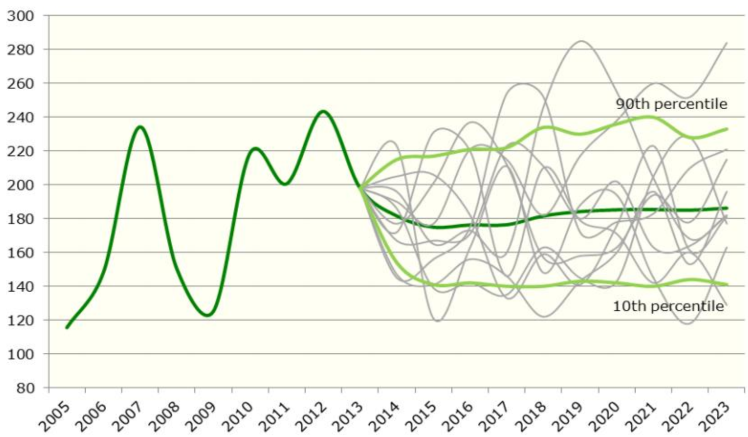


Figure 15. Estimated Production Costs in a Medium Scale (5Ml/a) Refinery for Bread and Bakery Waste Based Ethanol, by Cost Component

2.5.4 *Feedstock Price Volatility and Supply Risks*

Feedstock cost is an important item in total production cost for bread and bakery waste based ethanol, although less so than for crop based biofuels (Figure 17). An uncertainty in business cases for a production facility for biofuels is the large variability in these feedstock cost (see also the ranges in Figure 17). Most biofuel production remains based on food crops, which are subject to considerable price volatility. Over the last ten years, prices for wheat and maize have moved, roughly, between €120 to €250/tonne, and the future outlook, too, is highly uncertain ([34]; see also **Source**: JRC [39].
Figure 16).

Sugar beets have moved roughly between €25 and €45/t [35], and rapeseed oil, used for making biodiesel (HVO; hydrotreated vegetable oil), has moved between €550 and €950/t [36]. Prices for used cooking oil (UCO) and animal fat have seen considerable variability as well. Different studies report values between circa €300 to €850/t [37, 38]. This large range is due, in part, to varying qualities of the oils and fats (e.g., level of purity, type of contamination), but has also depend on demand levels for biofuels and prices of competing biofuels. Oil prices, subject to volatility of at least comparable levels, matter too. First, because it determines the production cost of the primary competitor, fossil transport fuels, and second, because production costs of agricultural commodities strongly depend on, and move with, oil prices.



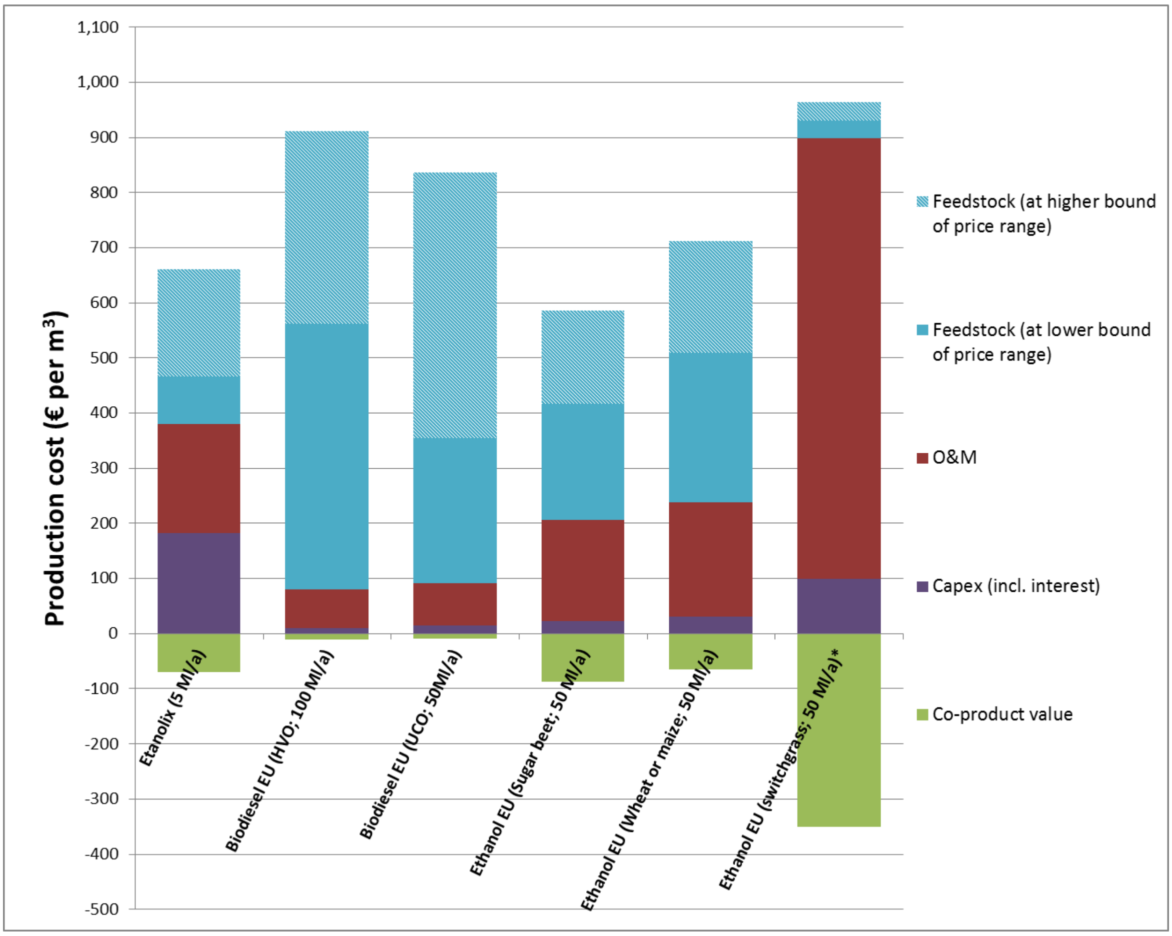
Source: JRC [39].

Figure 16. Historical Prices and Possible Future Price Paths for Common Wheat in the EU (€/t)

In the case of biofuel production on the basis of bread and bakery waste, variability in feedstock cost depends on the prices offered for alternative uses, primarily animal feed. This price, in turn, moves together with prices for cereals. The price for bread and bakery waste is not at all very well reported on, but one recent study put it at between €60 and €150/t [24]. Although these prices are well below those of wheat, price volatility is of comparable levels. An attractive feature of many other wastes is that these are less costly, but also subject to less price volatility.

An issue in the use of wastes as a feedstock, however, is the potentially limited scale of (local) feedstock availability and/or limited organization of feedstock supply chains. For example, St1 uses small scale plants (~1 or 2 Ml) to utilize waste streams from breweries, potato processing factories or the confectionary industry. These waste streams are watery solutions of starch or sugars, which do not lend themselves to economically feasible transport. Feedstock supply, then, is largely determined by the production volume of the plant to which the ethanol processing unit is connected. This also implies that the plant owner must be willing to have such a facility set up on the premises, and provide the feedstock at a reasonable fee. Some of these types of plants supplement feedstock supply with more easily transportable bread or bakery waste, but the continued supply of feedstock from the plant to which the ethanol processing facility is connected is an essential condition for its economic viability.
The feedstock supply for a number of St1 plants that run primarily on bread and bakery waste, requires considerable effort in organization. Collection networks were created in cooperation with bakeries and mills, depended on existing collection networks of unsold bread products returned from retailers to bakeries or other intermediaries, and/or required the set-up of St1 organized collection routes along local supermarkets. The 1.2 Ml/a plant in Lahti is supplied by nine different breweries, bakeries and mills [40]. Feedstock supply for St1's 5 Ml/a plant in Göteborg is currently even supplemented with wastes from Malmö and Stockholm. This is economically feasible only because many trucks deliver cargo to these cities from Göteborg's large seaport, with many having no cargo for the return trip. This makes transport capacity from these cities back to Göteborg available at relatively low rates. St1 indicated that they would focus on securing more local sourcing during the first year of the plants operation. Still, the feedstock base for the 5-10 Ml/a plants, the capacity which St1 considers the most suited scale for bread and bakery waste ethanol production, is found in cities of approximately 500.000 inhabitants and upwards.

A number of other wastes with a potential use in the production of ethanol, although via different technical processes, include biological fractions of household waste, crop residues and forestry industry wastes. These wastes may suffer less from the collection issues described above because their production is more concentrated, or because existing collection services are in place. There is competition for these wastes as well, however. Forestry industry waste has a competing use in heat and power generation, whereas much biowaste is used in biogas production. In Finland, St1's home market, biowaste is utilized to such a high degree that it expects few further applications of its Bionolix technology in this market. Lastly, although these feedstocks are more attractive in price and price stability, the conversion technologies are less mature, and CAPEX and OPEX are (much) higher than for crop based ethanol production; compare e.g., with the estimate for switchgrass based ethanol production in Figure 17.



Note: estimates on Etanolix: authors calculations, see section 2.5.3; other fuels: authors calculations based on values reported in De Wit [27]; HVO: hydrogenated vegetable oil; UCO: used cooking oil; *) note that the estimate for switchgrass based ethanol is largely hypothetical and quite uncertain; there are no known commercial demonstration plants of this type. Note also that biodiesel has a higher energy content than ethanol; these differences are accounted for in the comparison provided in Figure 18.

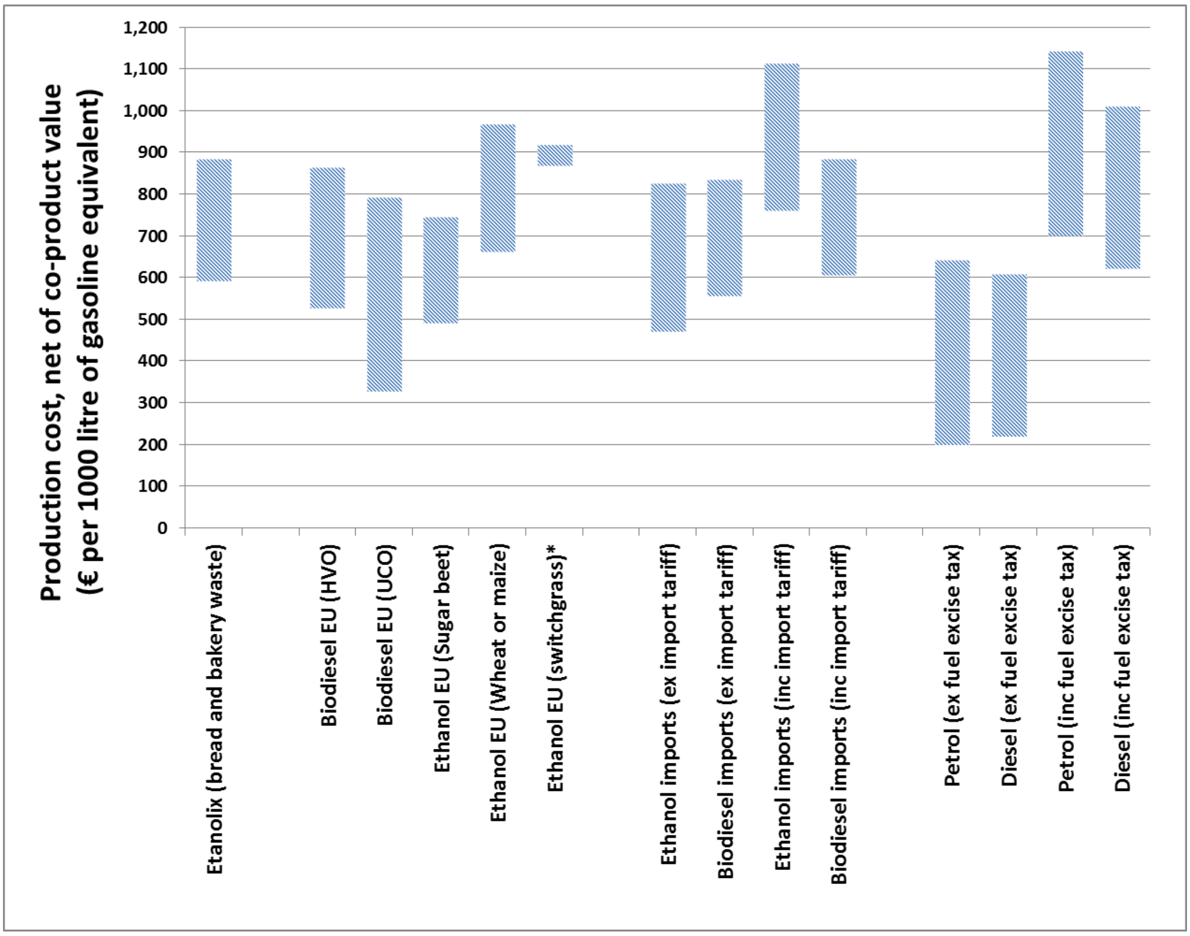
Figure 17. Comparison of Production Cost Components in Selected Biofuels (€/m³)

2.5.5 *Comparison of Production Costs with Conventional and Other Biofuels*

In Figure 18, we present a comparison of production cost for a number of different biofuels and fossil fuel alternatives. These include a range of these costs; this range is based entirely on variability in feedstock (or oil) prices. Line items such as CAPEX and OPEX etc. were kept equal in determining upper and lower bounds for each fuel type.

Note that production cost listed are not in in €/1000 l of physical volume, but in litres of gasoline equivalent. This is to correct for the strongly differing energy content of each of the fuels, which largely determines their economic value. Biofuel blending targets, at the EU level, and those for fuel distributors, are also determined in percentages of energy content, not physical volume.

Fuel excise taxes are included for fossil fuels only; values reported are approximate EU member state averages [41]. Biofuels are exempt from such levies in many member states, but to very differing levels (see next section for more). The import tariffs included for imported biofuels are the generally applicable tariffs for bioethanol and biodiesel. On top of this, the EU has imposed 5 year anti-dumping duties of 62.9 €/t on US bio-ethanol, starting 2013 [42] , of around 250 €/t on US biodiesel starting 2009 [43], and similar duties on Argentinian and Indonesian biodiesel since 2013 [44].



Source: EU based biofuels: see notes with Figure 17; imported biofuels [30, 36]; fossil fuels: [45].
Note: all notes as provided with Figure 17 apply; gasoline equivalent conversion factors are: Gasoline: 1.00; Diesel: 1.14; Ethanol (100%): 0.67; Biodiesel: 1.04.

Figure 18. Comparison of Production Costs for Different (Bio)Fuels, Net of Co-Product Value, € per 1000l of Gasoline Equivalent.

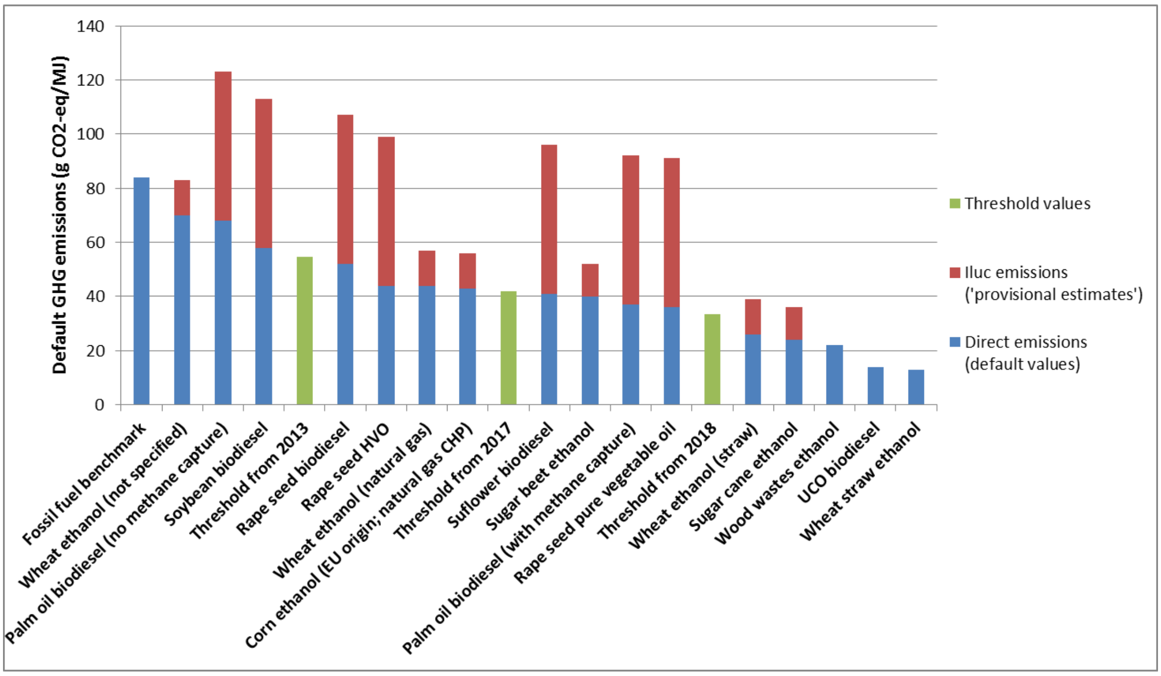
2.5.6 *Demand Side Policies and Relative Competitiveness of Different Biofuels*

The competitiveness of biofuels versus fossil fuels, as well as the relative competitiveness of crop based and waste based biofuels, remain very strongly dependent on demand side policies.

The main EU level instruments impacting the promotion of biofuel use are:

- The renewable energy directive (2009/28/EC) [4]:
  - set a mandatory target of 10% minimum share of renewable transport fuel use, in every Member State, to be achieved by in 2020. This was up from a 5.75% target by 2010.
  - The directive allowed the share of fuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material to be counted twice that toward the 10% target (double-counting).
  - Biofuels are eligible to be counted towards meeting targets only when their life-cycle emissions are a 35% CO_2 emissions savings compared to fossil alternatives; this threshold is increased to 50% by January 2017, and 60% by 2018 (the latter only for production facilities starting production from January 2017 onwards). The practical implications for different biofuel types are provided in Figure 17.
- The 'iluc' directive on fuel quality and renewable energy (P8_TA-PROV(2015)0100; provisional text adopted) [7]:
  - 10% target maintained.
  - Introduced a 7% cap on the use of first generation biofuels (derived from food crops, or technically 'land based biofuels'); further consumption cannot be counted towards meeting the 10% target.
  - Standards for life-cycle emissions including 'indirect land-use change' (iluc). A number of 'provisional estimated mean values' (see Figure 17) have been provided for different crop feedstocks, although these include very large ranges reflecting uncertainty about these emissions. Iluc values have to be reported, but are not accounted for when comparing with GHG thresholds.
  - Threshold values are changed to 50% CO_2 savings by January 2018, for installations producing before entry into force of the adopted text, and 60% for installations starting production after the entire into force of the text.
  - Double-counting remains in place.
  - Within the waste based fuels, a new distinction is introduced between 1) used cooking oil and animal fats and 2) other wastes including municipal and industrial biowaste, algae, cellulosic material, crop residues, etc. The latter category of wastes are considered 'advanced biofuels' and subject to a 'reference' (i.e., not mandatory) target of 0.5%.
- Guidelines on State aid for environmental protection and energy 2014-2020 [46]:
  - Aims to limit member states' stimulus for biofuels if these have potential to distort internal (EU) markets, whilst preserving room for developing novel environmentally sound technologies.
  - 'Notifiable aid' are measures that need to be reported and approved by EC. These include:
    - investment aid exceeding 15 million € for a single production plant;
    - operating aid for the production of biofuel for plants with production capacity exceeding 150 kton/a;
    - Exemptions from excise taxes. Exemptions from 'environmental taxes', including CO_2 taxes, are not subject to notification.
  - Approval for notifiable aid hinges on a number of criteria, amongst others:
    - Non-selectivity: the stimulus measure may not benefit certain operators more than others
    - 'Proportionality: tax exemptions may not 'overcompensate'; they may only

account for the difference in production costs between biofuels and fossil alternatives (in an attempt to 'level the playing field'). Calculations on production costs have to be updated regularly, at least every year.
- Tax exemptions need to a temporary nature. The commission may authorise measures of up to four years, but e.g., approval for Sweden's biofuel tax exemptions have been renewed bi-annually [47].



Note: iluc emissions are 'provisional estimated mean values'; reporting [7]. Note that Iluc values have to be reported, but are not accounted for when comparing with GHG thresholds. Direct emissions are default values for cultivation, processing, transport and distribution; fuels mentioned between brackets refer to the fuel used in processing steps [4].

Figure 19. Default Values of GHG Emissions Savings for Biofuels Compared with Fossil Alternatives

Although the EU's biofuel policies have general applicability to all member states, there is room for individual member states to differentiate in a number of ways, including choices in:

- a fuel blending mandate (member states may meet the 10% target through other measures);
- a sub-target in fuel blending mandates for e.g., diesel, petrol or gas alternatives. With the adoption of the latest fuel quality directive, member states are encouraged but not required to set sub-targets for 'advanced biofuels' as well;
- whether to implement double-counting for waste-based biofuels in obligations to fuel distributors;
- whether to allow trade in mandates between fuel distributors;
- whether to exempt biofuels from CO2 and or energy taxes, and to what level;
- whether to stimulate high-blend consumption with tax reductions on flex-fuel vehicles, e.g., in road taxes, purchase taxes etc..

A full overview of the specifics of all policies in all member states would exceed the level of detail possible in this report.

The following table provides a summary overview, however. For further details we refer to the original sources used to draw up that table [48-50]. Note, too, that these policies are subject to change; Germany and Italy, for example, allowed double counting, but have annulled this possibility starting 2015 [49]. Member states should further be expected to adjust national level policies with the recent adoption of the 'iluc' directive. Italy has recently announced a strict 1.2% mandate for advanced biofuels by 2018 [51].

Table 14. Summary Overview of Member State Differentiation in Demand Side Biofuel Policies

Member state	AT	BE	BG	CY	CZ	DK	EE	FI	FR	DE	EL	HU	IE	IT
Mandate	X	X	X	X	X	X	X	X	X	X		X	X	X
Fuel specific mandate	X	X			X					X		X		
Double counting	X							X	X			X		
Tax exemption (excise tax)	X	H	X		H				X	H		H		X
Tax exemption (CO_2 tax)	n/a	n/a	n/a	n/a	n/a	X	X	X	X	n/a	n/a	n/a	n/a	n/a
Vehicle tax benefits/subsidies		X		X		X			X				X	

Member state	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE	UK
Mandate	X	X	X	X	X	X	X	X	X	X	X		X
Fuel specific mandate					X			X	X		X		
Double counting					X	X	X			X	X		X
Tax exemption (excise tax)	H	H	X	X	H				X	X	X	X	X
Tax exemption (CO_2 tax)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	X	n/a
Vehicle tax benefits/subsidies				X	X	X	X						X

Source: [48] and [49],
Note: updated with country specific info form the state aid registry [50]. For tax exemptions on excise tax: X indicates the presence of a tax reduction; H indicates the presence of such a reduction for high blend biofuels only; note that the presence of a tax exemption does not necessarily imply full exemption. For tax exemptions on CO_2 tax: n/a indicates the country does not have CO_2 taxation in place for fossil fuels. Vehicle tax benefits/subsidies refers to vehicle registration or circulation tax.

These different demand side policies will affect the competitiveness of different biofuels in following ways:

- Sub-targets for individual fuel alternatives will tend to improve demand for ethanol fuel. Currently, biodiesel varieties are the least costly of the biofuel alternatives (see also Figure 18).
- Double counting will improve demand for waste-based fuels. Although waste-based fuels remain more costly than crop-based fuels, it is more cost-efficient to blend 1 litre of waste based fuels vs 2 litres of crop based fuels.
- A combination of double counting and sub-targets for individual fuel alternatives will improve demand for waste-based ethanol. Waste-based biodiesels, in particular from used cooking oil and animal fats remain cost-competitive with waste-based ethanol. Biofuels produced from these two feedstocks account for circa 90% of current double-counted biofuel use in the EU [52].
- Mandates will create most strongest demand for the lowest cost biofuel; again this would be biodiesel variants;
- Mandates at ambitious levels, in particular mandates that exceed the 'blend wall' (the maximum percentage of biofuels that can mixed into petrol or diesel without damaging the engine or impacting engine performance), in combination with double-counting, creates demand for waste-based fuels. This is true because it allows meeting a 10% target even if blending is regulated to a maximum of 5% physical biofuel content. In particular in markets without strong tax exemptions, fuel distributors will have not be able to create much demand for high blend fuels, and therefore need to resort to blending the more expensive waste-based fuels in order to meet mandates and avert penalties.
- Tax exemptions may obviously reduce cost for fuel distributors as well as final prices to consumers. In order for biofuels to be competitive with fossil alternatives, these exemptions need to be of very substantial levels (see also Figure 18).

Current EU biofuel goals target two transitions; towards waste-based fuels (or away from crop based fuels) and towards high-blend markets (as low blend solutions will never allow consumption levels of very far over 10% volume of all fuel). A somewhat simplistic dichotomy is that the former goal could be realised most easily with ambitious mandates including double-counting, whereas the latter is most easily realised with strong tax exemptions. Good examples reflecting these divergent paths are the Finnish and Swedish market developments, summarized in Table 15.

Both countries are near the top when considering current biofuel consumption, as a percentage of all motor fuels; Sweden is the number one by a large margin [52]. Developments in Finland have taken of somewhat later than in Sweden, but that market is one of the fastest growing markets in the EU [52]. Finland is amongst EU leaders in advanced biofuels, whilst Sweden is the only EU market with a significant high blend market share.

The Finnish success is thanks in large part to the ambitious mandate; up to 8% already in 2015, and a 20% target recently adopted [53]. Ethanol blends are allowed in 5% or 10% v/v; with the latter recommended only for vehicles from 2001 or newer. Ethanol energy content is approximately 66% of that of gasoline, so even the 8% target of 2015 pushes fuel distributors to double-counted fuels in order to meet mandate targets whilst staying below the blend wall.

This strong demand for waste-based fuels has already resulted in investment in production capacity. St1 has 7 plants; 5 running on bread, bakery and/or brewery wastes, one running on municipal biowaste, and another one starting production 2016, running on forestry industry wastes. Combined production capacity is 23 Ml. UPM has recently started producing ethanol from tall oil, a waste product from paper pulping, in a plant with a capacity of 115 Ml. Neste Oil produces 215 Ml biodiesel annually in Finland and has further production capacity in the Netherlands and Singapore. The feedstock used is circa 2/3 used cooking oils and animal fats, and 1/3 palm oil; the aim is to be running on 100% waste oils and fats by 2017 [54].
Although a number of fuel distributors have made high blend ethanol (E85) available to consumers, demand is entirely lacking. Ethanol is exempt from CO_2 taxation (16.3 €ct/l of petrol). It is not exempt from energy taxes, which is 51.2 €ct/l of petrol or 33.6€ct/l of ethanol, which is equal when accounting for the differing energy content of the two fuels. This means pump prices to consumers are much higher, when accounting for this differing energy content (see also the Swedish example below), and very few consumers have been willing to invest in flex fuel vehicles, which are more expensive to purchase as well.

In Sweden, biofuel consumption has been largely promoted though fuel excise tax exemption. This has made biofuels less costly than fossil alternatives, and has incentivized distributors to blend exactly 5% ethanol v/v into low blend fuels (equal to the maximum level exempt from these taxes in low blend fuels; [47]). The strong difference in taxation levels has also meant that high blend ethanol (E85) pump prices to consumers have generally been below that of petrol (Figure 20). This, combined with tax reductions on 'environmental cars', which include flex fuel vehicles, and an obligation to fuel distributors to offer at least one environmental fuel at each filling station, has enabled a strong growth of the high blend ethanol market. Approximately half of all ethanol consumed in Sweden is high blend E85, the rest being consumed as low blend E05 [55].

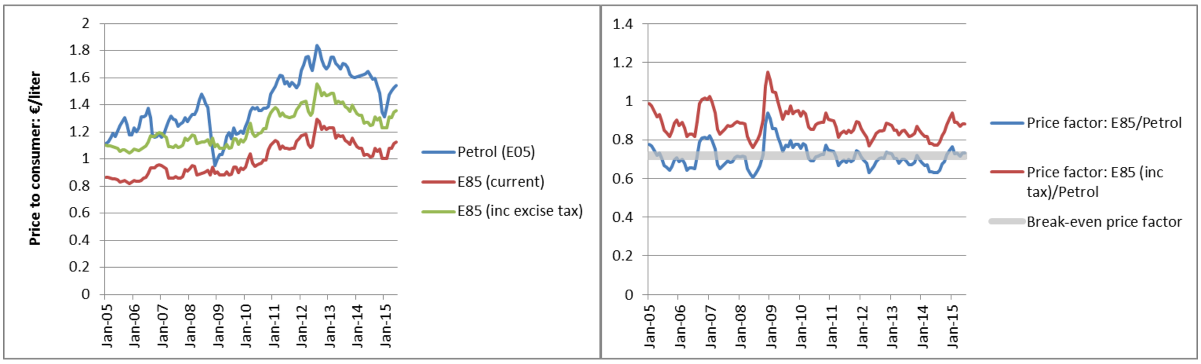
Waste based biofuels, on the other hand, have not taken of in Sweden as they have in Finland. St1 has recently opened a 5 Ml ethanol plant based on bread and bakery waste, and Lantmännen agroetanol, a Swedish biofuel producer, is feeding an existing wheat based ethanol refinery with similar wastes as well. Sweden's most advanced bio-refinery is the Domsjö plant in Örnsköldsvik. This plant was developed by SEKAB as a pilot to demonstrate the potential of using forestry industry wastes into fuel. SEKAB initially had plants to expand the pilot plant to more commercial sizes, but opted to sell the plant to SP Processum, which continues to run tests at pilot scales today. The difficulty of realizing commercial value of waste-based ethanol in a market that does not differentiate between first and second generation ethanol proved difficult.

When asked about preference for either tax exemptions or mandates, industry representatives indicated that long-term perspective mattered most. Mandates, in this sense, were preferable because these may be implemented with a very long term time horizon; tax exemptions, on the other hand, are subject to repeated renewal of approval from the EC due to EU state aid regulations.

EU biofuel targets post-2020 will require the development of high blend fuel markets. Even with double-counting, there are limits to the amount of biofuel that can be blended into petrol or diesel. When asked about the problem that these limits impose, a Finnish industry representative argued that this was a typical chicken and the egg problem: consumers would not be interested in high blend ethanol as prices remained too high, too few flex-fuel cars are being offered by the car manufacturing industry, and too few fuel filling stations have E85 on offer. Fuel distributors, on the other hand, see little use in offering E85 as few consumers have flex-fuel cars or are willing to pay higher prices for the E85 fuel. The existence of this apparent stale-mate is surprising, as neighbouring Sweden has managed to develop this market.
The possibility to develop such a high blend fuel market, however, has been entirely dependent on substantial tax exemptions. Without EU approval to exempt E85 from such taxes, it would not have been a cost competitive solution (Figure 20). Continued friction with EU guidelines on state aid [7, 47] and the currently stalled overhaul of the EU energy taxation [56, 57] remain a factor of uncertainty in the level of Swedish stimulus to these fuels, which may hamper future growth, or even undo past successes.

Table 15. Different Demand Side Biofuel Policies Lead to Different Outcomes: Comparison of Finland vs. Sweden

	Finland	Sweden
Biofuel % (2015)	8%	13%+
Policies	Mandate: 8% in 2015; 20% by 2020 Double counting ~20% tax exemption (exempt from CO2 tax component, not excise tax)	No mandate No double counting ~100% tax exemption Minimum 1 ren. fuel per station Tax benefits on flex-fuel cars
High blends	marginal	EU leader
Advanced biofuels	EU leader	marginal



Source: [55]. The graph shows that if the Swedish tax benefit (current exemption from energy taxes) would be disallowed by the EC on the basis of state aid rulings, E85 would not be able to compete with petrol anymore.
Note: E85 prices per litre need to be approximately 72% of the price of petrol (E05) to be provide a cost-benefit to consumers. E85 is less costly if the factor (right hand graph) is at or below the break-even price factor.

Figure 20. Swedish Prices to Consumers for Petrol and E85 (left) and Price Factor, Accounting for Differing Energy Content of Fuels (right)

2.6 Policy Implications

As with other biofuels and renewable energy solutions, waste-based bioethanol is dependent on a clear post-2020 framework for climate and renewable energy policy, and ambitious targets for the use of biofuels in transport would have a major demand-side impact.
Although a new biofuel directive has only just recently been adopted, there is already a need for a clear outlook post-2020 for financiers that are considering investing in new production capacity over the next few years.

A key consideration in post-2020 development plans will be the creation of high blend fuel markets, as biofuel consumption targets will exceed the 'blend wall' of 5 or 10% for most biofuels in low-blend fuels. The only successful experience in developing such a market is Sweden, where strong tax exemptions have enabled pump prices of ethanol to compete with those of petrol. Swedish policies have suffered from friction with EU guidelines on State aid, however, and continue to do so. Post-2020 high blend markets would, seen the current production cost differences between biofuels and fossil fuels, still require tax level differentiation, either in CO_2 taxes or in fuel excise taxes. Further, as post-2020 high blend market development will be required rather soon, care should be taken in limiting or even disrupting the development of the flex-fuel vehicle industry and infrastructure build-up in nascent markets.

The synthesis of ethanol based on other wastes, including forestry industry wastes, crop residues, and biological fractions of household waste remains under technical development, with a number of plants in operation across Europe. The scale of these projects is in between demonstration (up to several ML) and typical commercial sizes (approximately 100 ML+). This is exactly where the typical 'valley of death' in the innovation chain occurs; government funding for basic research is no longer applicable nor sufficient, whilst private investors are scared off by the limited technological track record. This requires a well-balanced policy framework with both demand side policies and investment aid. Research programmes remain important for the development of processes utilizing cellulosic and biowaste streams.

The development of waste based biofuels on the basis of food or feed wastes currently remain one of the technically least challenging feedstocks. A lack of clarity remains in the 'iluc' proposal, however, on what acceptable feedstocks for double counting are. The provision of a more specific white list for such feedstocks would help provide that clarity.

References

1. US Department of Energy, *Alternative fuels data center, online database at afdc.energy.gov/data/.* 2014.
2. IEA, *Key world energy statistics.* 2014.
3. Sánchez, Ó.J. and C.A. Cardona, *Trends in biotechnological production of fuel ethanol from different feedstocks.* Bioresource Technology, 2008. **99**(13): p. 5270-5295.
4. European parliament and Council, *Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.* 2009.
5. Greenea, *The double counting market in Europe: what to expect in 2015?* 2014.
6. European Commission, *2030 framework for climate and energy policies - online explanation of future targets at ec.europa.eu/clima/policies/2030/index_en.htm.* 2014.
7. EC, *Fuel quality directive and renewable energy directive ***II. Text adopted April 28th, 2015. .* 2015.
8. EC, *EU transport in figures – statistical pocketbook (multiple years used).* 2014.
9. european Commission, *Prospects for Agricultural Markets and Income in the EU 2013-2023* 2013.
10. Searle, S. and C. Malins, *Availability of cellulosic residues and wastes in the EU - The ICTT white paper.* 2013.
11. european Commission, *EU ENERGY, TRANSPORT AND GHG EMISSIONS TRENDS TO 2050 - REFERENCE SCENARIO 2013.* 2013.
12. IISD (International Institute for Sustainable Development), *Biofuels—At What Cost? A review of costs and benefits of EU biofuel policies.* 2013.
13. European Commission - DG Agriculture and Rural Development, *Prospects for Agricultural Markets and Income in the EU 2013-2023.* 2014.
14. Bacovsky, D., et al., *Status of Advanced Biofuels Demonstration Facilities in 2012 - report to IEA bioenergy task 39.* 2013.
15. EC Joint Research Centre, *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context.* 2014.
16. Chester, M. and E. Martin, *Cellulosic Ethanol from Municipal Solid Waste: A Case Study of the Economic, Energy, and Greenhouse Gas Impacts in California.* Environmental Science & Technology, 2009. **43**(14): p. 5183-5189.
17. Wang, M.Q., et al., *Energy and greenhouse gas emission effects of corn and cellulosic ethanol with technology improvements and land use changes.* Biomass and Bioenergy, 2011. **35**(5): p. 1885-1896.
18. Wang, M., M. Wu, and H. Huo, *Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types.* Environ. Res. Lett. , 2007. **2**.
19. Spatari, S., Y. Zhang, and H.L. MacLean, *Life Cycle Assessment of Switchgrass- and Corn Stover-Derived Ethanol-Fueled Automobiles.* Environmental Science & Technology, 2005. **39**(24): p. 9750-9758.
20. Slade, R., A. Bauen, and N. Shah, *The greenhouse gas emissions performance of cellulosic ethanol supply chains in Europe.* Biotechnology for Biofuels, 2009. **2**(1): p. 1-19.
21. Jacobson, M.Z., *Effects of Ethanol (E85) versus Gasoline Vehicles on Cancer and Mortality in the United States.* Environmental Science & Technology, 2007. **41**(11): p. 4150-4157.
22. IVL, *A comparison of emissions from ethanol and gasoline powered vehicles - Health risk assessment for Västra Götaland.* 2010.
23. Etanolix 2.0 for LIFE+, *project description - Demonstration of Innovative Method for converting Industrial Waste to Ethanol in oil refinery for LIFE+ reference LIFE12 ENV/SE/000529.* 2013.
24. project, B.P., *Demonstration plant project to produce Poly-Lactic Acid (PLA) biopolymer from waste products of bakery industry. Porject nr LIFE10/ENV/ES/479.* 2014.
25. council, T.S.t.a.i., *Business cost and prices of key services.* 2013.
26. Bernesson, S., *Life cycle assessment of rapeseed oil, rape methyl ester and ethanol as fuels - a comparison between large- and smallscale production. Swedish University of Agricultural Sciences, Department of Biometry and Engineering. Report nr 2004:01.* 2004.
27. Wit, M.d., *Bioenergy development pathways for Europe. Potentials, costs and environmental impacts. PhD Dissertation. Science, Technology and Society Group of Utrecht University and Policy Studies Unit of the Energy Research Centre of the Netherlands.* 2011.
28. Ecofys, *Fact check on biofuels subsidies.* 2013.
29. SAC Consulting, *Distillery feed by-products briefing. Report commissioned by the Scottish Government.* 2012.
30. FAO, *Biofuels: prospects, risks and opportunities.* 2008.
31. The Swedish Water & Wastewater Association, *Facts on water supply and sanitation in Sweden.* 2000.
32. Finnveden, G., et al., *Flexible and robust strategies for waste management in Sweden.* Waste Management, 2007.

27(8): p. S1-S8.
33. The Swedish trade and invest council, *Corporate taxes in Sweden.* 2014.
34. Committee for the Common Organisation of Agricultural Markets, *Market situation Cereals - AGRI C 4 - 30 July 2015.* 2015.
35. European Commission - Joint Research Centre Institute for Prospective Technological Studies, *EU sugar policy: A sweet transition after 2015 ?* . 2014.
36. Index Mundi, *Rapeseed Oil Monthly Price - Euro per Metric Ton FOB Rotterdam - http://www.indexmundi.com/commodities/?commodity=rapeseed-oil&months=120&currency=eur.* 2015.
37. LRS Consultancy, *The market for biodiesel production from used cooking oils and fats, oils and greases in London.* 2013.
38. Ecofys, *Trends in the UCO market.* 2013.
39. DG Agriculture and Rural Development/JRC-IPTS, *Prospects for Agricultural Markets and Income in the EU 2013-2023.* 2013.
40. St1, *St1 opens its fifth Etanolix® bioethanol plant next to the Hartwall brewery in Lahti, Finland. News item availabel via st1biofuels.com.* 2010.
41. union, E.C.-D.T.a.c., *Excise duty tables - Part II – Energy products and Electricity. Ref 1044, July 2015.* 2015.
42. Ethanol producer magazine, *ePURE welcomes EU anti-dumping measures on U.S. ethanol; February 22, 2013.* 2013.
43. ICTSD (International Centre for Trade and Sustainable Development), *European Commission Proposes Duties on Imports of US Biofuels; 30 January 2013.* 2013.
44. Bloomberg Business, *Argentina, Indonesia Hit With EU Tariffs on Biodiesel; November 19, 2013.* 2013.
45. IEA, *World energy outlook 2012*. 2012, Paris: OECD/EIA.
46. EC, *Guidelines on State aid for environmental protection and energy 2014-2020. 2014/C 200/01.* 2014.
47. EC, *Modification to the Swedish tax exemption on biofuels for low-blending. C (2013) 266 final. Ruling in the state aid registry.* 2013.
48. CE Delft and TNO, *Bringing biofuels on the market - Options to increase EU biofuels volumes beyond the current blending limits.* 2013.
49. USDA Foreign Agriculture service, *Biofuel Mandates in the EU by Member State.* 2015.
50. EC, *State aid register. Online access to rulings on state aid notifications; http://ec.europa.eu/competition/state_aid/register/.* 2015.
51. Bloomberg, *Italy to Require Advanced Biofuels in Gasoline and Diesel. Online news item.* 2015.
52. Eurobserver, *Biofuels barometer 2015.* 2015.
53. Focus on Finland, *Biofuel boom driven by ambitious targets; online news article; http://focus.finland.fi/biofuel-boom-driven-ambitious-targets/.* 2015.
54. USDA Foreign Agriculture service, *EU Biofuels Annual 2015.* 2015.
55. SPBI, *Delivered volume of renewable fuel in Sweden; online statistics (in Swedish); http://spbi.se/statistik/volymer/fornybara-drivmedel/.* 2015.
56. European Commission, *Proposal for a COUNCIL DIRECTIVE amending Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity. COM(2011) 169/3* 2011.
57. EC, *Commission Work Programme 2015 - A New Start. Annex II - COM(2014) 910 final.* 2015.
58. Christiansen, R.C., *Sweden's Drive for E85 - Ethanol producer magazine.* 2009.
59. Anttonen, M., *Case St1 Biofuels and energy perspectives. Presentation by ST1 Oy Chairman of the Board, bio-economy forum 2012.* 2012.
60. Business Wire, *St1 Biofuels: From Sawdust to Transport Fuel - Cellunolix® Ethanol Plant to Be Built in Finland.* 2014.
61. Wessberg, N. and A. Eerola, *Basic value chain analysis for Etanolix® and Bionolix® bioethanol production by St1 in Finland - TOPNEST – WP3 report.* 2013.
62. Advanced Ethanol Council, *Cellulosic biofuels - Industry progresss report 2012-2013.* 2013.
63. European Biofuels technology platform, *Database on Pilot & Demonstration Plants.* 2015.
64. Alvira, P., et al., *Pretreatment technologies for an efficient bioethanol production process based on enzymatic hydrolysis: A review.* Bioresource Technology, 2010. **101**(13): p. 4851-4861.
65. EPO (European Patent Office), *Espace net global patent database.* 2014.
66. Gosens, J. and Y. Lu, *From lagging to leading? Technological innovation systems in emerging economies and the case of Chinese wind power.* Energy Policy, 2013. **60**: p. 234-250.
67. St1, *St1 opens production of bioethanol in Lappeenranta -news item on St1 website.* 2007.
68. Cargill, *Cargill's CB1 yeast platform for cellulosic ethanol production - presentation at the symposium on biotechnology for fuels and chemicals.* 2014.
69. POET-DSM, *company website: poet-dsm.com/about.* 2014.

70. CE Delft, *Sustainable Alternatives for Land-based Biofuels in the European Union - Report commisioned by Greenpeace European unit.* 2013.
71. Council of the European Union Press office, *Proposal on indirect land-use change: Council reaches agreement* 2014.
72. European Parliament legal observatory, *Procedure file 2012/0288(COD) Fuels and energy from renewable sources: transition to biofuels to deliver greenhouse gas savings.* http://www.europarl.europa.eu/oeil/popups/ficheprocedure.do?lang=en&reference=2012/0288(COD). 2015.
73. CONCAWE Task Force FE/STF20, *Volatility and vehicle driveability performance of ethanol/gasoline blends: a literature review.* 2009.
74. Vierhout, R., *EU's Struggle for E10 - Ethanol producer magazine* 2014.
75. E3MLab - University of Athens, *Assessment of the implementation of a European alternative fuel strategy and possible support proposals.* 2012.
76. Renewable Fuels Association, *Ethanol Industry Outlook 2008-2013 reports.* 2014.
77. Voegele, E., *Brazil predicts increased ethanol production, exports - Ethanol producer magazine.* 2013.
78. EIA, *U.S. ethanol imports from Brazil down in 2013.* 2014.
79. AgriMoney, *Conditions 'very hard' for EU wheat ethanol groups.* 2013.

3 Use of Natural Solutions for Protecting Cities from Coastal Flooding

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Changes based on request of European Commission:
The following descriptions build on a previous narrative version, developed in December 2014 and published in March 2015[61]. It has been amended and refined due to the specific request of DG Research and Innovation to:

(a) Include more evidence on the (cost-) effectiveness of NBS to coastal protection
(b) Include and analyze cases of NBS for coastal protection from the Netherlands
(c) Conduct an assessment of existing case studies (e.g. from the Netherlands New York) by interviews
(d) Identify and discuss the bottlenecks to implement NBS for coastal protection.

In order to fulfill these requests, four interviews were conducted with relevant experts from the Netherlands on points (a)-(d).

Moreover, a workshop was organized at the ECCA conference in Copenhagen (May 2015) where particularly points (a) and (d) were discussed with international experts.

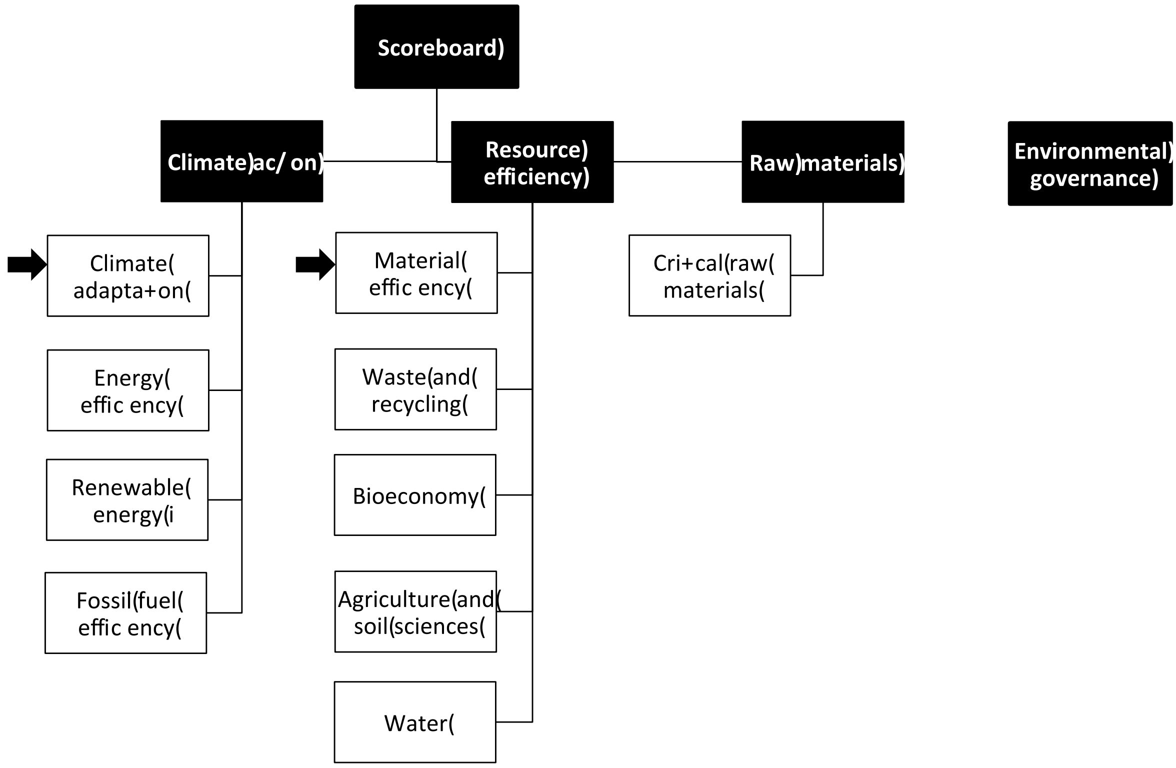
Furthermore, additional literature and case studies were reviewed, based on but not limited to recommendations by interviewees and workshop experts.

The information and new insights obtained from the extended literature review, the interviews and the workshop were used to update the narrative and to provide a more in depth analysis regarding points (a)-(d). In particular the barriers, drivers and policy recommendations sections were developed further.

Finally, the narrative's findings have been presented, discussed and complemented in a session on "Nature-based solutions" at the 2nd RECREATE Strategic Workshop.

[61] http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.1-SEI_final_clean_0.pdf

Links with RECREATE Scoreboard:



Climate action:
Increased CO_2 storage in created / restored ecosystems

Resource efficiency:
Reduced use of concrete / cement

Note: Links are marked with an arrow.

3.1 The Narrative

Globally and in Europe, the risk of coastal flooding events is expected to increase with climate change, the impacts of which are exacerbated by other global trends such as population growth, progressive urbanisation and land conversion or –consumption[62] . Low lying coastal and delta cities, even more than 50 km from the coast and still within the tidal range, are particularly vulnerable to climate change driven flooding. Scientific evidence suggests that, depending on different scenarios, up to 425,000 additional people might be affected by coastal flooding by 2080 in the EU, and the estimated expected annual damage caused by coastal flooding might be as high as € 25.4 billion (Brown et al. ,2011 and Fenn et al., 2014).

This narrative focuses on the use of natural solutions (or nature-based solutions, NBS) for protecting coastal cities from flooding, which can form a cost-effective way to achieve coastal protection. Nature-based solutions are understood as living solutions inspired by, continuously supported by and using nature (EC, 2015[63]). In coastal protection NBS can, for example, take the form of wetland or salt marsh creation, beach nourishment, or oyster reef creation. The potential of NBS in replacing conventional solutions is recognized by the European Commission by investing into research on NBS in scope of the Horizon 2020 programme[64]. NBS are addressed within societal challenge 5 of the work programme (Climate action, environment, resource efficiency and raw materials), which calls for research projects that contribute to enhancing the environment (through providing natural habitat, reducing disturbance, enhancing nutrient processing and aquifer recharge). NBS for coastal protection offer a range of other positive effects such as an increased carbon sequestration capacity in created/restored ecosystems and a reduced use of concrete/cement.

The multiple benefits of NBS as opposed to conventional coastal protection solutions include, for example, their capacity to adapt to sea-level rise, their resilience and robustness, and in some cases their relatively low maintenance costs. Furthermore, NBS often provide additional environmental and socio-economic benefits (e.g. for recreation and health). The current and future market share of NBS in the coastal protection of cities and their rural surroundings, or the amount of employment generated, are difficult to assess, due to a lack of aggregated data, and the existence of hybrid solutions, which combine nature based and conventional solutions, oftentimes as a result of retrofitting efforts. According to an estimate by the International Association of Dredging Companies (IADC) from 2011, whose members are mostly European, or affiliates of European companies, the total coastal, marine and river engineering market is expected to grow between 3 and 6% annually, and the market share of NBS is expected to increase by 19 % (estimates based on contract volume)[65]. Experts interviewed for this study (see annex 1 for an introduction into the methodology applied for the production of this narrative) suggested that there is a clear increase in market share of NBS in coastal protection, including of cities, but did not want to speculate on whether or how much employment would be generated by that. Likewise, no strong empirical evidence regarding the employment generated by NBS (other than for tourist values) for the protection of coastal cities could be obtained from literature. European enterprises, which are currently important market players in the worldwide development of conventional and nature- based coastal protection measures, such engineering firms (e.g. Royal Haskoning/DHV, Arcadis etc), as well as the big Dutch (e.g. Boskalis, Van Oord), Danish (e.g. Rohde Nielsen) and Belgian (Jan de Nul, DEME) dredging companies, could play a role in this future

[62] EEA, 2015: Exploring nature-based solutions. The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards. EEA Technical Report No 12/2015. http://www.eea.europa.eu/publications/exploring-nature-based-solutions-2014

[63] https://ec.europa.eu/research/environment/index_en.cfm?pg=nature-based-solutions

[64] Horizon 2020 Work Programme 2016-2017. European Commission Decision C (2015) 6776 of 13 October 2015, Calls on Nature-based Solutions for territorial resilience SC5-08-2017, SC5-09-2016, SC5-10-2016,

[65] Building with Nature, Dordrecht, Netherlands, IADC, Dredging in figures, 2011 (www.iadc-dredging.com)

market if the innovation system is appropriately supported.

In interviews, experts described the limited distribution of NBS in coastal protection as contradictory to the amount of information already available on their effectiveness from pilot cases. At the same time, however, they stressed that uncertainties about the effectiveness of NBS in comparison with conventional solutions, especially in extreme events involving exceptionally high water levels and on a longer term, continue to exist in the field of coastal protection. They attributed this to a lack of systematic testing, monitoring and reporting, as well as an insufficient diffusion of relevant information in- and outside networks, coupled with a disabling governance system, which function as barriers to the further implementation of NBS in coastal protection.

To overcome this barrier, a combination of a reform of governance systems and a more long-term monitoring and research approach is needed, including cost-effectiveness and cost-benefit analyses, as well as the diffusion of knowledge through, for example, the identification and dissemination of best-practice case studies.

3.2 Understanding the Innovation System

The Innovation

Nature-based solutions in coastal protection can take the form of wetland or salt marsh creation, beach nourishment, oyster reef creation, or mangrove re-establishment and protection. Oftentimes, the implementation of NBS in combination with conventional measures (i.e. a so-called ‘hybrid approach’) is observed in coastal protection (expert interviews).

Examples of NBS in coastal protection are the oyster reefs which are being created to protect the shoreline of New York City from waves in a hybrid approach together with conventional flood protection measures, or the oyster reef test-beds in the Oosterschelde in the Netherlands, monitoring results of which indicate that artificial oyster reefs can play an important role in the conservation and protection of the dike foreland from erosion (Klimaatbuffers 2.0, 2015). Another example of such a hybrid approach might be the beach replenishment near Bournemouth in the UK, where a combination of hard and soft coastal protection measures was applied (May, V.J., 1990), or the Folkstone harbour coast protection scheme, in which an artificial, crenulate bay was created using a combination of hard protection and sand nourishment (Herrington, 2005).
Evidence from the UK suggests that also salt marshes are significantly effective in reducing waves and erosion, and in stabilising and growing shorelines, thereby protecting coastal communities (Shepard et al. 2011). This is supported by Gedan et al. (2011), who find that ecosystem-based approaches (mainly mangrove and salt marsh vegetation) can protect the shoreline from erosion, storm surge, and potentially small tsunami waves. Such nature-based solutions may reduce wave heights, property damage, and human casualties in the affected regions. Another example of the use of salt marshes for the purpose of wave attenuation in coastal protection is the Lymington Harbour Habitat Replenishment in the UK, where a saltmarsh was re-established using dredged sediment from a nearby harbour, whereby the natural functions of the saltmarsh as a buffer against wave energy and as a protection from erosion were re-installed (Brooke et al. 2013). Similar examples can be found in Horsey Island (UK) and Salthouse Broad (UK) (Brooke et al. 2013).
The Delfland Sand Engine is an example of beach nourishment, in which both artificial and natural processes are employed. The Sand Engine was designed to use wind and currents to re-distribute sand in order to protect part of the Holland coast. It consists of a concentrated nourishment of 21.5 million cubic meters of sand, which is gradually redistributed by natural processes over the shoreline, beach and dunes. An added benefit for the ecosystems is that by using concentrated nourishments, the disturbance frequency can be reduced.

Following table summarises the different types of nature-based flood protection measures, describes their coastal protection functions, and lists example locations where they have been applied.

Table 16. Overview of Nature-Based Coastal Protection Solutions as Alternatives to Conventional Approaches such as Dikes and Embankments and their Specific Functions

Nature-based approach: creation/restoration of...	Nature-based coastal protection functions	Example list of locations
Coral reefs (artificial or restored)	Wave attenuation and erosion protection (NOAA 2008)	
Mangroves (artificial or restored)	Shoreline stabilization via wave attenuation (Gedan et al. 2011, Zhang et al. 2012)	Ho Chi Minh City (Vietnam) (other cases exist in Indonesia, Bangladesh, etc.)
Oyster reefs (artificial or restored)	Wave attenuation and erosion protection (Piazza et al. 2005; Beck et al. 2011)	New York (USA), Oosterschelde (NL)
Sea and dune grasses (artificial or restored)	Coastal erosion protection (Coastal Dune Protection & Restoration 2008)	**Houtribdijk (NL)**
Coastal salt marshes (artificial or restored)	Wave attenuation, shoreline stabilization via soil accretion, reducing erosion, and increases in marsh elevation (Shepard et al. 2011)	Lymington Harbour, (UK), Horsey Island (UK), Salthouse Broad (UK)
Coastal wetlands (artificial or restored)	Enlarged water storage and friction, lower inland storm surges (Wamsley et al. 2010)	Wallasea Island Wild Coast (UK)
Beach nourishment, sand reefs, barrier islands and dunes (artificial or restored)	Long-term build-up with rising sea levels (Temmerman et al. 2013), absorption of wave energy	Delfland Sand Engine (NL), Prins Hendrikpolder Texel (NL), Artificial sand reef at Bournemouth, (UK), Barrier island replenishment of Ship Island, Mississippi Delta (USA)
Creation of hard structures better aligned to nature	Erosion prevention	Crenulate shaped bays of Folkstone harbour coast protection scheme, Kent (UK)

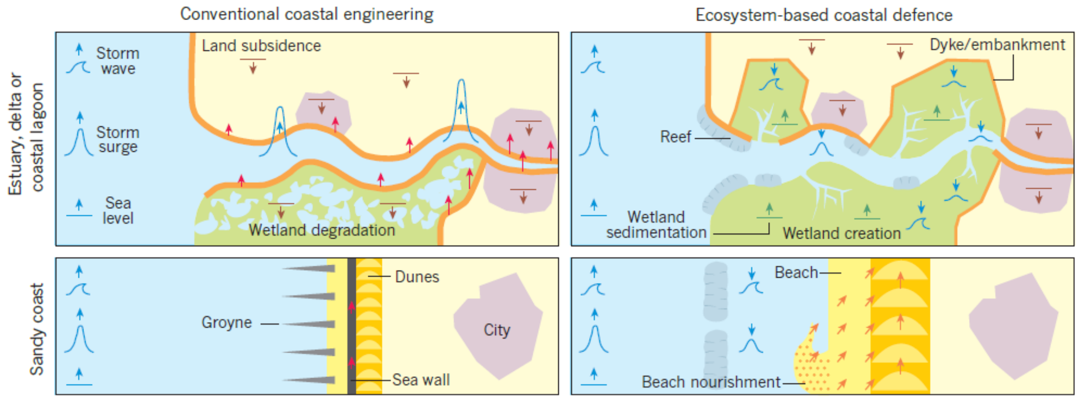
Note: The concentration of evidence here has been on Dutch and UK coasts.

The examples described and listed above demonstrate that NBS are increasingly being recognized by decision-makers as alternatives to conventional coastal protection schemes. Experts interviewed in scope of this study supported this observation and stressed the potential role of NBS in future coastal protection strategies in Europe and beyond. Ysebaert (2014) summarizes the main arguments for applying ecosystem-based approaches to coastal flood protection as follows:

- they are adaptable;
- they are resilient, robust and sustainable;
- they provide benefits (i.e. ecosystem services);
- the lead to cost reduction.

While the notion that NBS for coastal protection are more adaptable than conventional coastal protection measures, and that they provide added benefits is generally accepted in literature; whether they are resilient and robust, and whether they lead to cost reduction strongly depends on the design and type of

NBS chosen. Taking the example of wetland creation, Figure 21 below illustrates the benefits of two nature-based coastal defence approaches (i.e. wetlands and a combination of reefs and beach nourishment) compared to two conventional coastal engineering solutions (i.e. embankment of wetlands and groynes on a sandy coast).



Source: Temmerman et al. 2013
Note: Blue arrows indicate the increase/decrease of storm waves, storm surge and sea level (as specified), red arrows indicate the need for maintenance and heightening of dykes/embankments/sea walls with sea-level rise and brown arrows indicate land subsidence.

Figure 21. Conventional vs. Ecosystem-Based Coastal Defense Measures

As shown in Figure 21, and suggested by literature, a main benefit of oyster beds, mangroves, coastal wetlands and to lesser extent salt marshes, as opposed to traditional, concrete based coastal defence, is that through the trapping of sediments, they can grow over time, and thereby adapt to and compensate for sea level rise (ABPmer, 2014). Thus, if well designed and adapted to the locality, NBS can be more climate robust on the long term, while conventional, concrete- based coastal protection measures tend to cause unwanted erosion or land subsidence in other places (expert interview). Furthermore, even in cases where the natural accretion process is not fast enough to adapt to the rising sea level, or other climate change-related threats, generally, NBS are easier to modify and adapt than conventional, concrete-based coastal defense structures (expert interview).

Scientific evidence supporting Ysebaert's statement that NBS for coastal protection are robust and resilient is not as strong as the data regarding their capacity to adapt. This is due to a lack of long-term performance data on NBS in coastal protection in natural environments, and with regard to their functioning in mitigating (e.g. the potential to reduce storm surges) and coping with extreme flooding events (expert interviews, RECREATE workshops in Copenhagen and Brussels).

In contrast, a lot of evidence can be found on the co-benefits of NBS in general, and specifically for coastal protection, such as, for example, their value for nature, but also for recreation, tourism and public health. In 2011, Naumann et al. prepared a review on the potential of ecosystem- based approaches to climate change adaptation and mitigation in Europe. Among the initiatives reviewed, some aimed at regulating flood events by providing additional retention areas along rivers and coasts. The created or maintained ecosystem often provides regulating services such as nutrient processing and aquifer recharge. The construction of conventional embankments and dykes, on the other hand, usually leads to increased water drainage and has a negative impact on water purification and local water supply. Another example is the "sandy dike" at the Prins Hendrikpolder on the island of Texel in the Netherlands, where a dike will be enforced by placing artificial sand dunes in front of it. Despite being more expensive than conventional options for dike strengthening, this NBS was chosen because of its many co-benefits for nature and recreation, as it creates a more smoother transition between the wet and dry habitats, offering breeding spaces for birds and room for the establishment of blue mussels and salsola (Programma rijke Waddenzee,

2015).
As shown by Naumann et al. (2011), comparing the costs and benefits of ecosystem-based projects to those of engineered approaches (i.e. the construction of conventional flood prevention systems or conventional habitat management practices) is rather difficult.

Firstly, there is no homogeneous and comparable method to evaluate potential damage caused by coastal flooding at different heights of sea- level rise in monetary terms, which reflects i.e. future population growth and distribution, economy, land use and assets and their distribution in the city. This challenge applies likewise to conventional and NBS for coastal protection, which could be solved by using damage functions according to RAMSES D1.2 Grant Agreement No. 308497, (2015) adapted to the case of NBS that ensure consistency and comparability of results. Moreover, how the averted damage as consequence of implemented measures can be valued against their depreciation and their maintenance costs for a given time frame to determine the actual benefit of these measures is still a matter of scientific debate.

Secondly, the provision of services provided by ecosystems usually shows a non-linear behavior on spatial and temporal scales. Flood protection based on ecosystem services such as NBS is therefore difficult to evaluate concerning its effectiveness and monetary benefit. Especially in temperate regions, the coastal protection function of ecosystems varies, which is due to seasonal changes in vegetation density (Koch et al., 2009). According to Koch et al., the provision of coastal protection by ecosystems also varies temporally between the micro scale (hours) and the macro scale (decades). Wave attenuation depends on tidal level and the height of the biotic structure. The following behavior was noted in Koch et al.: The impact of sea grass on wave attenuation is large during low tide when the biomass is compressed into a smaller water column. During a rising tide level, wave attenuation through sea grass, marshes and mangroves decreases in a nonlinear way. Once the tidal level reaches the leaves and branches of e.g. mangroves, the effect of wave attenuation is reinforced again due to a stronger barrier for wave propagation. Chen et al. (2007) reported that during the early growing season, the sea grass *Ruppia maritima* contributes only little to wave attenuation and coastal protection. The sea grass bed has to reach a certain density (1000 shoots m^{-2}) to make a sea grass ecosystem service observable. Furthermore, storm and hurricane seasons and the occurrence of tsunamis strongly influence the effectiveness of ecosystem services for coastal protection. Mangroves, in contrast, were found to be a relatively constant coastal protection, even independent of the typhoon season (Tam, Wong, Lan, & Chen, (1995) in Koch et al., (2009)). Methodologies to quantify and incorporate the non-linear behavior and therefore limiting factor for the flood protection function of NBS in their evaluation concerning effectiveness are still in development.

Finally, in most cases, the limited evidence base does not allow for a profound monetary assessment of costs and benefits to be compared to those associated with conventional engineered approaches. Evidence from selected case studies suggests that investment and management costs are not necessarily higher and can be even lower than in the case of conventional engineered approaches. In 2011, de Bel et al., on behalf of Rijkswaterstaat (i.e. the agency of the Ministry for Infrastructure and Environment in the Netherlands), compared the costs for initial investment, operation and maintenance of NBS with those of conventional coastal protection measures in three different case study areas (Markermeerdijk, Noordwaard, Oesterdam). They found that while the initial investment for installing NBS for coastal protection was not as high as for conventional solutions, the maintenance costs of NBS were in fact much higher for NBS than for conventional solutions. It is important to note, however, that the benefits provided were not accounted for in this study. De Bel et al. (2011) found that only when investment and operation and maintenance were analyzed over a longer timeframe did the NBS score better than conventional solutions. Other scientific evidence suggests that this effect could be exacerbated by climate change: With regard to return on investment, Broekx et al. (2011) who have conducted a comprehensive cost-benefit analysis for the establishment of a long-term flood risk management plan for the Scheldt estuary in the Netherlands, provide estimations of the payback periods for a selected ecosystem-based flood protection measure under different scenarios. They show that the payback period depends on the expected sea-level rise, i.e. the payback period will be shorter if the sea level-increase is higher (Broekx et al., 2011). In the Scheldt estuary, NBS for coastal and flood protection have also been implemented in combination with conventional measures within the long-term flood risk management plan for the Scheldt estuary. Here, planners had to choose between a set of potential flood protection measures, including the creation of a storm surge barrier, dyke heightening and additional floodplains with or without the development of wetlands. In a comprehensive cost-benefit assessment, researchers found that while drastic measures such as a storm surge barrier offer more protection for very extreme storms, a combination of dykes and floodplains can offer higher benefits at lower costs (Broekx et al. 2011).

An interesting development in this respect is also the exploration of possibilities to combine conventional coastal protection with NBS which provide functions which can provide added value generating private income, as it is currently happening in the Eems Dollart delta in the Netherlands. Here, different options for protecting the shoreline are being explored, one of them being the establishment of a mudflat between a double dike-line, in which natural processes lead to an accumulation of mud. This mud would then be used for strengthening of dikes, for improving soil fertility or for leveraging land and thereby counteracting land subsidence (Eemsdelta 2014). Another option which is explored in the Eems Dollart delta is a NBS for coastal protection which forms the basis for mussel aquaculture, which could provide up to 20,00-30,000 Euro per year of private income generated (expert interviews).

The information provided above indicates that NBS can form viable alternatives to conventional flood and erosion protection, and that they carry a strong potential for implementation further in Europe and abroad, particularly in the face of the rising sea-levels and the higher frequency of storms and floods to be expected through sea level rise in many regions in the world.

Structural Factors

Actors

Key actors involved in the establishment of NBS for coastal protection are public authorities, since flood protection is usually a public task. This means that the public authorities are financing the implementation of flood protection, and oftentimes they are also implementing the works. Apart from public authorities, typically involved parties are construction companies, consultancy firms, research institutes, universities and environmental NGOs, who have an interest in the application of NBS in coastal protection. Other possible actors who, depending on the local context, might have a stake in the issue can be neighborhood organizations and local interest groups on different topics (these typically function as advocates for NBS). A potential source of funding for flood protection could also be the insurance providers (only in cases where damage to private / public property caused by coastal erosion is covered by their policies). Due to the different co-benefits for nature, recreation, health and related sectors such as housing development, tourism, health and environmental protection, the formation of coalitions of actors from the different sectors affected, including from the coastal protection sector, could provide an enabling environment for the implementation of NBS (expert interview).
The Dutch Ecoshape consortium, in which dredging companies, consultants, government agencies on national and local level and research institutes joined forces to promote and implement NBS, is a good example for this (see also below).

Institutions

The prevailing institutions, particularly regarding the procedural rules for decision making on which measure to implement for coastal protection, usually form a barrier to the wider establishment of NBS in Europe according to expert opinions (expert interviews).

The institutional framework for coastal protection typically includes detailed lists of norms for coastal defense works, which can inhibit the development and implementation of alternative solutions. The reason for this being that although NBS oftentimes achieve the same goal as conventional measures (i.e. coastal protection), but they are using alternative means and mechanisms to do so (e.g. reducing wave action), which are not captured by the norms and regulations in place. In the Netherlands, for example, alternative, nature- based designs of dike forelands are not captured by the existing norms, although these have been proven to reduce wave action and thereby contribute to coastal protection. As a consequence, such NBS cannot be included into the safety scoring of coastal protection works and are excluded (expert interview).

A slightly different example for a disabling legal framework hampering the implementation of NBS is the Prins Hendrikpolder on the island of Texel in the Netherlands, which was introduced above. The Prins Hendrikpolder is located in a Natura 2000 area and the planning draft, despite contributing positively to the ecological diversity, is in conflict with the existing Natura 2000 legislation. Hence, an exemption had to be found in order to issue the permit for making a dike enforcement based on sandy dunes (Programma rijke Waddenzee, 2015).

Also, the criteria employed in the decision making processes usually fail to capture the added benefits which NBS can offer on top of their coastal protection function. These typically include benefits for recreation, public health or nature protection (see also above). Public authorities responsible for flood protection, however, score measures solely based on their cost and their ability to protect against floods and disregard the added value a measure might have for recreation, public health or nature protection. This is also reflected in the example of the NBS for enforcing the Prins Hendrikpolder, for which, due to it being more expensive than conventional dike enforcement, additional financing had to come from an environmental fund ("The Wadden Sea fund, managed by the provinces, managed by the provinces Noord-Holland, Groningen and Fryslân"), because it is stipulated, that the National Flood Protection Fund only funds the cheapest alternative achieving the desired purpose (expert interview).

Experts also reported that, construction budgets are assigned a higher importance in the decision making processes than maintenance budgets. This can counteract the establishment of such nature based solutions, which are more expensive in the construction, but have a longer lifetime and require lower maintenance costs (expert interview).

A solution would be to reform the criteria and procedures of decision-making processes towards a more integrated decision-making approach on coastal protection, which incorporates also criteria reflecting goals affecting other sectors, such as nature protection, recreation, public health, or the development of the housing sector.

Technology

The (technological) infrastructure for nature- based solutions to coastal protection is typically not a barrier for their implementation, as these are generally designed to meet the site-specific needs and to integrate with the existing coastal defense structure. However, particularly in urban environments, there can be a lack of space to accommodate NBS.

A cost-benefit analysis of the Wallasea Island Wild Coast project, in which a wetland landscape of mudflats and salt marshes, lagoons and pasture was installed for the coastal defence of an originally reclaimed island, found that the vast majority of costs were incurred at the beginning of the project (for modelling, planning, permissions, land purchasing etc), while maintenance costs were relatively low Eftec (2008).

Furthermore, the most important element in coastal protection planning and decision-making are the safety considerations, particularly where large assets or a high numbers of people are concerned, such as in big cities. The fact that NBS are fairly new and sometimes rely on mechanisms which's functioning under extreme conditions are not fully understood, hampers a more wide application of NBS. As stated above, there is a need for more long-term testing of NBS in the natural environment, also under extreme conditions, which do not occur very frequently in natural environments, in order to prove the effectiveness and reliability of NBS in extreme situations.

Current Market

There is a general lack of data on the current (and future) market of NBS for coastal protection. Hence, it is difficult to quantify economic indicators. The dredging industry, which is typically involved in the implementation of NBS for coastal protection, estimated the total turnover of global dredging contractors, including private as well as state- or port-owned companies, to be at €11.7billion in 2013. In an earlier estimation, a 16% share of the total dredging market was traced back to NBS (Climate-Kic, 2006).

Currently, most documentation on the implementation of NBS can be found for the Netherlands, the USA and the UK, where NBS seem to be gaining more and more momentum (expert interviews). In some instances, also European companies or consultancies are involved in establishing NBS outside Europe, for example in the application of Mangrove forests in South East Asia (De Vriend and van Koningsveld, 2012, expert interviews).

Evidence of damage costs caused by coastal flooding events in Europe and abroad suggests that there is indeed a growing market for the coastal protection sector in general, and potentially also for NBS in coastal protection. In a recent study, Temmerman et al. (2013) summarise the current knowledge (and future scenarios, see below) regarding coastal flooding events and the effects these may have on coastal communities as follows: "Coastal flood disasters are an ever-present threat to coastal societies. Recent examples include the flooding caused by Hurricane Katrina in 2005 in New Orleans, Cyclone Nargis in 2008 in southern Myanmar, Hurricane Sandy in 2012 in New York, and Typhoon Haiyan [...] in the central Philippines" (Temmerman et al., 2013, p.79). Such flood disasters are caused by extreme storm surges that can raise the local sea level by several metres through severe wind, waves and atmospheric pressure conditions.

Globally, at least 40 million people and US$3,000 billion of assets are located in flood-prone coastal cities today, and these figures are expected to increase in the future (Temmerman et al., 2013 - see also below). In a recent study Brown et al. (2011) estimated that currently, up to 10,000 people are flooded annually in the EU, and that coastal floods cause an average annual damage of 1,9 billion Euro. These numbers need to be interpreted with caution. As described above, the methodology for damage calculation is still debated by scientists; and the cost estimates are projected in idealized, modeled conditions. Nevertheless, considering the scale of these numbers, and the available experience regarding the effectiveness of NBS from pilots, experts from the field of coastal protection interviewed in scope of this study expressed surprise that NBS are not yet implemented more widely in the EU and abroad.

3.3 Estimation of the Investment Case

Investment Strategy

There are no specific funding schemes for fostering the implementation on nature-based solutions on a national or European level, which could be used to promote the implementation of NBS in the coastal protection of cities. Instead, NBS currently have to compete with conventional coastal protection measures for funding.

Typical investors in the implementation of coastal protection measures are public authorities, as flood protection is usually a public task (see above). Due to the multiple benefits delivered by NBS for coastal protection, financial constructions involving different public funding sources than just the budget for coastal protection are an option which could and should be explored in further depth (expert opinion). Where possible, also other opportunities for co-financing by the private sector could be explored, such as, for example, by insurance companies or environmental NGOs.

Initiated by two major Dutch dredging companies, the Ecoshape consortium is a good example in which private parties such as dredging contractors, equipment suppliers and engineering consultants, as well as public parties such as government agencies and municipalities, applied research institutes, universities and academic research institutes joined forces in a €30 million ‘Building with Nature’ innovation programme (2008–2012), which was dedicated to demonstrating the use and functioning of water-related NBS. The consortium was co-funded by the European Regional Development Fund (ERDF), the Dutch Ministry of Infrastructure and the Environment, and the municipality of Dordrecht (de Vriend and van Koningsveld 2012).

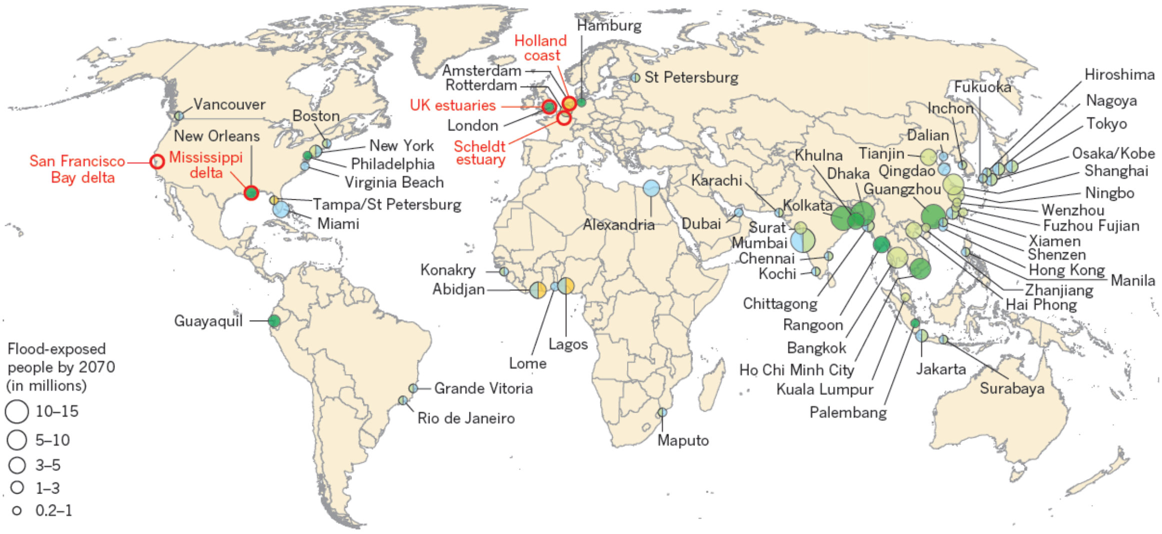
For the further establishment of NBS, experts interviewed in this study stressed the need for investing more money into research and testing of NBS in coastal protection, particularly with regard to their performance during extreme events and on a longer term. Furthermore, it was pointed out that a research need regarding the question on how and under which conditions NBS can be upscaled and transferred from one location to another exists, which should be explored in greater depth. This is also stressed by the EU-level Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities', who, informed by the findings of an e-consultation and a stakeholder workshop, recommended to the European Commission to take forward seven research and innovation actions, including one on nature-based solutions for coastal resilience.

Future Market Potential

Coastal flood risks are likely to increase over the coming decades owing to global and regional changes that include increasing storm intensity, accelerating sea-level rise (in relation with climate change) and widely occurring land subsidence (due to unsustainable drainage and construction habits).
Growing coastal populations also mean more people will be exposed to these increasing flood risks. This global trend is supported by Temmerman et al. (2013), who calculated that by 2070, worldwide 150 million people and $35,000 billion of assets will be located in flood-prone coastal cities. Temmerman et al. also provide an overview of cities with more than 200,000 people exposed to coastal flood risk by 2070 and a classification of cities into four colour groups displaying the potential application of four different ecosystem-based flood defence measures (see Source: (Temmerman et al., 2013, p.81).

Note: “Cities in estuaries or deltas and more than 50km from the sea (dark green) can be well-protected from flooding by marshes or mangroves and moderately protected by reefs, in addition to conventional engineering; cities in estuaries or deltas but less than 50km from the sea (pale green) can be moderately protected by marshes or mangroves and by engineering, and somewhat protected by

reefs; cities more than 5 km from the sea and behind a sandy coast (orange) can be well protected by dunes and protected to some extent by engineering; cities right at the coast (blue) can be protected by engineering and to some extent by reefs. Existing examples of large-scale applications of ecosystem-based flood defense are shown in red".
Figure 22).



Source: (Temmerman et al., 2013, p.81).
Note: "Cities in estuaries or deltas and more than 50km from the sea (dark green) can be well-protected from flooding by marshes or mangroves and moderately protected by reefs, in addition to conventional engineering; cities in estuaries or deltas but less than 50km from the sea (pale green) can be moderately protected by marshes or mangroves and by engineering, and somewhat protected by reefs; cities more than 5 km from the sea and behind a sandy coast (orange) can be well protected by dunes and protected to some extent by engineering; cities right at the coast (blue) can be protected by engineering and to some extent by reefs. Existing examples of large-scale applications of ecosystem-based flood defense are shown in red".

Figure 22. Global Need for Coastal Flood Protection, and Large-Scale Examples and Potential Application of Ecosystem-Based Defense

From Source: (Temmerman et al., 2013, p.81).
Note: "Cities in estuaries or deltas and more than 50km from the sea (dark green) can be well-protected from flooding by marshes or mangroves and moderately protected by reefs, in addition to conventional engineering; cities in estuaries or deltas but less than 50km from the sea (pale green) can be moderately protected by marshes or mangroves and by engineering, and somewhat protected by reefs; cities more than 5 km from the sea and behind a sandy coast (orange) can be well protected by dunes and protected to some extent by engineering; cities right at the coast (blue) can be protected by engineering and to some extent by reefs. Existing examples of large-scale applications of ecosystem-based flood defense are shown in red".
Figure 22 it becomes apparent that most cities with large populations exposed to coastal flooding are located in Southeast and Eastern Asia. Those cities are either located in estuaries or deltas (possibly even more than 50 km away from the coast and still within the tidal limit) or they are directly located at the coast. This observation is supported by Nicholls et al. (2007) according to whom the 14 out of the most affected cities/regions by coastal flooding in 2070 are located in Asia, four in the USA and two in the Netherlands. These cities and countries, most of them are emerging economies, will have to invest considerable amounts in flood protection technologies over the next decades. Hallegatte et al. (2013) suggest that worldwide, the annual costs for upgrading present protection of cities to prevent unacceptable losses caused by climate change and land subsidence could amount to US$1 trillion or more. The damage function for coastal floods employed byHallegatte et al., (2013) encompasses a large number of cities and the results are consistent and comparable with similar studies, such as, for example, Hanson et al. (2011). Such estimations of potential damage generally need to be interpreted with care, however, as they rely on a coarse empirical data basisand therefore does not perfectly represent local features and determinants of damage. Population numbers are employed as proxies for economic exposure by both authors, which appears implausible, as suggested in RAMSES D1.2 Grant Agreement No. 308497, (2015). A tested, reliable and commonly agreed damage function has yet to be agreed, as outlined in section 3.2 above. The method elaborated in in RAMSES D1.2 Grant Agreement No. 308497, (2015) for conventional flood protection measures could be adapted for NBS.

It is important to note that the exposure to coastal flooding in each city is different and must be determined individually. This means that damage estimates cannot be transferred from one city to another and the planning of flood protection measures has to be tailored for each city and its topographic and hydrologic setting separately. Moreover, cities are located at different types of coastlines and require different concepts of protection. Some of the nature-based flood protection measures mentioned in e.g. Temmerman et al., (2013) require a strip of land of a certain width separating the city from the shoreline in order to being implemented. This holds true for marshland and other wetlands, mangroves, beaches and dunes as confirmed by Koch et al., (2009) and Barbier et al., (2008). In port cities, for example, the implementation of nature-based flood protection may be difficult due to the prevailing urban landuse, including port or other urban infrastructures and which cannot be changed. For this reason, Temmerman et al. (2013) suggest that in cities directly located at the coast, engineering solutions and to some extent reefs can potentially be applied for coastal defence. For cities that are affected by coastal flooding but are not situated directly at the coast, Temmerman et al. suggest measures such as marshes, mangroves and reefs as efficient NBS to enhance coastal protection. Still it must be noted that, not all NBS can be applied on every type of coastline, and similar solutions do not always offer the same protection level. Mangroves for example reach the highest effect for wave attenuation in regions close to the equator (Twilley, Chen, & Hargis, (1992) in Koch et al., (2009)), while the mid-latitudes of the subtropics and northern latitudes are advantaged in the case of seagrass. (Koch et al., (2009), Duarte & Chiscano, (1999)). Furthermore, the functioning of ecosystems as flood protection depends on factors such as the width of the ecosystem belt. For European companies and consultancies, which are already now highly recognized on an international level for their technologies and skills related to ecosystem-based coastal flood protection, it is likely that the future market for NBS in coastal protection will to a large extent be an export market, as many of the low-lying cities where exposure is high are located not within Europe.In this respect it should be pointed out that the market potential in less developed countries and emerging economies should not be overestimated: Here, a lack of technical and financial capacity and weak governance systems form a barrier to the implementation of NBS. Awareness-raising, capacity-building and support are key factors to strengthen the local level and prepare the ground for a potential identification and implementation of nature-based flood protection measures. As long as the effects of NBS in coastal protection have not been fully understood and proven locally, a negative impact on the attraction of outside investors may be expected, which in return has direct effects on the local economy in regions where ecosystem services are implemented as coastal protection (Barbier et al., 2009).

While it depends on the specific features of the cities, whether and which NBS can be applied, and is not clear to what extent these countries will favour nature-based solutions over conventional approaches, it can be assumed that nature-based solutions will be part of the picture. How large a share of the flood protection market is taken by nature-based solutions is also likely to depend on success in over-coming systemic barriers to innovation diffusion, which are discussed below. Based on figures from the International Association of Dredging Companies (which is mainly composed of European companies or their subsidiaries), Brooke et al. (2013) calculated that the global market for NBS projects will have a volume of 7 to 9 billion euro in 2020. It must be pointed out, however, that as planning of protection measures heavily depends on local and geographic circumstances, possibilities for up-scaling remain limited, and increasing returns to scale for planning companies are unlikely to occur.

Temmerman's graphic above also shows that European cities will be affected by increased coastal flooding events, therefore part of the market for NBS will also manifest in Europe. Brown et al. (2011) estimate the number of affected people by coastal flooding in the EU and the expected annual damages by 2080. According to these estimates, up to 425,000 additional people might be affected from coastal flooding by the 2080s and annual damages up to €25.4 billion might occur in the EU. Even though these figures are not confined to urban areas, one can assume considerable damage will occur in coastal cities and populated estuaries, particularly in the Netherlands and in the UK. As Brown et al. (2015) state, "The cost of hard protection (projected to be €3.9 billion / year for a high emissions scenario, reducing more than six fold under a 2°C climate mitigation scenario) could continue to increase throughout time due to maintenance costs. However, costs of climate change adaptation could also reduce if alternative approaches of sand nourishment, accommodation of key infrastructure to sea-level rise or selective managed realignment were considered" (p.42).

All experts interviewed in scope of this study expressed the expectation that the market for NBS in- and outside Europe will increase in the future.

Employment Effects

So far, limited empirical evidence exists specifically with regard to the amount of jobs created by nature-based solutions for coastal flood protection in an urban context. In interviews, experts suggested that there might be an increase in employment regarding the design, maintenance and construction of NBS, but that also existing jobs e.g. in dredging companies currently dealing with the development of 'conventional' solutions for flood protection could partially shift towards the development of nature-based solutions (expert interviews). However, indirect effects on employment could be much stronger: For the Wallasea Island Wild Coast, in which, for the coastal defence of an originally reclaimed island, a wetland landscape of mudflats and saltmarshes, lagoons and pasture was installed, Eftec (2008) estimated that implementation of the project would have a variety of employment impacts in the local economy (Essex) and the wider region. Table 17 below shows that in the Wallasea Island Project, up to 16.6 net jobs can be created in the local economy and up to 20.9 in the wider region over a 10-year period.

Table 17. Estimated Employment Impacts of the Wallasea Island Project

Economic activity	**FTE jobs safeguarded**		
	Local Economy (Essex) over 10 yrs	EEDA Region, over 10 yrs	Longer-term (10-20 yrs), EEDA Region
Oyster fishery	10	10	10
Wallasea Infrastructure	c 100	c 100	c 100
Total jobs safeguarded	**110**	**110**	**110**
	Additional FTE jobs created		
Direct employment at site	8.9	10.9	4
Site development spending	5.2	7.5	0
Sheep grazing	0	0	0.7
Oyster fishery	2.5	2.5	5 - 10
Visitor spending	1	1	0 - 5.9
Gross jobs created	17.6	21.9	9.7 - 20.6
Lost agricultural employment	-1	-1	0
Net jobs created	**16.6**	**20.9**	**9.7 - 20.6**

Source: Eftec (2008)
Note: Full-time equivalent (FTE)

In addition to the jobs created on-site, it can be assumed that new jobs would be created in the research and consultancy sector and in enterprises, which specialize in the design and construction of nature-based solutions. The extent of this increase in employment opportunities would, however, depend on the extent to which nature-based solutions capture market share.

Environmental and Social Benefits

Besides direct economic impacts (e.g. jobs created), the environmental benefits (ecosystem services) provided by nature-based solutions are probably the strongest argument for supporting their implementation. The evaluation of the environmental and socio-economic benefits provided by nature-based flood protection is based on the idea that NBS for coastal flood protection will impact ecosystems positively (both regarding their quality and extent), which will result in a change of ecosystem services, which in turn will lead to positive impacts on human welfare and provide wider socio-economic benefits (Defra, 2007). The additional benefits provided by ecosystem services have been valued in many instances (e.g. Turner et al., 2007 and Barbier et al., 2011). In the Netherlands, Broekx et al. (2011) have conducted a comprehensive cost-benefit analysis for the establishment of a long-term flood risk management plan for the Scheldt estuary. Taking into account the ecosystem services provided by an ecosystem-based approach, they concluded that out of several alternatives "a combination of dykes and floodplains can offer higher benefits at lower costs". The results of their valuation exercise are summarised in the tables below.

Table 18. Valuation Approach for Ecosystem Benefits (€/year) for the Implemented Ecosystem Types in the Case of the Scheldt Estuary

Function	Quantification (unit/ha.year)					Valuation (€/unit)	
Ecosystem type Watertype	*FCA Fresh*	*CRT Fresh*	*CRT Salt-brackish*	*Wetland Fresh*	*Source*	*Value*	*Source*
Production functions (fish, aquaculture, wood)	pm	pm	pm	pm	pm	pm	pm
Regulation functions							
Denitrification		176 kg	107 kg	102 kg	MOSES: Soetaert and Herman (1995a, b)	2.5	CIW (1999)
Decrease in N washed away		252 kg	252 kg	252 kg	VMM (2003)	2.5	CIW (1999)
Decrease in P washed away		31 kg	31 kg	31 kg	VMM (2003)	8.5	CIW (1999)
Aeration	pm	23 mol/ha/year	10 mol/ha/year	pm	MOSES: Soetaert and Herman (1995a, b)	0.14	Witteveen and Bos (2004)
Erosion protection		2 m^3	2 m^3	2 m^3	Expert judgement	5	Witteveen and Bos (2004)
Climate		6.8 ton/ha/reed	6.8 ton/ha/reed	pm	Goosen et al. (1996)	66	Bickel and Friedrich (2005)
Regulation functions only first 15 years after construction							
Sedimentation		200 m^3	200 m^3	4 m^3	Expert judgement	5	Witteveen and Bos (2004)
C-burial		1.5 ton	1.5 ton	pm	MOSES: Soetaert and Herman (1995a, b)	66	Bickel and Friedrich (2005)
N-burial		148 kg	148 kg	pm	MOSES: Soetaert and Herman (1995a, b)	2.5	CIW (1999)
P-burial		25 kg	25 kg	pm	Dennhardt and Meyerhoff (2002)	8.5	CIW (1999)
Recreational amenities	25 Visits/day/km dyke				Witteveen and Bos (2004)	1.68	Witteveen and Bos (2004)
Non-use value						*pm*	

Source: Broekx et al. (2011)

In the Wallasea project introduced above, researchers found that the opportunity costs and negative impacts (on recreational yachting, oyster fisheries and the loss of farmland) would have been more significant in the (inevitable) event of an unmanaged breach of the old conventional protection infrastructure. On the benefits side, it was estimated that intertidal habitat is capable of capturing up to 2.2 tonnes of carbon per hectare per year (the benefits generated from carbon sequestration were valued at £1.7 million over a period of 50 years), while the same land used for farming would act as a net source of carbon. The environmental benefits of the project include: habitat creation, waterborne nutrient processing, the provision of fish feedings and nursery habitats. In addition, the authors found that society at large would benefit from avoided expenditures for flood defence infrastructure (ca. £5 – £10 million) and from the avoided loss of built assets on Wallasea worth £3.1 million under moderate flood event scenarios (Eftec, 2008).

3.4 Innovation System Functioning

Function 1. Entrepreneurial Activities (EA)

The majority of case studies for NBS to coastal protection presented in this narrative are located in the Netherlands. The Netherlands, where more than 85% of the coastal zones are located five metres below sea-level, is highly vulnerable to coastal floods. This situation has led to strong research and innovation structures in the field of coastal protection. Specialised research institutes such as Deltares[66] have been created, which are highly experienced in the design and construction of coastal defence measures. The Dutch Flood Control 2015 programme[67] is a five-year innovation programme, which, just like the above-presented Ecoshape consortium, provides a best-practice example for the collaboration between private companies, applied research institutes and government agencies on promoting innovative flood protection. These kinds of collaborations, or 'learning alliances', seem most promising when it comes to the further development of nature-based solution for flood protection. They carry potential with regards to overcoming above-described governance challenges and promoting trans-disciplinary research tailored to local needs. It can be assumed that entrepreneurial activities will pick up in countries where there is already some existing knowledge available, particularly the Netherlands, the UK, Germany and Denmark.

Function 2. Knowledge Development (KDev)

The knowledge required for the effective implementation of nature-based solutions for coastal flood protection can be divided into three parts. Firstly there is the technical side, i.e. the design and construction of flood protection measures, and how they can be integrated into the wider aspects of Integrated Coastal Zone Management in different types of coastal environments. Here, new and innovative measures related to ecosystem-based approaches should continue to be developed. Secondly, there is a need for research on the long term effectiveness of already existing nature-based solutions, particularly under extreme situations. So far, only very few long-term studies exist and the available knowledge is mostly limited to tidal marsh creation (Temmerman et al., 2013). Thirdly, information on the costs and associated economic impacts of NBS for coastal protection as opposed to conventional solutions, as well as research on adequate institutional and financing arrangements to promote their establishment is needed.

Thus, there is a need for funding of long-term monitoring and research on NBS in the field, so that reliable information on the effectiveness of nature-based solutions as part of coastal protection strategies becomes available to decision-makers. Lastly, experts in the field interviewed for this study also stressed that there is a need for research into possibilities for up-scaling NBS. Fountain (2013) states that "while some natural barriers like dunes have been shown to be very effective at absorbing much of a storm's energy, it is less clear that marshes, oyster reefs, kelp beds or the like provide much protection. [...] Interactions between a storm and natural features are complex, and the dynamics of every storm are different, making protection difficult to quantify." Thus, research will be needed on the effectiveness of alternative solutions in different geographic contexts.

[66] http://www.deltares.nl
[67] http://www.floodcontrol2015.com/

Function 3. Knowledge Diffusion through Networks (KDiff)

It has already been stated that the Netherlands provide a good example for the effectiveness of public-private collaborations when it comes to the investigation of effective flood protection measures. The Ecoshape consortium is an example of a learning alliance, or network of stakeholders, which is promoting knowledge diffusion on NBS. If requirements to innovate with NBS would become part of national coastal protection strategies, existing market players, which currently collaborate in the context of coastal protection programmes, joint industry projects and EU-funded projects, will likewise incorporate NBS into their research and innovation strategies. It is realistic to assume that many of the actors, which are currently involved in developing 'conventional' flood protection measures, would increase their involvement in the development of nature-based solutions if this would be part of a public strategy.

Function 4. Guidance of the Search (GoS)

Innovation in the field of nature-based solutions for coastal flood protection is unlikely to take place in the absence of public money which supports research efforts. Already in 2011, the European Commission has published a note entitled 'Towards Better Environmental Options for Flood risk management' (European Commission, 2011). The potential of NBS in replacing conventional solutions is furthermore recognized by the European Commission by investing into research on NBS in scope of the Horizon 2020 programme[68]. This allocation of research funds to NBS for reducing hydrological risks could promote a wider awareness and acceptance of NBS for coastal protection among policy-makers, which could eventually lead to the integration of nature-based solutions into coastal protection strategies and the reallocation of available national funds. Specific research needs to provide a more robust evidence base on NBS for coastal protection are outlined above under Knowledge development

Function 5. Market Formation (MF)

A prerequisite for the formation of a (global) market for nature-based solutions for coastal flood protection in an urban context is certainly the availability of reliable research results with regard to the effectiveness of these solutions. However, initial results show that nature-based solutions are effective and offer additional benefits to society. In the previous sections, a considerable global market potential for coastal defence measures in an urban context has been identified over the coming decades. As flood protection is typically a public task (an interesting exception to this is Denmark, where coastal defence is mostly funded privately), it will largely depend on public strategies (i.e. the decision on whether ecosystem-based approaches should be supported and potentially favoured over 'conventional' solutions) whether nature-based solutions will cover a big or a small share of this market. The example of the Prins Hendrikpolder on the island of Texel in the Netherlands shows how existing flood protection policies and decision-making procedures can function as barriers for the selection and establishment of NBS in coastal protection. Hence, the market formation will heavily depend on whether decision-making processes will be adapted to account for the added benefits of NBS to coastal protection. On a global scale, a source of funding for the implementation of NBS in developing countries could be the climate adaptation funds.

Function 6. Resources Mobilization (RM)

Financial resources are required both for the technical implementation and for the testing of the

[68] Horizon 2020 Work Programme 2016-2017. European Commission Decision C (2015) 6776 of 13 October 2015, Calls on Nature-based Solutions for territorial resilience SC5-08-2017, SC5-09-2016, SC5-10-2016,

effectiveness of nature-based solutions for urban flood protection. To a large extent, these resources will have to be provided by public funds, as flood protection is typically a matter of public security policies. No example cases were found in literature for participation of private entities in the funding of NBS for coastal protection. Possible private entities receiving benefits from NBS include the recreation sector, environmental NGOs or potentially the insurance sector.

The EU and individual Member States currently provide financial support to coastal protection research, part of which could be earmarked for the implementation and testing of pilot NBS in the field, where these are still missing. Part of the Horizon 2020 research programme already focuses on NBS. In addition, the implementation of nature-based solutions for urban flood protection requires the involvement of relevant stakeholders and the wider public. Experiences from the Netherlands in the "Room for Rivers" programme have shown that it is crucial to initiate public debates on (ecosystem-based) flood protection measures, particularly if they rely on the conversion of urban or agricultural land into floodplains.

As of today, EU programmes have already provided funds for research related to flood protection. 4 shows that money has been provided through the EU cohesion policy (operational programmes and selected projects) and through the Framework Programmes for research and technological development. In parallel, Member States have provided additional funding through their own flood protection programmes. On an EU level, it seems that the existing funding structures will remain the most promising routes for policy intervention in the innovation system. Table 19 provides an overview of the established funding mechanisms in place through which funding for NBS could potentially be provided.

Table 19. EU and Member State funds with potential relevance to coastal protection research

Money provided through the EU Cohesion Policy[(2)]	Risk prevention: Adopted OPs: €5,533 million Allocated to selected projects AIR 2011: €4,031 million Other measures to preserve the environment and prevent risks: Adopted OPs: €1,684 million Allocated to selected projects AIR 2011: €1,299 million
Money provided through research projects under the Framework programmes[(3)]	5th Framework Programme: €26.9 million EU funds 6th Framework Programme: €36.8 million EU funds 7th Framework Programme: €85.0 million EU funds
Investment made by Member States (total)[(4)]	Incomplete – data not available for all Member States or for all types of expenditure, not appropriate to provide total as this would be significantly uncertain. Range of expenditure is very wide, with greatest levels in Netherlands and UK and lowest levels countries such as Cyprus and Lithuania (but here information on investment may not be complete). On average, over a large number of projects, the benefits of investment appear to outweigh the costs by 6-8 times, although it is important to note that there is considerable variation between projects such that the actual benefits have to be determined on a project-by-project basis
Investment made by Member States in green infrastructure[(5)]	Information found suggests this is limited in many Member States, but may be of increasing importance as implementation of the requirements of the EU Floods Directive (2007/60/EC) continues. Progress is more advanced in countries with a longer history of significant flooding, such as the Netherlands, Germany, Belgium and the UK where plans for making room for rivers are already in place and being delivered. Green infrastructure projects found to require significant up-front investment that may require investment to encourage uptake. There is then potential to deliver significantly greater environmental benefits alongside reduction in flood damages and, potentially savings from reduced costs compared with traditional defences, deferment of investment in new defences and, hence, opportunity to use funds in other locations

Source: Fenn et al. (2014)

Function 7. Creation of Legitimacy (CoL)

Legitimacy is required on different levels: Firstly, policy-makers must be convinced that nature-based solutions for coastal protection can be effective on a long term and can perform well also during extreme events, and thus fulfil the objectives laid down in the relevant (public safety) legislation. Secondly, the wider public needs to accept nature-based solutions as reliable and beneficial flood protection measures. Thirdly, enterprises which have so far been involved in the development and implementation of 'conventional' flood protection measures need to be willing to shift (part of) their efforts towards the development nature-based solutions. In this context, the identification and dissemination of best-practice case studies will be essential. They should include proper cost-effectiveness and cost-benefit analyses.

Summary: Barriers and Drivers

Analysing the seven interrelated Innovation System Functions (ISF) typically results in insights with respect to drivers and barriers of the specific innovation, (Suurs and Roelofs, 2014) . This section summarizes the main drivers and main barriers from the pre-discussed Innovation System Functions and their relation to a further diffusion of "Use of Natural Solutions for Protecting Cities from Flooding". Based on the information provided in the preceding sections, the levels of ISF fulfilment is shortly discussed and is hence based on the author's own assessment. The fulfilment is scored by means of a five-point scale (1 – very weakly developed, 2 – weakly developed, 3 – developed, 4 – strongly developed, 5 – very strongly developed), see also following figure.

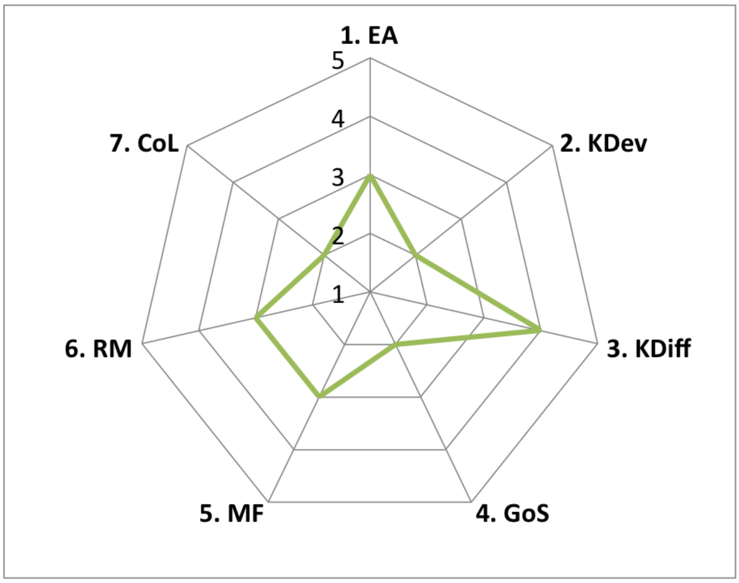


Figure 23. Fulfilment of Innovation System Functions: Use of Natural Solutions for Protecting Cities from Flooding

As discussed in the previous chapters, generally, the following key barriers exist regarding the further establishment of NBS for coastal protection of cities:

- Uncertainty about the effectiveness of nature- based solutions in practice - until they are more widely tested, proved and improved, due to a:
    - Lack of knowledge on performance of NBS on a longer term and under extreme events,
    - Lack of research on costs and associated direct and indirect economic impacts of NBS on coastal protection
    - Lack of information on the necessary conditions for up-scaling NBS for coastal protection.
- Institutional barriers and governance barriers:
    - Lack of adequate institutional and financing arrangements- particularly over long time scales
    - Diffusion of relevant information to relevant institutional actors and stakeholder networks
    - Lack of specific coalitions of actors, or learning alliances on national level.

Drivers, which would enable the further distribution of NBS in coastal protection include efforts to

- Influence the research agenda through promoting and funding research on NBS, particularly regarding
    - The development of a commonly agreed method to assess costs and benefits of coastal protection (implying also the development of a common damage function), for different types of NBS as their performance in coastal protection is generally non-linear and difficult to assess considering future developments i.e. population growth, asset development and distribution and economic factors..
    - the long term effectiveness of NBS and their functioning under extreme conditions in the field
    - the necessary institutional and financial arrangements
- Promote the collaboration of public agencies, developers, the research community, NGOs and private enterprises in ‘learning alliances’ (such as the Ecoshape consortium in The Netherlands)
- Adapt funding criteria and decision-making processes to account for co-benefits and longer life-spans of NBS to coastal protection
- Integrate the requirement to innovate with NBS into national coastal protection strategies

3.5 Further Evidence on the Innovation System

n/a

3.6 Policy Implications

A major advantage of nature-based solutions for flood protection is that, besides flood protection, they offer additional benefits by contributing to climate change mitigation, environmental quality and increased resources efficiency, thereby contributing to the flagship goals of the European Commission's DG R&I.

The development, design and implementation of natural solutions for protecting cities from flooding, however, requires combined efforts from all actors involved. Experiences from the Netherlands, such as from the Prins Hendrikpolder on the island of Texel, or the wide range of projects realized by the Ecoshape consortium, show that "the private sector, knowledge institutes and public users need to unite their skill and expertise through an integrated effort to achieve a cohesive, practical approach to determining and mitigating flood risk" (Vermeer et al., 2012).

The current barriers to the development and use of nature based solutions for coastal flood protection, as listed in the chapters above, are the starting point for the appropriate EU level (and national) interventions in the innovation system. Key external factors promoting innovation on NBS for coastal protection outlined above are an increase in the risks and severity of coastal flooding caused by storms combined with the need by public authorities for cost-effective solutions with minimal negative environmental impact, including ones which complement existing flood protection measures.

In line with the barriers and drivers identified above, EU level interventions to enable Europe to become a world leader both in R&I and in the growing market for nature-based solutions could focus on offering co-funding for the implementation of nature-based coastal flood protection projects with a particular focus on long-term performance monitoring under different conditions. Furthermore, innovation partnerships between public and private entities should continue to be promoted. A sharing of best practice examples on national and EU level could contribute to a wider acceptance of NBS as viable alternatives to conventional solutions in the coastal protection of cities.

The emerging EU Research & Innovation (R&I) agenda on NBS, following the recent publication 'Towards an EU Research and Innovation policy agenda for Nature-based Solutions & Re-Naturing Cities' (2015), provides a valuable first step and should be further promoted and strengthened.

The research field on NBS could benefit from investment into research on the potential of combinations of NBS and conventional solutions in coastal protection, such as the combination of dikes and dunes in the Prins Hendrikpolder case, as well as possibilities to combine NBS with functions providing services which can be sold such as,for example, the provision of fertile soils (Eemsdelta, 2014), the storage of CO_2, or the basis for mussel aquaculture (expert interviews). Apart from the technical (i.e. construction) side, increased research is particularly needed on the effectiveness of nature-based solutions for flood protection (Temmerman et al., 2013), and on the governance systems necessary for enabling the implementation of NBS.

At global level and with a particular focus on developing countries, an innovation support would be needed for research on the up-scaling of NBS for their adaptation to different conditions (and given market conditions) for a widespread penetration of such systems (expert interviews). This would involve a translation of lessons learnt in Europe to different geographic, environmental and socio-economic situations.

References

- ABPmer (2014): Case Study on the Welwick Managed Realignment Scheme (England. White Paper. ABPme, 2014)
- Barbier, E. B. et al. (2011): The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81, 169–193.
- Barbier, E. B., Koch, E. W., Silliman, B. R., Hacker, S. D., Wolanski, E., Primavera, J. H., … Reed, D. J. (2008). Coastal ecosystem-based management with nonlinear ecological functions and values. Science, 319(5861), 321–323.
- Barbier, E. B., Koch, E. W., Silliman, B. R., Hacker, S. D., Wolanski, E., Primavera, J. H., … Reed, D. J. (2009). Coastal ecosystem-based management with nonlinear in ecological functions and values. Science, 319, 321 – 323.
- Beck, M. W., R. D. Brumbaugh, L. Airoldi, A. Carranza, L. D. Coen, C. Crawford, O. Defeo, G. J. Edgar, B. Hancock, M. C. Kay, H. S. Lenihan, M. W. Luckenbach, C. L. Toropova, G. Zhang, and X. Guo. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. BioScience 61:107-116.
- de Bel, M., Schomaker, A.H.H.M., van Herpen, F.C.J. (2011) Meerwaarde Levende Waterbouw. Een maatschappelijke kostprijsanalyse. Rijkswaterstaat Waterdienst. 10 oktober 2011 Eindrapport 9W3635.A0 Royal Haskoning
- Brown, S., Lincke, D., Nicholls, R.J., Hinkel, J. (2015): The impacts of sea- level rise on European coasts in a 2° world. Results and analysis of Task 6.5 prepared as part of IMPACT2C: Quantifying project impacts under 2°C warming
- Brown S, Nicholls RJ, Vafeidis A, Hinkel J, and Watkiss P (2011): The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefitsof Adaptation. Summary of Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.
- Broekx, Steven, Steven Smets, Inge Liekens, Dirk Bulckaen and Leo De Nocker (2010): Designing a long-term flood risk management plan for the Scheldt estuary using a risk-based approach. Nat Hazards (2011) 57:245–266.
- Brooke, J.; Buytaert, W.; de Block, D.; Frances, F.; Janssen, S.; Ketelaars, M.; Lenselink, G.; Schellekens, E.; van Aalst, M.; van Slobbe, E.; Walder, T.(names in alphabetical order) (2013): Working with Nature. Wageningen University, ARCADIS and Deltares (NL); Imperial College and Jan Brooke Environmental Consultant Ltd.(UK), Technical University of Valencia (ES). October 2013 (unpublished version)
- Brown, S. et al (2011): The impacts and economic costs of sea-level rise on coastal zones in the EU and the costs and benefits of adaptation, Summary of sector results from the ClimateCost project, Technical Policy Briefing Note 02, accessed at: http://www.climatecost.cc/images/Policy_brief_2_Coastal_10_lowres.pdf
- on 4 January 2014.
- Coastal Dune Protection & Restoration (2008): Using 'Cape' American Beach Grass and Fencing. Woods Hole Sea Grant: Woods Hole.
- Defra (2007): An introductory guide to valuing ecosystem services. Department for Environment, Food and Rural Affairs: London.
- De Vriend, H.J. and Van Koningsveld, M.(2012) Building with Nature: Thinking, acting and interacting differently. EcoShape, Building with Nature, Dordrecht, the Netherlands.
- Duarte, C. M., & Chiscano, C. L. (1999). Seagrass biomass and production: a reassessment. Aquatic Botany, 65(1-4), 159–174.
- EEA, 2015: Exploring nature-based solutions. The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards. EEA Technical Report No 12/2015. http://www.eea.europa.eu/publications/exploring-nature-based-solutions-2014
- Eemsdelta (2014): Icoonproject Vitale kust Eems- Dollard. regionale E&E partners, www.ee-eemsdelta.nl (last accessed in August 2015)
- Eftec (2008): Wallasea Island Economic Benefits Study: Final report submitted to the East of England Development Agency. RSPB and ABPMer, 2008.
- European Commission (2011): Note by DG Environment - Subject: Towards Better Environmental Options for Flood risk management. DG ENV D.1 (2011) 236452, Brussels, 8.3.2011.
- European Commission (2015): Note by DG Climate – Subject: Towards an EU Research and Innovation policy agenda for Nature-based Solutions & Re-Naturing Cities. Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities' (full version): European Union, 2015
- Fenn, Teresa, David Fleet, Lucy Garrett, Elizabeth Daly, Chloe Elding, Marco Hartman, Job Udo (2014): Study on Economic and Social Benefits of Environmental Protection and Resource Efficiency Related to the European Semester. Final Report prepared for DG Environment, February 2014.
- Feyen L & Watkiss P (2011): The impacts and economic costs of river floods in the European Union, and the costs

and benefits of adaptation, Summary of sector results from the ClimateCost project, Technical Policy Briefing Note 03, accessed at: http://www.climatecost.cc/images/Policy_brief_3_River_floods_v11_lowres.pdf, on 4 January 2014.
- Fountain, Henry (2013): Natural Allies for the Next Sandy. New York Times, published October 28, 2013.
- Gedan, K.B., Kirwan, M.L., Wolanski, E., Barbier,E.B., & Silliman, B.R. (2011): The present and future role of coastal wetland vegetation in protecting shorelines: an answering recent challenges to the paradigm. Climatic Change, 106, 7-29.
- Hallegatte, S., Green, C., Nicholls, R. J., Corfee-Morlot, J. (2013): Future flood losses in major coastal cities. Nature Climate Change 3, 802-806
- Hanson, S., Nicholls, R., Ranger, N., Hallegatte, S., Corfee-Morlot, J., Herweijer, C., & Chateau, J. (2011): A global ranking of port cities with high exposure to climate extremes. Climatic Change, 104(1), 89–111.
- Herrington, S.P. (2005): The Hythe to Folkstone harbour coast protection scheme - The use of rock headlands to create static aquilibrium bays. Coastlines, structures and breakwaters 2005, 5a: schemes and construction
- Horizon 2020 Work Programme 2016-2017. European Commission Decision C (2015) 6776 of 13 October 2015, Calls on Nature-based Solutions for territorial resilience SC5-08-2017, SC5-09-2016, SC5-10-2016.
- Koch, E. W., Barbier, E. B., Silliman, B. R., Reed, D. J., Perillo, G. M. E., Hacker, S. D., … Wolanski, E. (2009). Non-linearity in ecosystem services: Temporal and spatial variability in coastal protection. Frontiers in Ecology and the Environment, 7(1), 29–37.
- May, V. J. (1990):Replenishment of resort beaches at Bournemouth and Christchurch, England. Journal of Coastal research. Special issue 5, 11-15
- McGranahan,Gordon, Deborah Balk and Bridget Anderson (2007): The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones Environment and Urbanization, 19(1):17-37.
- Naumann, Sandra, Gerardo Anzaldua, Pam Berry, Sarah Burch, McKenna Davis, Ana Frelih-Larsen,
- Holger Gerdes and Michele Sanders (2011): Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2, Ecologic institute and Environmental Change Institute, Oxford University Centre for the Environment.
- IADC (2013) Dredging in Figures 2013. International Association of Dredging Companies. Published by IADC, The Hague, The Netherlands.
- Klimaatbuffers 2.1, (2015) Oesterriffen Oosterschelde, Klimaatbuffers 2.0. (last accessed on August 24, 2015):http://www.klimaatbuffers.nl/oesterriffen-oosterschelde
- Nicholls, R, Hanson, S, Herweijer, C, Patmore, N, Hallegatte, S, Corfee-Morlot, J, Chateua, J, and Muir-Wood, R (2007). Ranking of the World's Cities Most Exposed to Coastal Flooding Today and in the Future: Executive Summary OECD (Environment), WP, Paris.
- NOAA (2008): Coral Reefs Protect Coastlines. Available at http://www.noaa.gov/features/protecting_1208/coastlines.html
- Piazza, B., P. Banks, and M. La Peyre (2005): The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. Restoration Ecology 13:499-506.
- Programma rijke Waddenzee (2015): Alternatieve dijkversterking Prins Hendrikpolder op Texel. http://www.rijkewaddenzee.nl/nieuws/nieuws/dijkversterking-prins-hendrikpolder
- Shepard, C.C., Crain, C.M. and Beck, M.W. (2011): The protective role of coastal marshes: a systematic review and meta-analysis. PloS One, 6(11): e27374.
- Temmerman, Stijn, Patrick Meire, Tjeerd J. Bouma, Peter M. J. Herman, Tom Ysebaert and Huib J. De Vriend (2013): Ecosystem-based coastal defence in the face of global change. Nature 504, 79–83.
- Turner, R. K., Burgess, D., Hadley, D., Coombes, E. & Jackson, N. (2007): A cost-benefit appraisal of coastal managed realignment policy. Glob. Environ. Change 17, 397–407.
- Twilley, R. R., Chen, R. H., & Hargis, T. (1992). Carbon sinks in mangroves and their implications to carbon budget of tropical coastal ecosystems. Water, Air, and Soil Pollution, 64, 265–288.
- Wamsley, T. V., Cialone, M. A., Smith, J. M., Atkinson, J. H. & Rosati, J. D. (2010): The potential of wetlands in reducing storm surge. Ocean Eng. 37, 59–68.
- Ysebaert, Tom (2014): Eco-system based coastal defence: opportunities & steps to take. Presentation at Workshop "Ecological Engineering for Coastal Protection and Food Production in Bangladesh" (ECOBAS), 26 November 2014, BRAC Centre, Dhaka, Bangladesh
- Zhang, K. Q. et al. (2012): The role of mangroves in attenuating storm surges. Estuar. Coast. Shelf Sci. 102–103, 11–23.

Annex 1. The Sand Engine

What is this solution about and why was it implemented?:
The province of South Holland is one of the most densely populated areas of the world and is mostly located below sea-level. Coastal protection typically consists of combinations of dikes and dunes created by artificial beach nourishments. The Sand Engine is an alternative way of coastal protection: It consists of a single, enormous sand nourishment which makes use of natural currents to distribute the sand along the coastline, where otherwise multiple smaller sand nourishments would have had to be carried out over the course of 20 years. Thereby, the total costs, the total amount of sand needed and the ecological impacts of sand nourishment are reduced, and a new recreational area is formed. Following several studies on feasibility, costs and environmental impacts, a Sand Engine pilot was installed on the coast of Delfland between the village of ter Heijde and the town of Kijkduin: Almost 20 million m^3 sand, which originated from a location 10 km off the shore, were deposited on the coastline in shape of a hook, by which a wide stretch of beach was created. Models predicted that the Sand Engine would change in shape over the coming 20 years and ultimately diminish, as natural currents would deposit the sand along the coastline from Hoek van Holland to Scheveningen, thereby creating and maintaining artificial dunes for coastal protection

The Sand Engine is seen as a long-term experiment, the results of which will be monitored over a period of 20 years, according to a detailed monitoring-plan. Research and monitoring conducted includes measurements and modeling of currents, sand accretion, development of dunes, flora and fauna, impact on groundwater, but also impacts on recreation and safety for swimming. A share of the budget was reserved should the Sand Engine develop differently than expected and unexpected situations arise. The project Sand Engine was accompanied with an extensive public information campaign.

Three policy goals to be achieved by the Sand Engine were identified:
1. To promote the growth of dunes along the coastline from Hoek van Holland to Scheveningen
2. To promote knowledge development
3. To establish an attractive recreation- and nature area at the coast of Delfland

Furthermore, from the beginning on, the possibility to export the knowledge generated with the Sand Engine pilot to other countries in the world was an important argument for its establishment.

Who were the stakeholders involved in its implementation?:
The actors involved in the establishment of the Sand Engine include:
- Government:
  - Rijkswaterstaat (subordinate agency to the Ministry for Infrastructure and the Environment) (initiator)
  - Province South Holland (initiator)
  - Municipalities of Den Haag, Westland, Rotterdam
  - Other cooperation partners: Delfland Waterboard, Environmental Federation South Holland (Zuid-Hollands Landschap)
- Association of Life and Coast Guards
- Ecoshape Consortium (consisting of dredging companies, engineering and consultancy companies, government agencies on national and local level and research institutes)
- Naturecoast (consortium of collaborating universities and research programmes)

Where did the funding come from?:
  - National funds for flood protection, provincial and municipal funds
  - European Commission through the ERDF, as part of the Operational Programme for the western Netherlands

What were the barriers encountered and how were these overcome?:
  - Uncertainty associated with the Sand Engine pilot: Intensive monitoring, budget reserved for unexpected situations
  - Safety concerns by municipalities regarding recreation, occasional development of dangerous currents, enclosure by seawater during high tide: Safety plan, warning signs, communication campaign.

Sources:

- Rijkswaterstaat (2013) De Zandmotor- van zand naar land Zandmotor Delflandse Kust, Rijkswaterstaat, Ministerie van Infrastructuur en Milieu, Provincie Zuid Holland. http://www.dezandmotor.nl/uploads/2015/09/zandmotorweb-1.pdf
- van Slobbe, E. und Lulofs, K. (2011) Implementing "Building with nature" in complex governance situations. Terra et Aqua 124, September 2011

Annex 2. Methodology Underlying the RECREATE Evidence-based narratives on Nature-Based Solutions for Coastal Protection and Sustainable Urban Drainage Systems

The production of the two RECREATE narratives on Nature-Based Solutions NBS followed a process, which was structured into two phases. In phase 1, a first draft of the narratives was produced based on a thorough literature review. Following reviewing and commenting by the European Commission's DG Environment, this draft was revised and improved, based on a review of available literature and on the collection of empirical data in two workshops and 8 interviews with international experts on the respective topic (4 on the topic of NBS for coastal protection and 4 on the topic of Sustainable Urban Drainage Systems). In the following paragraphs the setting, structure and content of the Workshops and Interviews will be explained in detail.

1. RECREATE breakfast-workshop at the ECCA conference 2015
Date: 12.05.2015, Time: 08:00 - 10:00
Location: Bella Center, Copenhagen (DK) Room 16

The objective of this RECREATE breakfast workshop was to exchange views on the use of sustainable urban drainage systems (SUDS) and nature based solutions (NBS) for coastal protection, as well as customized Climate Information Services. Invitations were sent out to topic-related panelists, session moderators and presenters of PowerPoint-presentations or posters at the ECCA conference. The workshop was attended by 21 participants. See
Table 21 for an overview of the workshop programme. Interest in RECREATE was high and after a group discussion, participants formed three round tables (the most popular being the SUDS table) and discussions were flowing well (see

Table 20 for an overview of the discussion-questions for the round tables on NBS). Participants were asked to note down their thoughts and inputs on reporting sheets, as well as indications on where to find additional sources information (e.g. scientific literature), which were collected afterwards to include into the analysis.

Table 20. Discussion Questions for the Two Round Tables on NBS During the RECREATE Breakfast-Workshop at the ECCA Conference

Sustainable Urban drainage systems	1. What are the differences between SUDS and piped drainage systems regarding cost-effectiveness? 2. Are you aware of any trade-offs to the benefits delivered by SUDS? 3. What barriers need to be overcome for upscaling SUDS and exploiting their full market potential? 4. What role can EU innovation policy play in enhancing the market penetration of SUDS?
NBS for coastal protection of cities	1. What are the differences between NBS and traditional coastal protection of cities regarding their cost-effectiveness? 2. What is the role of the private sector in promoting these NBS to coastal protection? 3. Where would the market potential for these NBS to coastal protection be highest in your eyes? 4. What barriers need to be overcome for upscaling these NBS and exploiting their full market potential?

Table 21. Programme of the RECREATE Breakfast-Workshop at the ECCA Conference

Time	Programme
08:15 – 08:25	Welcome, introduction to RECREATE and the purpose of the three parallel sessions: Martin Drews, Technical University of Denmark
08:25 – 09:25	Round table sessions facilitated by Ina Krüger, Ecologic Institute, and Martin Drews, Technical University of Denmark Introduction (10 minutes) then discussion of 4 questions (see above) Table 1 : Sustainable urban drainage systems Table 2: Nature based solutions for flood protection Table 3: Climate Information Services
09:25 – 09:50	Plenary session (round table sessions reporting back)
09:50 – 10.00	Closure: Martin Drews, Technical University of Denmark

2. Session on Nature Based Solutions at the 2nd RECREATE Strategic Workshop

Date: 12.05.2015, Time: 13:45 - 15:30
Location: Diamant Conference centre Brussels

At the 2nd strategic RECREATE workshop in Brussels, the two NBS narratives were presented and discussed, suggestions for improvement were collected and parallels with the other three narratives produced within the RECREATE projects so far (i.e. EBN on Selling Solar Services, EBN on Bioethanol from Residues and Wastes and EBN on Climate Information System Support of Adaptation Projects) were identified.

3. Interviews with international experts on the topic of Nature Based Solutions

In order to gain insights deeper insight into the topic of EBNs, 8 interviews with international expert from the United Kingdom and the Netherlands on the respective topics (4 on the topic of NBS for coastal protection and 4 on the topic of sustainable urban drainage systems) were carried out. The purpose of these interviews was to collect additional information on cost-benefit evaluations of NBS carried out, to validate the narratives and to collect additional information for estimating the investment case and analyzing the innovation system functioning.

Interviews were held via telephone calls, lasting between 45 minutes and 1.5 hours, and the Chatham House Rule was applied, meaning that permission was asked to use the information obtained in the interviews in scope of the RECREATE project, but promising that neither the identity nor the affiliation of the interviewees would be revealed. The questions asked to interviewees are listed in Table 22 and

Table 23, respectively.

Table 22. Interview-Questionnaire: Nature Based Solutions for Coastal Protection

<table>
<tr><td colspan="2">About RECREATE and the aim of this interview:
I am conducting some research for the European Commission under a project called RECREATE. The purpose of this project is to derive an outlook and recommendations for future innovation and research policy priorities in the fields of climate, resource efficiency and raw materials, for example, for shaping the future research programme, including Horizon 2020.
We are investigating the global potential for the use of Nature Based Solutions for Protecting Cities from Flooding, through insight into specific case and research needs in this field, and expert opinions. Broadly, we are conducting interviews to gain a better understanding of:
• the effectiveness, costs and benefits of nature-based solutions (NBS) for coastal protection as opposed to, or together with, traditional solution,
• what are the barriers to the a more wider use of NBS in coastal protection of cities, and
• evidence on, or pointers to the Market potential of NBS in coastal protection

Warming up question:
Could you tell me about your research in relation to NBS in coastal flood protection?</td></tr>
<tr><td>Effectiveness, Impact</td><td>1. What evidence exists about the relative effectiveness of NBS for coastal protection? What research suggests that they perform better or worse than traditional solutions?
2. What are in your eyes the barriers for a more widespread implementation of NBS in coastal protection? What do you think are the reasons for choosing for NBS instead of a traditional solution in general?
3. What assessments of the cost-effectiveness of NBS in coastal protection as opposed to traditional solutions have been made? What do they tell us?
4. Which role do hybrid-solutions (which combine both NBS <u>and</u> traditional approaches) play?
5. Which role can the private sector play in the establishment of NBS for flood protection?
6. Do you have evidence on the jobs which can be created by NBS, compared to alternatives?</td></tr>
<tr><td>Examples of well documented cases[69] to be prompted into the questions above</td><td>1. What evidence do you have, or could point to, in relation to the implementation of a NBS solution in coastal protection (of cities) in NL and/or abroad? What was the funding construction for this NBS (private - public, who paid what?)</td></tr>
<tr><td>Market potential[70]</td><td>2. How do you assess the current and future market potential of NBS for flood protection in comparison with traditional solutions (2020-2050)?
3. What are the global applications of NBS, particularly in the face of climate change related events and sea level rise? e.g. South-East Asia)?
4. What is the transferability of knowledge from the EU to other countries (i.e. in ways that could capture a market for the constructors/designers)?
5. What are key countries for the application of NBS in coastal protection in your eyes?
6. Which other countries/institutes are developing expertise in this area? How could you quantify their relative success?</td></tr>
<tr><td>Research needs</td><td>7. What are the barriers which are preventing the potential of NBS for city protection being used - e.g. lack of awareness in decision makers, lack of construction expertise, etc?
8. What changes - e.g. in the state of knowledge, evaluation or demonstration projects could (or would be needed to) unlock global market potential?
9. Based on what we have discussed so far, what are in your eyes the research needs for NBS? Which topics should research funding focus on?</td></tr>
<tr><td>Concluding questions</td><td>10. Who else would you recommend me to interview?
11. What are leading institutes in other EU countries? (if not tackled above)
17. Would you be interested to be updated on the progress of the RECREATE work and can I call you again to clarify any matters which occur to me later?</td></tr>
</table>

Note: Objectives: Obtain hard information - based on appraisals or evaluations, about the various costs and benefits of NBS for coastal protection - particularly economic impacts, including jobs, and the current and potential for future market capture/revenue generation inside and outside the EU

[69] This is to treat comment [ASJM(3)]
[70] This section treats comments [ASJM(1)] and [ASJM(2)]

Table 23. Interview-Questionnaire: Nature Based Solutions for Sustainable Urban Drainage Systems

About RECREATE and the aim of this interview:
RECREATE is a research network (long title: The Research Network in Climate, Resource Efficiency and Raw Materials), which is financed by the European Commission under the FP7 Programme. The project aims to assess the impacts of research and innovation in Europe and beyond and to derive an outlook and recommendations for future research priorities in the fields of climate, resource efficiency and raw materials, in particular under the Horizon 2020 research programme.

Within the scope of the RECREATE project, we are preparing a narrative on 'Sustainable Urban Drainage Systems (SuDS)'. Through this interview series we would like to gain a better understanding of the market potential and the economic benefits of SuDS. For this, we are interested in the effectiveness as well as the costs and benefits of SuDS (as NBS) compared to traditional engineered solutions, and we would like to gain insights into specific implementation examples. We are interested in the scope of SuDS use in Europe and worldwide, particularly as climate changes, and what are the barriers to wider use of nature-based solutions (NBS) to cope with stormwater events and flooding in cities.

Warm up questions:
What is your area of work? How does your work generally relate to SuDS? On what particular aspects have you been working with regards to SuDS?

Establishment of SuDS	4. What are the quantifiable differences between SuDS and piped drainage systems regarding the absorption of stormwater/reduction of peak flow? (Please provide figures, if possible) 4. Can you give specific examples of SuDS which have been implemented or cases in which SuDS would be or would have been appropriate (inside and outside Europe) ? (In these cases, which (green) infrastructures are needed to establish effective SuDS and how should they be connected?
Future market potential	4. What were the key drivers for implementing SuDS in the examples you mentioned in the previous question? (e.g., increase in stormwater/high precipitation in some urban areas exceeding the current capacities of pipe wastewater systems, multiple benefits resulting from using a nature-based solution) 4. How would you assess the future market potential of SuDS at EU level? At global level? (How many cities would benefit from retrofitting urban drainage systems and/or establishing SuDS? Are there relevant differences between developed and developing countries in the pre-conditions necessary to establish SuDS? What are the sources of evidence on which this kind of assessment can be made? Can you personally provide any estimates, numbers, relevant literature with regards to the future market potential of SuDS?) 4. What is the role for hybrid-solutions (which combine both NBS and traditional approaches)? How are these different from/similar to, better/worse, more feasible, etc. than SuDS? 4. What are the limiting factors to fully exploiting the market potential of SuDS? (e.g., lack of knowledge and share of information, lack of financing and buy-in from the engineering sector, current institutional arrangements, uncertainty about ownership and responsibilities). 4. What are potential solutions that could overcome these barriers?
Costs, benefits and effectiveness	4. What are the costs associated with establishing SuDS? (For SuDS this question is just meant to be a small exercise to prepare for the cost-effectiveness question; there is plenty of evidence on costs and benefits from case studies and literature) 4. What are the environmental and wider socio-economic benefits delivered by SuDS? (see comment following the question above). (If not covered: What can you say about the jobs generated by SuDS construction and use?). Does the pay-back period differ compared to alternatives? 4. Are you aware of any trade-offs to the benefits delivered by SuDS? 4. How would you assess the cost-effectiveness of SuDS in general and in comparison with traditional drainage systems (grey infrastructure)?
Link to policy and strategies	12. What synergies with development of other green infrastructure could reduce the costs of installation of SuDS? 13. What role do you see for government (at regional, national and EU level) in fostering the planning and implementation of SuDS? 14. What role can EU innovation policy play in enhancing the market penetration of SuDS?
Concluding questions	15. If you were making the business case for large scale investment in SuDS , what sources of information would you draw on? E.g. Are you aware of any studies, which examine or reference the damage costs resulting from urban flooding caused by stormwater (exceeding the capacity of piped drainage systems)? 16. What points (other than those we've already discussed) would you put forward to make that case? 17. Who else would you recommend we interview? (e.g., personal contact, expert in the field or similar topic, academic or researcher, industry player, municipal official, etc.)

4. Feedback from international expert interviewees on the draft narratives

In order to validate the compiled narratives on NBS, the draft versions were sent via email to all of the international expert interviewees in order to receive their feedback, supplementary inputs and comments. To date, 2 of the interviewees on the topic of sustainable urban drainage systems have responded and their feedback has been taken into account and integrated where appropriate. The received comments serve to support the information presented in the narrative drafts and strengthen the line of argumentation and data foundation in the final versions.

4 Sustainable Urban Drainage Systems

Author(s):
McKenna Davis (Ecologic Institute)
Sandra Naumann (Ecologic Institute)

Changes based on request of European Commission:
The following descriptions build on a previous narrative version, developed in December 2014 and published in March 2015[71]. It has been amended and refined due to the specific request of DG Research and Innovation to

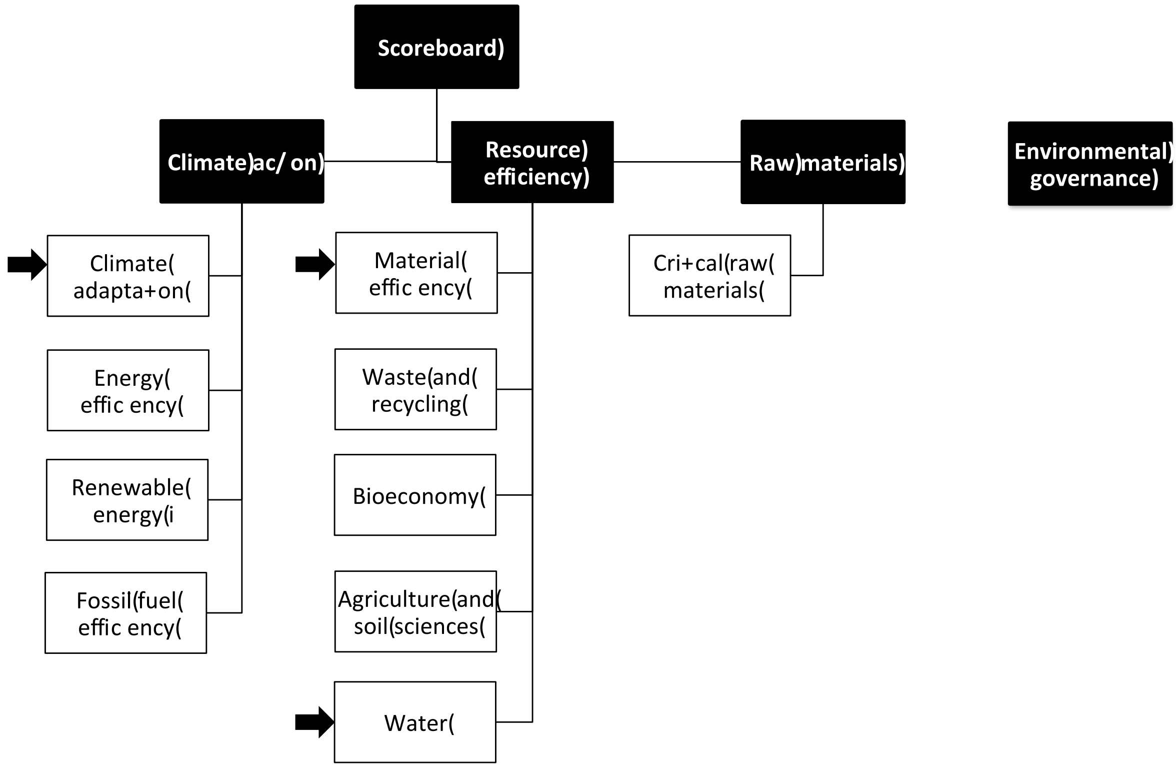
(a) Introduce the appropriateness (not only cost-effectiveness) of sustainable urban drainage systems earlier in the narrative
(b) Analyse the Malmö case study in more depth and outline funding, stakeholders, and other relevant aspects
(c) Increase the level of analysis and cross-disciplinary nature underlining the narrative.

In order to fulfill these requests, four interviews were conducted with relevant experts and additional literature and case studies were reviewed. The interviews targeted points (b) and (c) above, as well as obtaining more in-depth information for developing the barriers, drivers and policy recommendations sections. The interviews provided a range of insights that were integrated into the narrative and drew attention to additional sources of information which complemented the first draft. Additionally, the interviewees reviewed the revised draft and added their comments and details based on their expertise, which were then integrated into the version below.

Finally, the narrative's findings have been presented, discussed and complemented with input from a RECREATE breakfast-workshop at the ECCA Conference 2015 and in a session on "Nature-based solutions" at the 2nd RECREATE Strategic Workshop.

[71] http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.1-SEI_final_clean_0.pdf

Links with RECREATE Scoreboard:



Climate)ac/ on:)
Increased(CO_2(storage(in(created(/(restored(ecosystems,(climate(change(adapta+on(by(preven+ng(damage(from(natural(disaster(events(

Resource)efficiency:)
Improved(use(of(land(to(deliver(mul+ple(economic(benefits,(reduced(use(of(sealed(surface(

Note: Links are marked with an arrow.

4.1 The Narrative

European cities continue to experience an increase in the intensity and frequency of floods, with further escalations projected as a result of climate change and rapid urbanization (Santato, Bender, & Schaller, 2013). In the past decade, more than 165 major floods have taken place across the continent with significant economic damages. In 2002, for example, such events occurred in six EU Member States and created material damages rising to more than $ 21 billion (Santato, Bender, & Schaller, 2013), making flooding (including from rivers, the sea and direct rainfall) the most widespread natural hazard in Europe in terms of economic loss (CRED, 2009).

Particularly in urban areas, the management of water presents a serious challenge. The traditional solution to urban drainage in western cities has been 'grey' infrastructure solutions – piped drainage systems – which are mainly single-objective oriented designs to cope with rainwater as part of the wider urban landscape. However, these drainage infrastructures often do not have the capacity to keep pace with on-going urbanisation and the increasing rate of stormwater and can lead to urban flooding (American Rivers, 2012). Another indirect consequence is an inadequate discharge of excess water to the regional water system, increase of pollutants in the water caused by run-off and even increase in algal blooms, harming wildlife and reducing amenity values. Furthermore, managing stormwater runoff through grey infrastructure approaches typically entails high construction, maintenance, and repair costs (Hair et al., 2014).

Given this framework, sustainable urban drainage systems (SuDS)[72] have been increasingly utilized as a flood risk management tool to minimise the potential impact on the environment, people, and new and existing developments with respect to surface water drainage discharge, as well as an effective tool for improving water quality and environmental enhancement (Rose and Lamond, 2013). This type of nature-based solution is the focus of this narrative, particularly concentrating on the potential of these systems to offer cost-effective and long-term drainage alternatives to traditional systems in Europe and globally.

More specifically, SuDS is an approach or design philosophy which entails a sequence of practices and facilities. These practices, which can be on the surface or below, often rely on natural processes like storage, detention, evaporation, infiltration, and plant transpiration, can effectively and affordably complement traditional "grey" infrastructure, and can reduce stormwater runoff and pollution as well as energy and water treatment costs, diminish the impacts of flooding, improve public health, and reduce overall infrastructure costs, while also creating amenity values in urban areas and providing water resources. Many SuDS utilise or promote "green infrastructure" (GI) practices and facilities can include for example: permeable surfaces, filter strips, filter and infiltration trenches, green roofs, swales, detention basins, underground storage, wetlands and/or ponds.

The investment case for SuDS is based on the estimation of the damage costs in the EU and globally from stormwater based urban flooding, in the EU and global markets. These provide an estimate of the value of expenditure that would be justified on SuDS as a mitigation measure. This is coupled with the evidence and expert opinions that SuDS can be both more (cost-)effective than pure grey infrastructure solutions and offer significant co-benefits.[73]

It has been estimated that the benefits obtained from the implementation of SuDS can greatly exceed the benefits from piped drainage systems. Evidence from the stormwater management programme in the City

[72] Other terms are used elsewhere: *inter alia* BMP (Best management practices); LID (Low Impact Development); WSUD (Water Sensitive Urban Design (see: Fletcher et al, 2014 for a complete taxonomy).

[73] Note, the approach to use the damage costs stems from the authors analysis, which needs to be tested and applied (building on available data). The fact that SUDS is providing multiple benefits has been proven by various studies such as MWH (2013): CIRIA Research Project RP993. Demonstrating the multiple benefits of SuDS – A business case (Phase 2). Draft Literature Review (October 2013), Environment Agency (2007): Cost-benefit of SUDS retrofit in urban areas.

of Philadelphia, United States suggests that the net benefits of using surface techniques are almost $3 billion compared with less than $100 million for the piped alternative. The $3bn figure includes many diverse benefits such as: changes to property values, green jobs created (although this point is contestable as there remains a lack of evidence), reduction in greenhouse gas emissions, and reduced crime (MWH, 2013). However, such figures should be interpreted with caution given the high level of uncertainty and contextual variations surrounding effectiveness. This narrative considers the evidence for these and other claims.

As evidenced in the literature and confirmed by expert interviews, the main barriers limiting the implementation of SuDS to date have been uncertainty about long-term maintenance, performance and cost(-effectiveness) as well as difficulties in obtaining the revenue to undertake maintenance, which spark a plethora of further challenges. Informational limitations are particularly problematic in this regard as SuDS is a rapidly evolving technology and – given its site-specific nature - the levels of effectiveness, fulfillment of regulatory requirements and associated costs and benefits vary greatly from case to case (Green Nylen and Kiparsky, 2015). Technical, institutional/political, financial and social barriers which often relate to the above considerations are further impediments. Yet, a range of potential solutions and needs have also been identified to improve the confidence and competence associated with designing and implementing SuDS, including e.g. conducting further sound science to develop tools and guidance materials, implementing demonstrative or pilot projects, improving stakeholder collaborations and engagement, and optimizing dissemination efforts (Ashley et al, 2013).

4.2 Understanding the Innovation System

The Innovation

Conventional drainage infrastructures often do not have the capacity to keep pace affordably with on-going urbanisation and the increasing rate of stormwater, leading to increased run-off and a higher risk of urban flooding both locally and downstream (American Rivers, 2012; Zhou, 2014). Additional indirect consequences are an insufficient discharge of excess water to the regional water system, and increase of pollutants in the water caused by run-off (e.g. oil, organic matter and toxic metals) (Sharma, 2008) and even increases in algal blooms, harming wildlife and reductions in amenity value.

Instead of focusing on the “end-of-pipe” or “at the point of the problem” solutions, sustainable urban drainage systems (SuDS) concentrate on reducing the harmful impacts of non-point source (diffuse) pollution to urban water bodies (Zhou, 2014) and reduce the potential impact of new and existing developments with respect to surface water drainage discharge. By starting at the point at which the rain falls, utilising the water wherever possible, increasing infiltration and retention, SuDS utilize a sequence of natural processes (e.g. evaporation, infiltration, re-use and plant transpiration) and components (e.g. permeable surfaces, filter strips, filter and infiltration trenches, green roofs, swales, detention basins, underground storage, wetlands and/or ponds) to effectively and affordably complement traditional ‘grey’ infrastructure.

SuDS leads to a reduction in the overall amount of water entering local storm sewers or surface waters and therewith flooding-related impacts, such as decreased property values and tax revenues associated with flooding, damages to public infrastructure and associated repair costs and damages to private and public property. Further benefits include added water resources, improvements in local amenities, public health, increased recreational opportunities for urban populations, enhanced local ecology and biodiversity, carbon capture, and reduced energy and water treatment costs.

Structural Factors

Actors

A diversity of actors and agencies from different disciplines are involved in the development, implementation and maintenance of SuDS. Of key relevance are, for example, water service providers, local authorities and public bodies, developers and environmental regulators (expert interviews). Additional stakeholders include: NGOs, highway authorities, engineers, research institutions, planners, urban designers, potential funders, landscape architects, land or housing developers/associations, drainage consultant or suppliers, flooding managers, ecologists/biodiversity/environment managers, and the public.

While the responsibility for SuDS tends to lie with the local municipality throughout Europe, interviewed experts highlighted that the UK constellation of actors takes a slightly different form. Here, the drainage network and the flood protection that it achieves are delivered by public or private regional authorities/agencies (in England, these are privatized water companies), with some responsibility still retained by the local authorities and the environmental regulators. This results in split responsibilities between the various levels of authorities and institutions and can complicate implementation. For example, land drainage falls within the local authorities (regions or cities) and pipe drainage systems fall within the responsibility of the water and wastewater companies, while the main rivers are the responsibility of the Environment Agency. Furthermore, there is no unified approach to the way drainage of new developments take place across the UK, leaving substantial room for interpretation. This divide hints at a wider barrier to the deployment of SuDS, namely the uncertainty over responsibility for ownership and maintenance.

Regarding research and development, sustainable drainage design is considered to be a multi-disciplinary research field and, as such, requires knowledge from specialists with a wide range of different backgrounds. At present, decision-making processes are often dominated by the prioritization of single fields, resulting in subject-specific techniques being applied instead of considering the urban water cycle as a whole planning unit. Zhou (2014) and expert interviewees emphasizes that an integrated and trans-disciplinary approach is necessary to take account of the diversity of relevant fields and areas of expertise in a common platform and therewith facilitate innovative and sustainable drainage solutions. Greater involvement of a wider range of stakeholders in the development and implementation of the research agenda can also help to increase transparency and legitimacy, therewith accelerating the acceptance of findings and reducing some of the associated uncertainty surrounding SuDS.

Institutions

The goal of reaching high-level water quality has become increasingly central in the design of urban drainage as a result of the growing EU, national and local political recognition of the multifaceted, long-term benefits possible with such nature-based approaches (Zhou, 2014). However, as long as the requirement for implementing SuDS takes the form of guidance instead of being statutory, there are concerns that local authorities may use their decision-making power to prioritize other issues over SuDS in order to foster development when determining planning applications (expert interviews; Ashley et al, 2015).

In the UK, for example, there are strong differences between the institutional framework and therewith the deployment of SuDS in the constituent countries. Only in Scotland has the uptake of SuDS become business as usual, following the implementation of the EU Water Framework Directive and flooding objectives. In Wales, the Dwr Cymru Welsh Water (DCWW) operates in the public interest, so SuDS is viewed as a new environmental sustainability approach to high quality life for its citizens (expert interview). This has resulted in the development of a surface water management strategy as part of a broader sustainability vision, including the creation of a 'business case' that stresses the wider benefits that SuDS can bring to communities as a whole (Ashley et al, 2015). This has, however, only facilitated limited retrofitting schemes and is not yet mainstreamed. In England, while Defra has a strategy for the implementation of SuDS on new developments through the national planning regulation, expert interviewees emphasized that the foreseen delivery of the strategy through the Department for Communities and Local Government creates a disconnect in terms of the envisioned objectives and actual implementation processes. In practice, without adequate regulation and a clear mechanism for adoption and maintenance, SuDS is often met with resistance by the local communities and house builders who fear that it is more expensive than traditional approaches and will inhibit new house buildings (Ashley et al, 2015; expert interviews).

Adequate institutional arrangements (e.g. legal frameworks) to promote SuDS in new developments and for retrofitting processes are thus essential (EA 2013). In addition to adjusting legal frameworks and e.g. the introduction of green factor approaches (Berlin and Seattle) to enforce ecologic compensation for new developments, national efforts to foster inclusive and collaborative research on SuDS can help as well. More specifically, national regulators can use their authority to more actively accelerate and improve SuDS development by adopting standardized SuDS monitoring and reporting protocols and guidance, incentivizing and highlighting the importance of voluntary monitoring, etc. (Green Nylen and Kiparsky, 2015).

Technology

Sustainable urban drainage systems are a compilation of individual drainage techniques and structural and non-structural devices. According to Zhou (2014), the main structural devices currently employed are fixed physical constructions, such as wetlands, ponds and swales, while non-structural devices include small scale decentralized facilities (e.g. vegetation) and soft measures using knowledge and practice to influence the behavior and attitude of stakeholders. Additionally, other proprietary SuDS can include sedimentation and filtration devices (also known as proprietary devices) as their treatment processes are based on physical adsorption, precipitation, and chemical processes (e.g. sedimentation tanks, silt baskets and filter gullys) (Dierkes, Lucke and Helmreich, 2015). These elements can be sorted into three groups with regard to their hydrological role, namely:

1. Source control measures to detain, utilize and attenuate excess water runoff upstream (e.g. local harvesting, infiltration, impervious pavements and green roofs)
2. On-site control measures to prevent and reduce flood hazard impacts on recipient susceptibility, (e.g. individual assets protection and topographic modification) and
3. Downstream measures focusing on the conveyance capacity of the system (Zhou, 2014).

Experts emphasize that it is possible and recommended to have a hybrid mix of grey and technical/green SuDS components across the entire drainage systems as these elements are complementary and increase the cost-effectiveness of the systems as a whole. That being said, further long-term research is necessary on the cost-effectiveness in different scenarios, contexts and combinations to improve the targeted deployment of particular aspects and combinations of these technologies (expert interviews) and design an optimal framework which integrates technical, social, environmental, economic, legal and institutional aspects (Zhou, 2014).

Current Market

Data on the magnitude of economic losses incurred to date as a result of flooding and storms can serve as a baseline for estimating the current market for SuDS in Europe. In 2002, for example, major flood events took place in six Member States and reached a record of more than $ 21 billion in damages to private and public property, including small business owners. In fact, estimates reveal that almost 40% of small businesses never reopen their doors after a flooding disaster. Moreover, property values can decrease by 10-25% due to wet basements (CNT, 2013), not including the indirect costs of flooding to the homeowner such as lost work hours, lost personal mementos, and a (temporary) loss of the use of a part of their property. In the UK in 2004, impacts of urban flooding due to drainage systems being overwhelmed by rainfall was estimated to cost £270 million a year in England and Wales, with 80,000 homes thought to be at risk. The Emergency Management Agency in the US estimates that 25% of the $1 billion (ca. 800 Mio €) in annual damages caused by flooding are linked to stormwater caused by piped drainage systems being overwhelmed by the intensity of rainfall[74] and the US National Flood Insurance Program estimates that its payments at ca. $2.8 billion since 1978 to claims related to localized urban flooding (CNT 2013). A further example of damages is provided for Copenhagen below.

Box 8. Case: Damage Example, Flooding in Copenhagen (July 2011)

After a very hot period, Copenhagen was hit by a huge thunderstorm on 2 July 2011. During a two hour period, over 150 mm of rain fell in the city centre, constituting the biggest single rainfall in Copenhagen since measurements began in the mid-1800s. The city's sewers were designed to handle much smaller amounts of precipitation and combined rainwater and sewage together thereby making the city vulnerable if the amount and intensity of rainfall increases. Therewith the sewage system was unable to handle all of the water and as a result many streets were flooded and sewers overflowed into houses, basements and onto streets thereby flooding the city. The consequences were quite drastic as emergency services had to close roads and attend to people trapped in their

[74] Total insurance claims paid out that were related to urban flooding in Cook County (Illinois) totalled $660 million in just 5 years. Up to 25% of economic damages caused by flooding occur because runoff overwhelms urban drainage systems (CNT 2013).

cars. The emergency services were within minutes of having to evacuate the city's two biggest hospitals because of flooding and power cuts. Insurance damages alone were estimated at EUR 650–700 million. Damage to municipal infrastructure not covered by insurance, such as roads, amounted to EUR 65 million.

Source: (EEA 2012)

Considering the state of available knowledge, multifaceted benefits delivered by SuDS, and the demonstrated need for alternatives to conventional solutions to urban flooding, interviewed experts were surprised that SuDS are not yet implemented more widely in the EU and abroad and expect an increasing uptake in the future (see 'Future market potential'). Currently, however, only scattered strategies, regulatory frameworks and national level targets exist to support its implementation, with the majority of information on implementation and case studies originating from the UK, United States and Australia. Other countries such as Denmark, New Zealand, Sweden, Canada, the Netherlands, and Taiwan have also contributed best management practices to a global database.

Further coordinated research is thus still urgently needed on the performance, implementation and effectiveness of SuDS in cities to highlight their proven utility and therewith address people's hesitations and scepticism in implementing SuDS, particularly that of risk adverse developers (expert interviews). Other research needs are in adequate institutional arrangements, human resource requirements and performance indicators for urban drainage and the improved quantification of benefits in order to capitalize on the potential future market (see subsequent chapter). Evidence on employment aspects of SuDS is also needed to better argue the business case for implementation. However, some experts estimate that the amount of additional jobs created from SuDS will be relatively small given that existing and new developments will have to be drained in any event, whether through conventional approaches or by utilizing SuDS. Thus while some experts argue that *additional jobs* are projected to be relatively insignificant, there is larger consensus that the longevity of these jobs stands in contrast to those produced by traditional approaches.

4.3 Estimation of the Investment Case

Investment Strategy

The major driver for implementing SuDS and retrofitting existing drainage systems is the need to tackle the increasing rate of high precipitation and stormwater runoff, which results in flood events in urban areas. Conventional pipe wastewater systems have insufficient capacities to deal with such events as well as increasing urbanisation. In addition, the share of impervious surfaces (soil sealing) increases resulting in an overload of the capacity of the sewage system in the face of extreme events. Some regions are also dealing with inadequate discharge of excess water to the regional water system (as e.g. in delta areas in the Netherlands). Thus, there are three main market areas for SuDS across the globe:

- Installation in new build urban spaces
- Complementing or substituting piped drainage solutions (e.g. to cope with changing demands); and
- Being chosen as the drainage system when existing (mainly piped) drainage systems come to the end of their life and need replacement.

In the US alone, for example, a total of ca. 85 billion Euro is needed for stormwater management and combined sewer correction upgrades or improvements to cope with future stormwater events (American Rivers, 2012).

Typical investors for SuDS include environmental and water agencies, but are foreseen to increasingly encompass insurance companies, previous funders of other forms of green infrastructure, and private investment and water companies (expert interviews). Individual households could also increase their contributions via the establishment of tax breaks or other incentives. Potential for increased European level support is also suggested by the interviewees, and is discussed in more detail in the final section of this chapter.

Future Market Potential

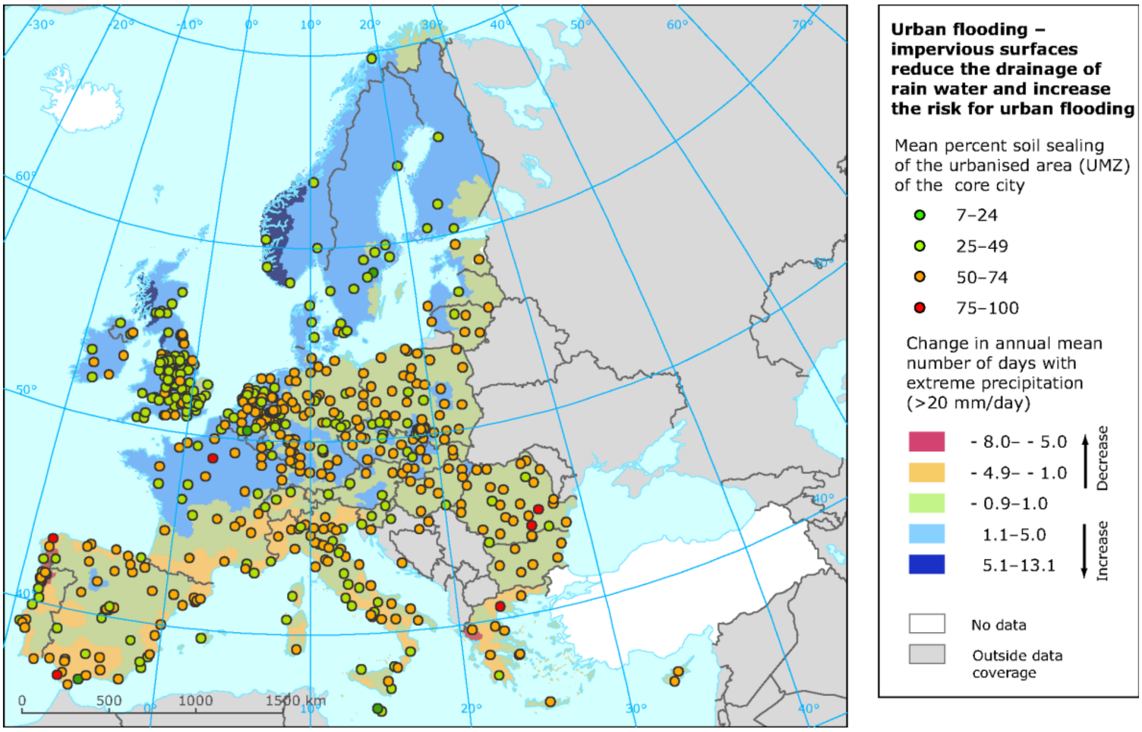
The future market potential for SuDS is based on the estimation of the damage costs in the EU and globally from stormwater based urban flooding, in the EU and global markets. This is coupled with the evidence that SuDS has the potential to be more (cost-)effective and sustainable than traditional solutions when considering the significant co-benefits generated.[75] In this context, expert interviewees emphasize the enormous market potential for both new builds and – while more challenging due to funding and site-specific considerations – retrofitting actions, with some arguing that essentially all existing buildings have the potential to be successfully retrofitted with SuDS.

SuDS can also be associated with other needs and thus arguments for its uptake, including management of the urban heat island – in a process of 'climate proofing' when building stock comes up for renewal. There is a need to look at the damage potential (early mortality) from this source, as has been done in Australia; as yet there are no European data for this (expert interview). There are also ecological impacts from climate change which are also potentially able to be offset by using blue and green infrastructure and SuDS. Such approaches can further address European needs such as meeting the requirements outlined by

[75] NOTE: The approach to use the damage costs stems from the authors analysis, which needs to be tested and applied (building on available data). The fact that SUDS is providing multiple benefits has been proven by various studies such as MWH (2013): CIRIA Research Project RP993. Demonstrating the multiple benefits of SuDS – A business case (Phase 2). Draft Literature Review (October 2013), Environment Agency (2007): Cost-benefit of SUDS retrofit in urban areas

the Water Framework Directive; this is in some cases, such as in Scotland, the main line of argumentation underlying SuDS' wider implementation.

In recent years, the natural hazards that have caused the greatest economic losses in Europe are flooding and storms. Warmer climate projections show a further increase of urban drainage flooding problems, in particular in western and northern Europe. Feeding into these projections, Figure 7 shows the estimated change in the annual number of days with heavy rainfall in 2071–2100 against the reference period (1961–1990), indicating an approximate north-south division (EEA 2012).



Source: EEA (2012)

Figure 24. Urban Flooding—Impervious Surfaces Reduce the Drainage of Rain Water and Increase the Risk for Urban Flooding

Climate extremes are expected to further exacerbate the flooding situation with increased risk of riverine, coastal and urban flooding by 2030–2040, which would lead to widespread damage to infrastructure, livelihoods and human settlements (ODI 2014). Economic losses from flooding in the European Union are projected to increase from currently €4.9 billion annually to €23.5 billion by 2050 (Jongman et al., 2014). Taking the UK as an example, a Foresight report (Evans et al. 2004) predicts that the costs of urban flooding could rise to between £1-10 billion pounds a year by the 2080s if no action were taken to reduce the risks.

Table 24. UK Estimate of Flood Risk and Flood Defense Costs

Flood risks expressed as Expected Annual Damage (EAD) and the baseline costs of flood defence for the business as usual option (continuation of current flood-management policies and expenditure into the future) – intra-urban					
	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Baseline case, EAD £ million/year	270	7,880	5,060	740	1,870
Baseline cost £ million/year	320	320	320	320	320

Adopting a more global perspective, vast amounts of urban expansion - particularly in Asia and Africa - will greatly increase the infrastructure and population at risk from flooding in the coming decades. It is estimated that 60% of the urban infrastructure required to accommodate the world's growing population by 2060 remains to be built. For example, populations living in urban floodplains in Asia may rise from 30 million in 2000 to between 83 and 91 million in 2030, and then to 119–188 million in 2060 according to different scenarios; by 2070, Asia will be home to 15 of the world's top 20 global cities for the exposure of the population to vulnerability and 13 of the top 20 for exposure of assets (ODI 2014).

Employment Effects

Some case studies (projects) indicate that through the implementation and maintenance of SuDS, jobs are being created and maintained as e.g. illustrated by the example of Severn Trent Water (see box below).

Box 9. Case: Severn Trent Water Ripple Effect investigation: benefits of retrofitting SuDS to create green streets in Coventry

Creating green streets would require maintenance and care of the landscaped areas. One job is equivalent to eliminating job-seekers allowance for one person. At £65.45 per week for a year, this is £3,403.40. If the value of housing benefit is included of £63/week this would be an additional annual cost saving of £3,276. Combined, this is £6,679. Scaled across Coventry this is equivalent to 48 jobs created, or roughly £320,592 benefit to the city. Over 40 years these jobs are worth more than £7.4 million (MWN, 2013).

Source: AECOM & Severn Trent Water (2013)

However, more overarching data and statistics on the comparison of grey vs green drainage system employment generation are largely lacking. Expert interviewees emphasize that while the SuDS systems may not create a net gain in jobs, the type of jobs produced have a longer-term nature and are more sustainable over time. Furthermore, given the extent of research and development still necessary in this field, it can be assumed that additional jobs will be produced in these areas within the coming decade as well as in the provisioning of expert advice and guidance regarding the planning, implementation and maintenance of SuDS.

Environmental and Social Benefits

Compared to traditional piped drainage systems SuDS offer very substantial additional economic, environmental and social benefits. These are listed in tables below, following the illustrative description of a case study of a successful case of retrofitting SuDS in Malmö, Sweden. Some key benefits are climate change adaptation, contributions to mitigation depending on the nature of the SuDS, and a plethora of further hydrological and human well-being contributions.

Box 10. Case: Retrofitting SUDS in an urban regeneration area, Augustenborg / Malmö (Sweden)

Augustenborg, a highly populated neighbourhood in Malmö, was the target of this project after having experienced socio-economic decline and floods from overflowing drainage. The key aim of the initiative was to create a more socially, economically, and environmentally sustainable neighbourhood by focusing on combating flooding, waste management and enhancing biodiversity. In order to minimise flood risk, a system was created to collect rainwater from rooftops and other impervious surfaces and channel it through canals, ditches, ponds and wetlands before finally draining into a traditional closed sub-surface storm water system (known as a "Sustainable Urban Drainage System" (SUDS)). Biodiversity was addressed through the creation of new wetland habitats.

In the case of the Augustenborg project, the total sum invested in the area added up to around SEK 200 million (€22 million). Costs related to project planning amounted to approximately SEK 6 million (€660,000) and infrastructure investments (pumping station and storm water pipes) amounted to approximately SEK 17 million (€1.9 million). Ongoing costs of maintenance equal SEK 155,410 (€17,000) per year. No opportunity costs related to foregone land-use were reported; however, there were potential foregone recreational uses (i.e. large open fields used for sports, were to be used for retention ponds) in the initial design of the project.

The benefits provided by the project are mainly associated with improved water regulation in the area: the system of swales, retention ponds, green roofs and other elements of the Sustainable Urban Drainage System serve to protect the neighbourhood of Augustenborg from flooding and regulate surface runoff. However, WWF and RSA (2011) reported additional benefits, including:

(a) improved water quality;
(b) reduced carbon emissions:
(c) reduced pluvial and sewer flood risk;
(d) aquifer recharge (relieving stress in water scarce areas);
(e) enhancement of urban spaces; and
(f) increased biodiversity

Habitat creation has led to an enhanced level of ecosystem resilience. As a side-effect, the project contributed to increased aesthetic and amenity values of the landscape and resulted in increased eco-tourism in the region. The City of Malmö has become known for sustainable architecture, innovative ecosystem-based adaptation and mitigation and a high quality of life for residents. Moreover, a neighbourhood in decline has been transformed into a recreational hub (as a result of the many new parks, ponds etc.) and symbol of social sustainability (Naumann et al, 2011b).

According to Kazmierczak, A. and Carter, J. (2010) Rainwater run-off has decreased by half. The image of the area has improved. Biodiversity has increased by 50 % (green roofs have attracted birds and insects and an open stormwater system provides a better environment for the local plants and wildlife. The impact on the environment decreased by 20 %. Unemployment rate has fall from 30 % to 6 %. The turnover of tenancies has also decreased by 50 %.

The following table outlines the potential environmental, economic and social benefits of introducing SuDS. The extent and nature of these benefits is site-specific and depends on the nature of the build or retrofit.

Table 25. Overview of Environmental and Social Benefits Resulting from SuDS

Benefit	Examples (figures)
	Economic benefits
Increase in labour productivity	In case habitats are improved or cultural heritage is sustained, labour productivity in dependent tourist industries will increase, which again improves labour productivity in other connected industries. People will be employed in construction periods and in the subsequent maintenance activities. The impacts on labour productivity can include: (g) Physical health improvements – resulting principally from increased exercise and improved air quality; (h) Mental health improvements – from the calming effects of the presence of trees and green spaces, and also from physical exercise. Both of which are linked to health benefits; improvements at work because it was found that when workers have access to plants and green spaces they can be more patient, better at problem-solving and more productive; A reduction in short-term absenteeism. Labour productivity of SuDS (using GI) can be estimated through the impact on labour productivity and increased profit as a result of reduced costs of recruitment (both enhancing the GVA per company) (Ashley et al. 2012).

Energy savings and reduced GHG emissions	If SuDS are installed in an existing development over 1 ha permeable area: avoided cost of pumping to the water company: £88 /yr; potential carbon savings: 0.5 t/yr (EA 2009)
Reduces water treatment needs / Reduces need for water purification & waste treatment	One approach to value the reduction in stormwater runoff for these cities is an avoided cost approach. Runoff reduction is at least as valuable as the amount that would be spent by the local stormwater utility to treat that runoff. In this case, the valuation equation is simply: runoff reduced (gal) * avoided cost per gallon ($/gal) = avoided stormwater treatment costs ($) This figure can be aggregated to a larger scale to demonstrate the cumulative benefit that can be achieved in a neighbourhood/region. Reducing or limiting volume of flow to the sewage treatment works will help reduce energy costs. Reduced pumping from storage facilities and less diluted sewage may result in more efficient treatment of wastewater. This would also help reduce the need to provide additional capacity. A number of sewage works are already at the limit of their capacity. (EA 2007)
CSO reduction monetary savings	Improved river water quality by reducing pollutants discharged to surface water sewers and by reducing discharges from Combined Sewer Overflows (CSOs): £51,000 per CSO (EEA 2007) Traditional (piped) drainage systems prevent moreover natural percolation of rainfall into groundwater resources that support summer river flows. This can lead to the concentration of nitrates and phosphates in rivers and wetlands, causing an increase in algal blooms, harming wildlife and reducing amenity value
Reduced water use **Discounted water bill savings**	Some SUDS, such as water butts and rainwater harvesting, provide an alternative source for non-potable water within domestic and commercial settings. These will help to meet water efficiency targets. (EA 2007) Total water bill savings of a scheme is estimated as the product of total water savings and cost per m^3 of water saved (this was estimated as £2.01/m3 for properties on meters) (EA 2007)
Enhances tourisms	The value of GI to increased tourism is calculated by assessing the money spent on travel and local expenditure in order to visit a particular site (calculations can also include the number of jobs supported by tourism and GVA associated with employment)
Environmental benefits[76]	
Reduce flooding, Storm protection	Direct disconnection of rainwater from the sewer systems or by reducing the volume and rate of run-off of the rainwater that still enters the sewer system. The context of flooding is highly site specific; no general instructions for the valuation of reduced flooding exist. Hedonics can be used to assess how flood risk is priced into the real estate market. Insurance premiums paid for flood damage can be used as a proxy for the value of decreased flood risk. The most robust technique uses hedonics to investigate housing price discounts associated with a floodplain location. A 2-5% Discount was found for houses within the 100 yr flood plain when compared to those outside. According to the EA (2007) a uniform 10% reduction in the connected area to the sewer system over the entire country would achieve a 90% reduction in the numbers of incidents of flooding due to hydraulic overload of the sewer system in the UK. (For each SUDS scheme, the annual run-off reduction = unit benefit of run-off reduction/ m^2 of impermeable area and cumulative total potential area constructed over the conversion life of the scheme.) Monetary savings resulting from reduced number of flooding incidents: £39,000 per incident.
Reduced stormwater runoff	Valuing water benefits is to determine the amount of rainfall (gallons) retained on the site. This is then used as the resource unit for all water benefits.

[76] Some of these benefits could be also provide economic advantages

Improves water quality (e.g. via reduced erosion and sedimentation, and lower pollutant concentrations in rivers, lakes and streams)	Studies in USA have estimated implicit marginal prices for a one meter change in water clarity (turbidity reduction) ranging from $1,100 to $12,938 per waterfront property. Estimates of the value of not having to treat runoff at wastewater plants – for example a 5,000 ft2 green roof contributes to an annual electricity savings from reduced water treatment needs of 110.77 kWh
Reduces need for grey infrastructure	The SEA streets in Seattle provide cost savings for the city of 15–25%, or $100,000–$235,000 per block, as compared with conventional stormwater control design. The city of Portland (USA) estimates that it costs the city $2.71/ ft2 in infrastructure costs to manage the stormwater generated from impervious areas using: *total expenditure for grey approach ($) * % retained = avoided cost savings ($)* (David Evans and Associates, 2008)
Reduces urban heat island effect, / Climate regulation (local temp, GHG sequestration etc.)	Adding 10 % green cover keeps maximum surface temperatures in high density residential areas and town centres at or below the 1961-1990 baseline up until the 2080s (Gill et al., 2007).
Improves biodiversity	Many SUDS types, such as swales, filter ditches and infiltration ponds mimic the natural environment, retaining water that will attract wildlife, creating stable habitats and providing corridors along which wildlife can move. (EA 2007)
Social benefits	
Preserves/ sustains/creates heritage	The use and non-use values = the economic value of a heritage asset or of the goods and services to which it gives rise. (potential methodologies: contingent valuation methodology (CVM, incl. WtP), travel cost assessments, and hedonic pricing.)
Increases amenity and recreation opportunities	The value of added recreational opportunities may be measured by avoided costs in connection to health benefits, or via an increase in recreational trips, the “user days”, gained from GI.
Improves aesthetics	Increased greenery has been shown to increase the aesthetic value of neighbourhoods. For example Willingness to Pay studies have shown an increase in property values of 2-10% in areas with new street tree plantings. In Portland, Oregon – street trees have been shown to add $8,870 to sale prices in residential properties and reduce the time on the market by 1.7 days.
Social relations (e.g. fishing, grazing, cropping communities)	Investment in green infrastructure (and SuDS) can enhance access to natural green space and provide opportunities for various forms of formal and informal recreational activity

Source: (based on Ashley et al. 2012)

The table below provides a summary of the comparable benefits for water management between SuDS and conventional grey infrastructure drainage systems given projected climate change impacts.

Table 26. Responses of Current Traditional and Flexible Sustainable Drainage Systems to Climate Change

Urban water management aspect	Non-exhaustive examples of climate change impacts	Current system response example	Potential responses to changing conditions from a flexible system
Water supply	Reduced water supply, either seasonally or throughout the year	Increasing water supply through additional infrastructure such as dams, boreholes, desalination facilities or bulk supply transfers	Demand reduction through efficiency increases, active leakage management, behaviour change or pricing policies
			Sourcing of alternative supplies for non-potable demand: rainwater harvesting or treated wastewater effluent reuse
			Increasing sustainable storage capacity, for example through Aquifer Storage and Recovery
Wastewater management	Increased inflow of pollution, caused by flooding	Improving treatment technology	Control of pollution at source and use of natural treatment techniques
	Flooding of wastewater treatment plants located near rivers or coasts	Construction of protective barriers or lifting of equipment	Use and appropriate siting of decentralised natural treatment techniques
Stormwater management	Increased stormwater flows and combined sewer overflows	Improving and extending the infrastructure conveying stormwater away from the city	Attenuation of runoff through the use of Sustainable Urban Drainage Systems options, for example green roofs, porous paving, swales, rainwater harvesting, and detention ponds and basins

Source: ICLEI European Secretariat (2011)

4.4 Innovation System Functioning

Function 1. Entrepreneurial Activities (EA)

The Augustenborg case (Sweden) demonstrates the value of partnerships between multiple authorities within an urban context. Without the partnership between the Malmö water company, housing authority, and others, the funding for this project would not have been sufficient. There are several additional initiatives and demonstration projects revealing entrepreneurial activities in the implementation of SuDS, stemming from the UK, Sweden, the US and Australia, bringing together sanitation engineers, water supply staff, environmentalists, road engineers and communities. These examples indicate that entrepreneurial activity is required more on the purchaser's side (e.g. the city authority) than it is on the supply side.

Another approach to partnerships is illustrated on the research front, in the form of 'learning alliances'. These collaborations aim to bridge the gap between research and practice, i.e. scientists and experts on the one side and water users and other stakeholders on the other. The underlying principle is that the research agenda itself can be developed in partnership with stakeholders, enabling their needs and concerns to be met, and that the responsibility for conducting the research itself is shared with these stakeholders, ultimately increasing legitimacy and adoption of the results (ICLEI, 2011).

Function 2. Knowledge Development (KDev)

There is an extensive body of literature and knowledge about SuDS, encompassing guidance for technical implementation (e.g. for local authorities and developers) as well as outlining some of the costs and benefits involved. The majority of this literature stems from European countries (in particularly the UK) and the US, but several major research projects have also been initiated worldwide. Zhou (2014: 979) outlines some of these initiatives, including:

- In Denmark, large national research programs include the "Water in urban areas" project working on transformation of the city water infrastructure to climatically robust systems and the 2BG "Black, Blue & Green" project committed to integrated infrastructure planning for sustainable urban water systems. The working papers from 2BG further expound their main goals and include case studies on sustainable urban drainage design implemented in Denmark and the Netherlands (Birch et al, 2008).
- In the UK, the Construction Industry Research and Information Association (CIRIA) promotes sustainable drainage systems and also published a series of documents on design practices and applied projects.
- In Ireland, Dublin's strategic drainage study involves several local authorities to perform an in-depth drainage assessment of integrated constructed wetlands.
- In Sweden, a large six-year research project entitled "Sustainable Urban Water Management" was initiated by the Swedish Foundation for Strategic Research Programme with its focus on protecting valuable water resources in urban areas.
- In Australia, one of the largest research activities on sustainable drainage solutions is the Cooperative Research Centre (CRC) for Water Sensitive Cities, which brings together over 70 inter-disciplinary partners to deliver sustainable water strategies facilitating transformation of the city into a more liveable and resilient environment.

Moreover, there are some international websites such as:

- International Best Management Practices (BMPs) Database – a platform featuring a database of over 530 BMPs performance analysis results studies (from New Zealand, the US, Sweden, Taiwan and Canada), tools for use in BMP performance studies, monitoring guidance and other study-related publications.
- Stormwater Industry Association of Australia
- CIRIA susdrain database (UK focused)

Evidence on the implementation and effectiveness of SuDS in cities in developing countries is lacking, which reveals the need for additional research. Further areas for research include: adequate institutional arrangements, human resource requirements and performance indicators for urban drainage and the improved quantification of benefits (including more research on diffuse pollution).

SuDS are already being used (often informally) successfully in urban areas of low-income countries and therefore can be considered a technology that is suitable for use in these countries. Water pollution is a major problem countries and an adverse impact of poorly managed urban drainage, leading to disease and poor drinking water quality. There is a strong need for technical research to support physical interventions, especially for the design of drainage systems that can cope with silt and also for the development of design procedures where there is limited data and staff with limited drainage expertise (Reed, 2004).

Function 3. Knowledge Diffusion through Networks (KDiff)

Platforms exist to inform about SuDS, e.g. susdrain - a UK-based, independent and authoritative platform for stakeholders involved in delivering sustainable drainage. It provides up-to-date guidance, information, case studies, videos, photos and discussion forums that help to underpin the planning, design, approval, construction and maintenance of SuDS. Susdrain is created by CIRIA, an independent member based, not-for-profit construction industry research and information association. Another UK-based platform is 'Engineering Nature's Way', providing information and best practice on SuDS relevant to people working in flood risk management strategy or concerned with SuDS in local and central Government, developers, consulting engineers and contractors.

These show that networking is possible. However, guidance, dissemination and promotion of information across affected regions, for the city level, and for relevant stakeholders is largely lacking. It would be most relevant to provide information on SuDS to all relevant actors highlighted earlier in this chapter, and particularly to mid-level managers and strategic planners within utilities or relevant local government departments who are responsible for taking decisions in the area of urban water management.

Function 4. Guidance of the Search (GoS)

There is an urgent need to cope with increasing stormwater events in urban areas, which exceeds the capacity of pipe drainage systems and cause urban flooding and can cause high damage costs. There is evidence from several cases that the cost-benefit ratio of SuDS often performs better than conventional, purely 'grey' piped drainage systems, but further evidence is necessary for making the 'business case' for SuDS and therewith ensuring wider political support and deployment (expert interviews). Collaboration between developers, the research community, the wider public and other stakeholders could contribute to more appropriately shaping the research agenda, fostering innovation and ensuring a greater uptake of results (expert interviews).

Function 5. Market Formation (MF)

The implementation of SuDS requires the involvement and coordination of multiple actors and agencies involved in urban planning, development and water management (including residents, housing association, parish councils, local authorities and highway authorities) and adequate consultation and communication mechanisms. Adequate institutional arrangements (e.g. legal frameworks) to promote SuDS in new developments and for retrofitting processes are needed (EA, 2013) as well as an availability of a minimum area of public open space for some of the more land-intensive SuDS techniques for retrofitting permeable paving in densely built areas (this might be addressed through regulatory intervention or financial resources for land purchase). In addition to adjusting legal frameworks and e.g. the introduction of green factor approaches (Berlin and Seattle) to enforce ecologic compensation for new developments, a business case is crucial in order to take the wider value of SuDS into account and increase its uptake and implementation (Ashley et al, 2015). It is also crucial to address concerns of performance uncertainty and questions regarding the ownership and responsibility for maintaining SuDS (EA 2103).

Function 6. Resources Mobilization (RM)

Despite the many benefits of SUDS for water quantity and quality management, there have also been questions and scepticism regarding their performance and feasibility (Zhou, 2014). Addressing these concerns and aspects of uncertainty is necessary as the first step in mobilizing resources for SuDS. Once addressed, financial resources are potentially available from e.g. public flood prevention funding or in inclusion of costs for new development. These funds must also take into account the crucial aspect of maintenance and ensuring that sufficient financing and responsibilities have been delegated for these activities already in the planning phase (expert interviews).

Existing funding budgets may not yet have been adapted to future increased risks, and the need to update and replace piped infrastructure. For example, aging stormwater infrastructure, along with the pressure to construct new facilities, adds billions of dollars to future municipal, state and federal fiscal needs. According to the United States Environmental Protection Agency, U.S. communities are facing a total of $106 billion (ca. 85 billion Euro) in needed stormwater management and combined sewer correction upgrades or improvements (American Rivers et al. 2012).

Furthermore, the success of urban adaptation also is highly dependent on the availability of knowledge, technical capability, institutional resources and targeted tools in addition to the financial resources outlined (ICLEI, 2011).

Function 7. Creation of Legitimacy (CoL)

There have been a wide range of successful cases, in which SuDS has been show to generate multiple benefits compared to traditional pipe systems with underground storage in addition to the long-term management of stormwater and avoidance of flooding, as well as improvements in water quality. Some additional legitimacy comes from SuDS' ability to deliver long-term solutions to adapt to climate change (as noted in public policy strategies, like the EU Adaptation Strategy). It has also been noted to contribute to objectives of the EU efforts to increase the resource efficiency by saving energy and reducing GHG emissions as well as reduced water treatments (water purification).

Despite these numerous benefits and several existing example case studies, however, scepticism remains prevalent in society at large as well as in risk-hesitant developers, and additional long-term research is necessary. There is a need to make SuDS as an alternative technique "legitimate" and not second- best and therewith overcome the reluctance to pioneer alternative drainage methods[77]. For instance, there is lack of consistent cost and benefit methodology for wide-scale retrofitting, monitoring performance and quantifying benefits (EA, 2013), which could be addressed via investments in research e.g. via H2020 Programme.

The experts interviewed emphasized that there is also a need to better engage the developers in the research process in order to support their feeling of ownership of the data which is being created and strengthen their belief in its legitimacy (see 'Entrepreneurial activities' for more on learning alliances as a possible tool). Furthermore, one expert highlighted that an underlying principle for increasing legitimacy should be supporting sound data and good science via e.g. the peer review process and increasing acceptance in the eyes of the target audiences.

Summary: Barriers and Drivers

Analysing the seven interrelated Innovation System Functions (ISF) typically results in insights with respect to drivers and barriers of the specific innovation, (Suurs and Roelofs, 2014) . This section summarizes the main drivers and main barriers from the pre-discussed Innovation System Functions and their relation to a further diffusion of "Sustainable Urban Drainage Systems". Based on the information provided in the preceding sections, the levels of ISF fulfilment is shortly discussed and is hence based on the author's own assessment. The fulfilment is scored by means of a five-point scale (1 – very weakly developed, 2 – weakly developed, 3 – developed, 4 – strongly developed, 5 – very strongly developed), see also following figure.

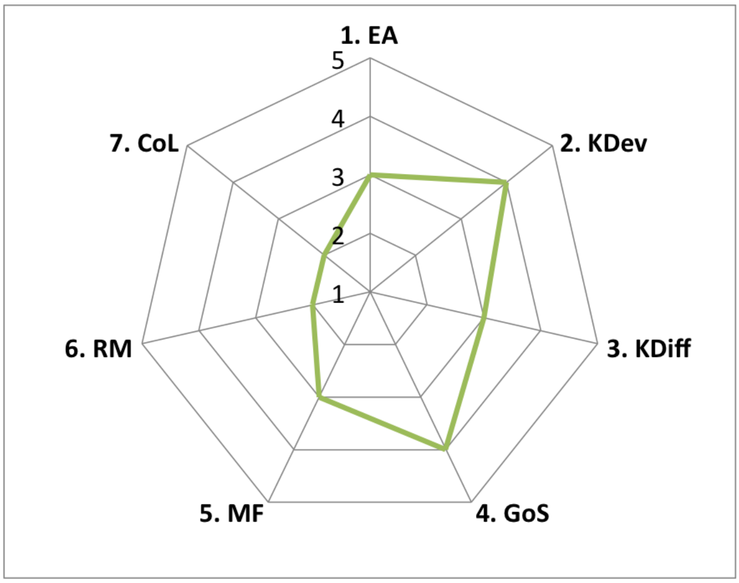


Figure 25. Fulfilment of Innovation System Functions: Sustainable Urban Drainage Systems

The key drivers currently propelling the uptake and development of SuDS have been identified in the literature and in expert interviews as follows:

- Increase in stormwater/ high precipitation in some urban areas exceeding capacities of pipe wastewater systems
- Generation of multiple benefits and demand of urban society for green spaces and urban regeneration projects (e.g. goal to deliver 'better places and spaces' in Wales)
- Protection of properties and infrastructure from flooding

[77] Reed (2004): Sustainable Urban Drainage in Low-income Countries - a Scoping Study. Project report

- Needs to cost-effectively address issues of water quality (EU Water Framework Directive)
- Wider blue and green corridor agenda, given the EU Green Infrastructure Strategy and national/local policy planning frameworks

Despite these strong drivers, there are also a number of counteracting inhibiting factors acting as barriers towards the wider deployment of SuDS which have been outlined in the previous chapter, namely:

- Current institutional and legislative arrangements (e.g. planning authorities in the UK require SuDS unless it can be shown that this approach is not feasible, leaving the door open to establishing excuses for not implementing it instead of optimizing the approach)
- Uncertainty about ownership and responsibilities, particularly when systems cross public and private lands. This leads to problems in determining who pays for, operates and maintains SuDS in the long-term. There is also a lack of enforcement of existing regulations in some cases (e.g. Scotland), which requires not only effective policing of design, but also of what is built and how it is operated and maintained
- Lack of diffusion of relevant information, experiences, guidance and tools across relevant institutional and stakeholder networks, leading to knowledge and capacity gaps amongst relevant actors and authorities
- Disconnect between those responsible for implementing the drainage systems and those working on the development and research, particularly on costs, etc, thereby inhibiting its legitimacy and the sense of ownership
- Site-specific nature of SuDS requires the systems to be adapted and designed for each case individually, preventing the development of a technical ‘one size fits all’ solution
- Lacking information on and standardized tools for measuring performance and costs/benefits, particularly on a city scale and considering the often long-term nature of payback period for benefits
- Scepticism and hesitancy of the general public, relating to a lack of knowledge and uncertainty
- Potentially high land requirements of SuDS can be costly and difficult to accept for planners and local authorities

While SuDS have been proven to be a cost-effective solution to reduce urban flooding and run-off, they still require further innovation actions to exploit the full potential, both in the EU and for expanding global markets. The variety of actors involved in the implementation of SuDS also calls for a systemic innovation, covering several aspects of the innovation system (e.g. diffusion of information and generation of new knowledge through research coupled to deployment (demonstration projects) and networking around suitable legal conditions for success).

4.5 Further Evidence on the Innovation System

n/a

4.6 Policy Implications

At the EU level and in other industrialized countries, the innovation support required would focus on the experimentation with and adjustments of institutional settings, considering alternative local capacities and site-specific cultural considerations. Another focus would be on strengthening the 'business case' for SuDS, highlighting the delivery of multiple benefits in addition to flood protection (e.g. improvements in water quality, human well-being, biodiversity protection, etc). New business-models for public-private partnerships are one aspect of this process, combining blue/green spaces, human well-being, water management and climate change adaptation interests. Establishing such arguments will serve as the foundation for increased investment, public and political support and ultimately SuDS deployment. These processes should comprise part of an integrated perspective which views all forms of water as both opportunities and resources and which joins up the water cycle, i.e. adopting the approach that 'today's flood can be tomorrow's resource'.

Additional potential areas where EU support for innovation could foster the greater deployment of SuDS include, for example (expert interviews; Hair et al, 2014):

- Regulations and financial agreements/investment banks that bridge the gap between short-term thinking and long-term investments
- Support for transdisciplinary approaches for implementation of SuDS, product innovation, testing performance (long-term studies) and showcasing positive examples
- Financial contributions to help alleviate part of the risk of failure associated with innovative SuDS solutions, via the creation of a security fund accessible to Member States
- Highlighting synergies with existing policies that could foster SuDS, for example under the EU Green Infrastructure Strategy
- Increasing the level of European endorsement and financial support for SuDS, e.g. under the Water Framework Directive and Floods Directive
- Mainstreaming SuDS into decision making processes and eventually establishing them as business as usual

In addition, increasing the awareness, knowledge basis and perceived legitimacy of SuDS is essential for increasing its market potential. This could be done through targeted websites at national and regional level across all EU Member States (e.g. embedding this information in the websites of the Ministries for Environmental infrastructure planning as well as at the global level), and through relevant educational programmes e.g. for urban planners and engineers. Other recommendations are to use demonstration projects as public education tools, communicate the results of economic analyses and openly acknowledging assumptions (Hair et al, 2014).

Expert interviewees also suggest concentrating efforts on involving local communities in decision-making process, instead of only being presented with end results. This is underlined by Hair et al (2014), who suggest to encourage stakeholder involvement and education at all levels of decision-making processes to improve transparency and foster trust and therewith increase improve acceptance and address citizen, business and political concerns. Investments in social-cultural research and the development of cross-disciplinary language could be valuable venues by which to increase public acceptability and support, particularly given that many of the decisions on SUDS retrofits are the responsibility of property owners.

Once confidence exists that SuDS is effective and affordable as a nature based solution technology, governments can support wider implementation by establishing a legal framework which offers:

- "Stability for business and public sectors, with a requirement for compatible technical guidance across all sectors.
- Clarity on adoption and vesting, supported by adoption standards, which must deliver a legal remit for public bodies to have budget for retrofits with ongoing maintenance" (Ashley et al, 2015:4).

At the global level and with a particular focus on developing countries, an innovation support would be needed for the adaptation of SuDS to different conditions (and given market conditions) for a widespread penetration. One specific challenge is the need for technical research to support physical interventions, especially for the design of drainage systems that can cope with silt and also for the development of design procedures.

References

- AECOM & Severn Trent Water (2013). The Ripple Effect – Building resilience of urban water systems to climate change. Technical Report: The Case for Birmingham and Coventry.
- American Rivers (2012): Banking on Green.; CNT (2013): The Prevalence and Cost of Urban Flooding: A Case Study of Cook County, IL. The Center for Neighborhood Technology.
- Ashley R M., Christensson A., de Beer J., et al. (2012): Selling sustainability in SKINT. SKINT INTERREG IIIb project report. Cited in: CIRIA (2013): Demonstrating the multiple benefits of SuDS – A business case (Phase 2). Draft Literature Review.
- Ashley, R; Shaffer, P; Walker, L (2013). Sustainable drainage systems: Research roadmap. On behalf of UKWIR. Final report.
- Ashley, RM; Walker, L; D'Arcy, B; Wilson, S; Illman, S; Shaffer, P; Woods-Ballard, B; Chatfield, P (2015). UK sustainable drainage systems: past, present and future. Civil Engineering – Proceedings of the Institution of Civil Engineers. ICE Publishing.
- Birch, H; Bergman, M; Backhaus, A; Fryd, O; Invertsen, ST (2008). Sustainable urban drainage systems – 8 case studies from the Netherlands. Available for download at: http://ign.ku.dk/forskning/landskabsarkitektur-planlaegning/landskabsteknologi/2bg-black-blue-green/filer/2bg_workingpaper1_holland_excursion.ashx.
- Burch, S. (2011). Ecosystem based approaches to climate change mitigation and adaptation: Augustenborg. Completed within the report: Naumann, S; Anzaldua, G; Berry, P; Burch, S; Davis, Frelih-Larsen, A; Gerdes, H; and Sanders, M (2011): Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2, Ecologic institute and Environmental Change Institute, Oxford University Centre for the Environment.
- CNT (2013): The Prevalence and Cost of Urban Flooding: A Case Study of Cook County, IL. The Center for Neighborhood Technology.
- CRED (2009), "Disaster data: A balanced perspective", CRED Crunch, Centre for Research on the Epidemiology of Disasters (CRED), Issue No. 17, Brussels.
- David Evans and Associates (2008). Cost Benefit Evaluation Of Ecoroofs. Report prepared for the City of Portland Bureau of Environmental Services. Available for download at: https://www.portlandoregon.gov/bes/article/261053.
- Dierkes, C; Lucke T; and Helmreich, B (2015). General Technical Approvals for Decentralised Sustainable Urban Drainage Systems (SUDS)—The Current Situation in Germany. Sustainability 7, 3031-3051.
- Dublin Drainage (2005). Greater Dublin Strategic Drainage Study, Final Strategy Report. Regional Drainage Policies - Volume 3 – Appendices. Available for download at: http://www.dublincity.ie/sites/default/files/content/WaterWasteEnvironment/WasteWater/Drainage/GreaterDublinStrategicDrainageStudy/Documents/Vol%203%20-%20%20Appendix%20D%20-%20SuDS%20Policies%20and%20Case%20Studies.pdf
- Environment Agency (EA) (2007). Cost-benefit of SuDS retrofit in urban areas.
- Environment Agency (EA) (2009). Potential of SUDS in reducing water related greenhous gas emissions. Report: SC070010/R4.
- Environment Agency (EA) (2013): An assessment of evidence on Sustainable Drainage Systems and the ThamesTideway Standards.
- EEA (2012): Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies.
- Evans, e., Ashely, R., Hall, J., Penning-Rowsell, E., Sayers, P., Thorne, C. and Watkinson, A. (2004): Foresight Future Flooding, Volume I and Volume II. Office of Science and Technology, London.
- Green Nylen, Nell, and Michael Kiparsky (2015). Accelerating Cost-Effective Green Stormwater Infrastructure: Learning from Local Implementation. Center for Law, Energy & the Environment, U.C. Bekeley School of Law. http://law.berkeley.edu/cost-effective-GSI.htm.
- Hair, L; Clements, J; Pratt, J (2014). Insights on the economics of green infrastructure: A case study approach. Water Economics Federation, WEFTEC 2014: 5556-5585.
- iBUILD (2015). Are you being served? Alternative infrastructure business models to improve economic growth and well-being, iBUILD manifesto and mid-term report. Newcastle University. ISBN 978-09928437-1-7.
- ICLEI European Secretariat (2011). Handbook on 'Adapting urban water systems to climate change'. Prepared within the framework of the European research project SWITCH (2006 to 2011). Available for download at:

http://www.iclei-europe.org/fileadmin/templates/iclei-europe/files/content/Topics/Water/SWITCH_Adaption-Handbook_final_small.pdf.

- Jongman, B., Hochrainer-Stigler, S.,Feyen, L.et al. (2014): Increasing stress on disaster - risk finance due to large floods. Nature Climate Change 4, 264–268.
- Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies. GRABS-Project. http://www.grabs-eu.org/membersArea/files/malmo.pdf.
- MWH (2013): CIRIA Research Project RP993. Demonstrating the multiple benefits of SuDS – A business case (Phase 2). Draft Literature Review (October 2013).
- Naumann, S., Anzaldua, G., Berry, P. et al. (2011b): Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2. Brussels; European Commission.
- Gill, S., Handley, J., Ennos, A., and Pauleit, S. (2007). Adapting Cities for Climate Change: The Role of The Green Infrastructure. Built Environment 3 (1): 115-133.
- ODI (2014): Humanitarian trends and trajectories to 2030: North and South-East Asia. Regional Consultation. Author: Katie Peters.
- Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies. Available for download at: http://www.grabs-eu.org/membersarea/files/malmo.pdf
- Reed (2004). Sustainable urban drainage in low-income countries – a scoping study. Project report.
- Rose, C. and Lamond, J. (2013) Performance of sustainable drainage for urban flood control, lessons from Europe and Asia. In: International Conference on Flood Resilience, Experiences in Asia and Europe, Exeter, United Kingdom, 5-7 September 2013.
- Santato, S., Bender, S. & Schaller, M. (2013): The European Floods Directive and Opportunities offered by Land Use Planning. CSC Report 12, Climate Service Center, Germany. Available for download at: http://www.climate-service-center.de/imperia/md/content/csc/csc-report_12.pdf.
- Sharma, D (2008). Sustainable Drainage System (SuDS) for Stormwater Management: A Technological and Policy Intervention to Combat Diffuse Pollution. 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK, 2008. Available for download at: http://web.sbe.hw.ac.uk/staffprofiles/bdgsa/11th_International_Conference_on_Urban_Drainage_CD/ICUD08/pdfs/753.pdf.
- WWF and RSA (2011). Dealing with the deluge – Urban water management in a changing climate. Available for download at: http://www.wwfrsapartners.com/static/uploads/page_files/WWFRSA_SuDSReportFINAL.pdf.
- Zhou, Q (2014). A Review of Sustainable Urban Drainage Systems Considering the Climate Change and Urbanization Impacts. Water 6, 976-992.

Annex 1. Augustenborg, Malmö

What is this solution about and why was it implemented?:
The neighbourhood of Augustenborg (Malmö, Sweden) has experienced periods of socio-economic decline in recent decades, and frequently suffered from floods caused by overflowing drainage systems. Augustenborg was prone to annual flooding caused by the old sewage drainage system being unable to cope with the combination of rainwater run-off, household wastewater and pressure from other parts of the city. Resulting flooding was leading to damage to underground garages and basements, and restricted access to local roads and footpaths. Untreated sewage also often entered watercourses as a result of increasing pressure on the sewage treatment works.
The area underwent a significant regeneration between 1998 and 2002 as part of the 'Ekostaden Augustenborg' initiative. The key aim was to create a more socially, economically, and environmentally sustainable neighbourhood, focusing on combating flooding, waste management and enhancing biodiversity. Significant physical changes in infrastructure took place, focusing on the creation of sustainable urban drainage systems, including ditches, retention ponds, green roofs and green spaces. The project was carried out collaboratively by the city council and a social housing company, with extensive participation of the residents in Augustenborg. The project has resulted in a successful outcome as the rainwater runoff rates have decreased by half, and the increase in green space has improved the image of the area.

Who were the stakeholders involved in its implementation?:
The City of Malmö and the MKB social housing company jointly managed and funded the project. As extensive stakeholder engagement processes were undertaken, the project also involved local residents living within the retrofitted area and local school representatives, as well as practitioners to design and adapt the plans, and private companies and businesses.

Where did the funding come from?:
The physical improvements in Augustenborg and related projects totaled approximately 200M SEK (ca. 21 million Euro). Approximately half of the funds were invested by the MKB housing company, while the other half came from:
- Local authorities (principally the city of Malmö)
- Swedish government's Local Investments Programme for Ecological Conversion and Eco-Cycle Programme
- Swedish Department of the Environment
- EU LIFE Programme
- EU URBAN programme

Management work is jointly funded through the MKB housing company (which incoroporates costs into rents), the water board (through the water rates) and the city council's standard maintenance budgets.

What were the barriers encountered and how were these overcome?:
Main challenges arose as a result of the project involving retrofitting SuDS within existing development and infrastructure and as a consequence of many residents currently living in the area. This required developing a plan that was acceptable to local residents, and addressed their concerns (e.g. prioritization of aesthetics over functioning; worries about health and safety issues for elderly, disabled, and school-aged citizens). Another technical challenge was finding physical space to incorporate the SuDS into the already existing development. These difficulties were overcome by re-designing, re-sitting and – in some cases – not implementing certain elements of the system and utilizing technical solutions. Importantly, an extensive and iterative process of stakeholder engagement was also initiated during the design and execution of this project, involving a 'rolling programme' of consultation with local residents, representatives from the local school, practitioners, city staff and many other individuals. Safety issues related to the open water were discussed with residents, with perceived risk being lower than expected by project designers.

Sources:

- Burch, S. (2011). Ecosystem based approaches to climate change mitigation and adaptation: Augustenborg. Completed within the report: Naumann, S; Anzaldua, G; Berry, P; Burch, S; Davis, Frelih-Larsen, A; Gerdes, H; and Sanders, M (2011): Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2, Ecologic institute and Environmental Change Institute, Oxford University Centre for

the Environment.

- Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies.
- Available for download at: http://www.grabs-eu.org/membersarea/files/malmo.pdf

Annex 2. Ashby Grove

What is this solution about and why was it implemented?:

The Ashby Grove rain garden retrofit was designed to remove roof water from a social housing block in Islington. The aim was to disconnect one of the roof downpipes and allow water to flow directly into a newly designed rain garden. In 2011, initial works to disconnect the downpipe from the roof of Ashby Grove (a low rise residential block) was commenced. Driven forward by Islington Council to improve the amenity in the local area, a rain garden was designed to allow rainwater to naturally infiltrate into the subsurface or flow slowly to the sewer, thereby reducing the peak flow rate from the site. As part of the build process, monitoring has been incorporated to allow Middlesex University to monitor water volumes, water quality and soil moisture content. A bespoke water butt and service chamber has been designed and built to incorporate the monitoring equipment. All equipment will be removed once the monitoring is complete. The rain garden is maintained by Homes for Islington who provide maintenance services for all of the borough's open space on social housing estates. This has certain implications with regards to the planting used as part of the rain garden.

This project is one of the first raingardens in the UK. This kind of technique is particularly important in inner city areas like Islington where there is little green space and our Victorian drainage system is under pressure as new homes are built and climate change brings heavier rainfall.

Who were the stakeholders involved in its implementation?:

There are multiple stakeholders involved with this project, showing the complexity that is evident even when small scale retrofitting of SuDS takes place, including:

- Islington Borough Council has led the development of this rain garden. This runs in parallel with the Borough's guidance on implementing SuDS. The Council agreed to the work on the basis that the rain garden would provide improved amenity to the local area.
- Thames Water is supporting the work, providing support and funds to allow for the monitoring of the rain garden.
- Middlesex University are responsible for the monitoring of the site. The monitoring will be carried out by a PhD student and work will focus on the volumes held by the rain garden, the quality of water entering and leaving the rain garden, and the soil moisture content recorded over a 12 month period.
- The rain garden was designed by Bob Bray (from Robert Bray Associates), a SuDS design specialist with many years experience of designing and building above ground SuDS across the UK in a variety of developments.
- Murphy, who are contracted to Islington Council to provide works on social housing estates, completed the construction of the rain garden as part of their corporate social responsibility and ongoing community work on the estate.
- The rain garden will be maintained by Homes for Islington who currently provide maintenance services on all of Islington's social housing estates.

Where did the funding come from?:

Islington London Borough Council commissioned sustainable drainage consultants Robert Bray Associates to design a pilot rain garden in the Ashby Grove development. Thames Water Utilities Ltd, known as Thames Water, is the private utility company responsible for the public water supply and wastewater treatment in large parts of Greater London and provides the funds to allow for monitoring the rain garden.

What were the barriers encountered and how were these overcome?:

A number of difficulties were encountered in implementing this small rain garden. Internal agreement within the council was needed to get the go ahead, including the Council's building control team, and this was only achieved through the hard work and persistence of a local champion. In order to ensure the rain garden would not have a negative impact on the neighboring building, a geotechnical investigation was carried out by an independent consultant engineer, which confirmed that the rain garden would be likely to have a beneficial effect in stabilizing the predominantly clay soils in the area. The complexity of stakeholders involved also led to some difficulties, with several areas of the council and Homes for Islington, who manage the estate, needing to be signed up to the project. Ensuring the contractor understood and was able to deliver the innovative project and timing the involvement of Thames Water and Middlesex University to set up the monitoring arrangement was also important.

Sources:

- Susdrain project database (http://www.susdrain.org/case-studies/case_studies/ashby_grove_residential_retrofit_rain_garden_london.html)

Annex 3. Methodology underlying the RECREATE evidence-based narratives on Nature-Based Solutions for Coastal Protection and Sustainable Urban Drainage Systems

The production of the two RECREATE narratives on Nature-Based Solutions NBS followed a process which was structured into two phases. In phase 1, a first draft of the narratives was produced based on a thorough literature review. Following reviewing and commenting by the European Commission's DG Environment, this draft was revised and improved, based on a review of available literature and on the collection of empirical data in two workshops and 8 interviews with international experts on the respective topic (4 on the topic of NBS for coastal protection and 4 on the topic of Sustainable Urban Drainage Systems). In the following paragraphs the setting, structure and content of the Workshops and Interviews will be explained in detail.

1. RECREATE breakfast- workshop at the ECCA conference 2015

Date: 12.05.2015, Time: 08:00 - 10:00
Location: Bella Center, Copenhagen (DK) Room 16

The objective of this RECREATE breakfast workshop was to exchange views on the use of sustainable urban drainage systems (SUDS) and nature based solutions (NBS) for coastal protection, as well as customized Climate Information Services. Invitations were sent out to topic-related panelists, session moderators and presenters of PowerPoint-presentations or posters at the ECCA conference. The workshop was attended by 21 participants. See

Table 21 for an overview of the workshop programme. Interest in RECREATE was high and after a group discussion, participants formed three round tables (the most popular being the SUDS table) and discussions were flowing well (see

Table 20 for an overview of the discussion-questions for the round tables on NBS). Participants were asked to note down their thoughts and inputs on reporting sheets, as well as indications on where to find additional sources information (e.g. scientific literature), which were collected afterwards to include into the analysis.

Table 27. Discussion Questions for the Two Round Tables on NBS During the RECREATE Breakfast-Workshop at the ECCA Conference

Sustainable Urban drainage systems	5. What are the differences between SUDS and piped drainage systems regarding cost-effectiveness? 6. Are you aware of any trade-offs to the benefits delivered by SUDS? 7. What barriers need to be overcome for upscaling SUDS and exploiting their full market potential? 8. What role can EU innovation policy play in enhancing the market penetration of SUDS?
NBS for coastal protection of cities	5. What are the differences between NBS and traditional coastal protection of cities regarding their cost-effectiveness? 6. What is the role of the private sector in promoting these NBS to coastal protection? 7. Where would the market potential for these NBS to coastal protection be highest in your eyes? 8. What barriers need to be overcome for upscaling these NBS and exploiting their full market potential?

Table 28. Programme of the RECREATE Breakfast-Workshop at the ECCA Conference

Time	Programme
08:15 – 08:25	Welcome, introduction to RECREATE and the purpose of the three parallel sessions: Martin Drews, Technical University of Denmark
08:25 – 09:25	Round table sessions facilitated by Ina Krüger, Ecologic Institute, and Martin Drews, Technical University of Denmark Introduction (10 minutes) then discussion of 4 questions (see above) Table 1 : Sustainable urban drainage systems Table 2: Nature based solutions for flood protection Table 3: Climate Information Services
09:25 – 09:50	Plenary session (round table sessions reporting back)
09:50 – 10.00	Closure: Martin Drews, Technical University of Denmark

2. Session on Nature Based Solutions at the 2nd RECREATE Strategic Workshop

Date: 24.09.2015, Time: 13:45 - 15:30
Location: Diamant Conference centre Brussels

At the 2nd strategic RECREATE workshop in Brussels, the two NBS narratives were presented and discussed, suggestions for improvement were collected and parallels with the other three narratives produced within the RECREATE projects so far (i.e. EBN on Selling Solar Services, EBN on Bioethanol from Residues and Wastes and EBN on Climate Information System Support of Adaptation Projects) were identified.

3. Interviews with International Experts on the topic of Nature Based Solutions

In order to gain insights deeper insight into the topic of EBNs, 8 interviews with international expert from the United Kingdom and the Netherlands on the respective topics (4 on the topic of NBS for coastal protection and 4 on the topic of sustainable urban drainage systems) were carried out. The purpose of these interviews was to collect additional information on cost-benefit evaluations of NBS carried out, to validate the narratives and to collect additional information for estimating the investment case and analyzing the innovation system functioning.
Interviews were held via telephone calls, lasting between 45 minutes and 1.5 hours, and the Chatham House Rule was applied, meaning that permission was asked to use the information obtained in the interviews in scope of the RECREATE project, but promising that neither the identity nor the affiliation of the interviewees would be revealed. The questions asked to interviewees are listed in Table 22 and

Table 23, respectively.

Table 29. Interview-Questionnaire: Nature Based Solutions for Coastal Protection

<table>
<tr><td colspan="2">About RECREATE and the aim of this interview:
I am conducting some research for the European Commission under a project called RECREATE. The purpose of this project is to derive an outlook and recommendations for future innovation and research policy priorities in the fields of climate, resource efficiency and raw materials, for example, for shaping the future research programme, including Horizon 2020.
We are investigating the global potential for the use of Nature Based Solutions for Protecting Cities from Flooding, through insight into specific case and research needs in this field, and expert opinions. Broadly, we are conducting interviews to gain a better understanding of:
the effectiveness, costs and benefits of nature-based solutions (NBS) for coastal protection as opposed to, or together with, traditional solution, that are the barriers to the a more wider use of NBS in coastal protection of cities, and
evidence on, or pointers to the Market potential of NBS in coastal protection

Warming up question:
Could you tell me about your research in relation to NBS in coastal flood protection?</td></tr>
<tr><td>Effectiveness, Impact</td><td>7. What evidence exists about the relative effectiveness of NBS for coastal protection? What research suggests that they perform better or worse than traditional solutions?
8. What are in your eyes the barriers for a more widespread implementation of NBS in coastal protection? What do you think are the reasons for choosing for NBS instead of a traditional solution in general?
9. What assessments of the cost-effectiveness of NBS in coastal protection as opposed to traditional solutions have been made? What do they tell us?
10. Which role do hybrid-solutions (which combine both NBS <u>and</u> traditional approaches) play?
11. Which role can the private sector play in the establishment of NBS for flood protection?
12. Do you have evidence on the jobs which can be created by NBS, compared to alternatives?</td></tr>
<tr><td>Examples of well documented cases[78] to be prompted into the questions above</td><td>18. What evidence do you have, or could point to, in relation to the implementation of a NBS solution in coastal protection (of cities) in NL and/or abroad? What was the funding construction for this NBS (private - public, who paid what?)</td></tr>
<tr><td>Market potential[79]</td><td>19. How do you assess the current and future market potential of NBS for flood protection in comparison with traditional solutions (2020-2050)?
20. What are the global applications of NBS, particularly in the face of climate change related events and sea level rise? e.g. South-East Asia)?
21. What is the transferability of knowledge from the EU to other countries (i.e. in ways that could capture a market for the constructors/designers)?
22. What are key countries for the application of NBS in coastal protection in your eyes?
23. Which other countries/institutes are developing expertise in this area? How could you quantify their relative success?</td></tr>
<tr><td>Research needs</td><td>24. What are the barriers which are preventing the potential of NBS for city protection being used - e.g. lack of awareness in decision makers, lack of construction expertise, etc?
25. What changes - e.g. in the state of knowledge, evaluation or demonstration projects could (or would be needed to) unlock global market potential?
26. Based on what we have discussed so far, what are in your eyes the research needs for NBS? Which topics should research funding focus on?</td></tr>
<tr><td>Concluding questions</td><td>27. Who else would you recommend me to interview?
28. What are leading institutes in other EU countries? (if not tackled above)
17. Would you be interested to be updated on the progress of the RECREATE work and can I call you again to clarify any matters which occur to me later?</td></tr>
</table>

Note: Objectives: Obtain hard information - based on appraisals or evaluations, about the various costs and benefits of NBS for coastal protection - particularly economic impacts, including jobs, and the current and potential for future market capture/revenue generation inside and outside the EU.

[78] This is to treat comment [ASJM(3)]
[79] This section treats comments [ASJM(1)] and [ASJM(2)]

Table 30. Interview-questionnaire: Nature Based Solutions for Sustainable Urban Drainage Systems

<table>
<tr><td colspan="2">About RECREATE and the aim of this interview:
RECREATE is a research network (long title: The Research Network in Climate, Resource Efficiency and Raw Materials), which is financed by the European Commission under the FP7 Programme. The project aims to assess the impacts of research and innovation in Europe and beyond and to derive an outlook and recommendations for future research priorities in the fields of climate, resource efficiency and raw materials, in particular under the Horizon 2020 research programme.

Within the scope of the RECREATE project, we are preparing a narrative on 'Sustainable Urban Drainage Systems (SuDS)'. Through this interview series we would like to gain a better understanding of the market potential and the economic benefits of SuDS. For this, we are interested in the effectiveness as well as the costs and benefits of SuDS (as NBS) compared to traditional engineered solutions, and we would like to gain insights into specific implementation examples. We are interested in the scope of SuDS use in Europe and worldwide, particularly as climate changes, and what are the barriers to wider use of nature-based solutions (NBS) to cope with stormwater events and flooding in cities.

Warm up questions:
What is your area of work? How does your work generally relate to SuDS? On what particular aspects have you been working with regards to SuDS?</td></tr>
<tr><td>Establishment of SuDS</td><td>4. What are the quantifiable differences between SuDS and piped drainage systems regarding the absorption of stormwater/reduction of peak flow? (Please provide figures, if possible)
4. Can you give specific examples of SuDS which have been implemented or cases in which SuDS would be or would have been appropriate (inside and outside Europe) ? (In these cases, which (green) infrastructures are needed to establish effective SuDS and how should they be connected?</td></tr>
<tr><td>Future market potential</td><td>4. What were the key drivers for implementing SuDS in the examples you mentioned in the previous question? (e.g., increase in stormwater/high precipitation in some urban areas exceeding the current capacities of pipe wastewater systems, multiple benefits resulting from using a nature-based solution)
4. How would you assess the future market potential of SuDS at EU level? At global level? (How many cities would benefit from retrofitting urban drainage systems and/or establishing SuDS? Are there relevant differences between developed and developing countries in the pre-conditions necessary to establish SuDS? What are the sources of evidence on which this kind of assessment can be made? Can you personally provide any estimates, numbers and relevant literature with regards to the future market potential of SuDS?)
4. What is the role for hybrid-solutions (which combine both NBS and traditional approaches)? How are these different from/similar to, better/worse, more feasible, etc. than SuDS?
4. What are the limiting factors to fully exploiting the market potential of SuDS? (e.g., lack of knowledge and share of information, lack of financing and buy-in from the engineering sector, current institutional arrangements, uncertainty about ownership and responsibilities).
4. What are potential solutions that could overcome these barriers?</td></tr>
<tr><td>Costs, benefits and effectiveness</td><td>4. What are the costs associated with establishing SuDS? (For SuDS this question is just meant to be a small exercise to prepare for the cost-effectiveness question; there is plenty of evidence on costs and benefits from case studies and literature)
4. What are the environmental and wider socio-economic benefits delivered by SuDS? (see comment following the question above). (If not covered: What can you say about the jobs generated by SuDS construction and use?). Does the pay-back period differ compared to alternatives?
4. Are you aware of any trade-offs to the benefits delivered by SuDS?
4. How would you assess the cost-effectiveness of SuDS in general and in comparison with traditional drainage systems (grey infrastructure)?</td></tr>
<tr><td>Link to policy and strategies</td><td>29. What synergies with development of other green infrastructure could reduce the costs of installation of SuDS?
30. What role do you see for government (at regional, national and EU level) in fostering the planning and implementation of SuDS?
31. What role can EU innovation policy play in enhancing the market penetration of SuDS?</td></tr>
<tr><td>Concluding questions</td><td>32. If you were making the business case for large scale investment in SuDS , what sources of information would you draw on? E.g. Are you aware of any studies, which examine or reference the damage costs resulting from urban flooding caused by stormwater (exceeding the capacity of piped drainage systems)?
33. What points (other than those we've already discussed) would you put forward to make that case?
34. Who else would you recommend we interview? (e.g., personal contact, expert in the field or similar topic, academic or researcher, industry player, municipal official, etc.)</td></tr>
</table>

4. Feedback from international expert interviewees on the draft narratives

In order to validate the compiled narratives on NBS, the draft versions were sent via email to all of the international expert interviewees in order to receive their feedback, supplementary inputs and comments. To date, 2 of the interviewees on the topic of sustainable urban drainage systems have responded and their feedback has been taken into account and integrated where appropriate. The received comments serve to support the information presented in the narrative drafts and strengthen the line of argumentation and data foundation in the final versions.

Annex 4. List of Case Studies Referenced in SuDS Narrative

Within the narrative, a number of implemented case studies were referenced to build the foundation of the lines of argumentation and data presented. These cases are listed below, highlighting their location and source(s) where further information may be accessed.

Table 31. Case Studies Referenced Within the SuDS Narrative

Case study location(s)	**Source**
Philidelphia, USA	MWH (2013)
Scotland	Ashley et al (2015)
Netherlands (Utrecht, Culemborg, Hertogenbosch, Arnhem, Haaksbergen, Enschede, Heerhugowaard, Amsterdam)	Birch et al (2008)
Malmö, Sweden	Naumann et al (2011b;) Kazmierczak. and Carter(2010)
Coventry, UK	MWN (2013)
Portland, USA	David Evans and Associates (2008)
UK	CIRIA database (http://www.susdrain.org/case-studies/)
New Zealand, USA, Sweden, Taiwan, Canada	International Stormwater BMP Database (http://www.bmpdatabase.org/)
UK, US, Sweden, Australia, Ireland and Malaysia	Dublin Drainage (2005)

5 Urban Climate Information Services—Copenhagen

Author(s):
Martin Drews (DTU)

Changes based on request of European Commission:
The following descriptions build on a previous narrative version, developed in December 2014 and published in March 2015[80]. It has been amended and refined due to the specific request of DG Research and Innovation to

a) More strongly separate the implementation of the climate information service in Copenhagen and its deployment e.g. in terms of the Copenhagen Adaptation Plan and its estimated costs and benefits
b) Collect further data from Copenhagen through a series of workshops and stakeholder interviews for a more detailed and multi-faceted picture of values added and lessons learned from innovating and implementing the climate information service and to identify key drivers and barriers e.g. to be addressed by policy interventions

In order to fulfill these requests, the following evidence-based narrative has been based on different sources of information, used jointly to document the innovative use of climate information services by the city of Copenhagen in the planning phase of the Copenhagen Climate Adaptation Plan.

Extensive desk research was initially conducted, collecting qualitative and quantitative evidence from relevant Danish and international sources e.g. primarily reports, minutes of meetings and workshops, strategy documents and journal papers. Part of this work is documented in the preceding RECREATE report published in March 2015. Based on the recommendations from the Commission mentioned above, we subsequently carried out a small number of semi-structured interviews with key representatives of some of the central actors in Copenhagen: the Technical and Environmental Administration (primary stakeholder, user), COWI (one of the main providers of climate services to the city), and Smith Innovation (SME, market research, representing the investors). Semi-structured interviews were conducted with:

- **Technical and Environmental Administration, Municipality of Copenhagen:**
  The Technical and Environmental Administration in Copenhagen is responsible for planning and implementing the city's Climate Adaptation Plan as well as for ensuring that Copenhagen will be carbon neutral by 2025. Together with the capital's water utility company (HOFOR), the Technical and Environmental Administration are presently the main stakeholders and users of climate information services.

- **Smith Innovation:**
  Smith Innovation is a Danish SME and consultancy firm working solely within the building industry. Founded in 2009 Smith delivers holistic analyses for trade organisations, funding agencies and governmental institutions that create the infrastructure for innovation in the building industry. In the role of serving as administrative secretariat for the "Klimaspring" campaign, Smith Innovation has recently carried out a large number of interviews serving as input to an extensive analyses of the Danish and international market for climate adaptation solutions, including climate services. "Klimaspring" supports the commercial development of new rainwater management solutions in

[80] http://www.recreate-net.eu/dweb/system/files/files/PublicDeliverables/RECREATE_D4.1-SEI_final_clean_0.pdf

existing densely populated urban areas including Copenhagen and provides professional and financial support to consortium-driven innovation throughout the work process from concept to marketing. The campaign has been funded by private philanthropic association and investor Realdania by 60 million DKK (approx. 8 million EUR).

- **COWI:**
  COWI is a leading northern European consulting group counting more than 6,000 employees worldwide that provides state-of-the-art services within the fields of engineering, environmental science, and economics with due consideration for the environment and society. COWI has a long record of collaboration with academia and provides a portfolio of different tailor-made "360°" type climate information services for different sectors, including services supporting current urban adaptation in Copenhagen.

We also included the findings of the following two workshops:

- **RECREATE breakfast- workshop at the ECCA conference 2015**
  Date: 12.05.2015, Time: 08:00 - 10:00
  Location: Bella Center, Copenhagen (DK) Room 16

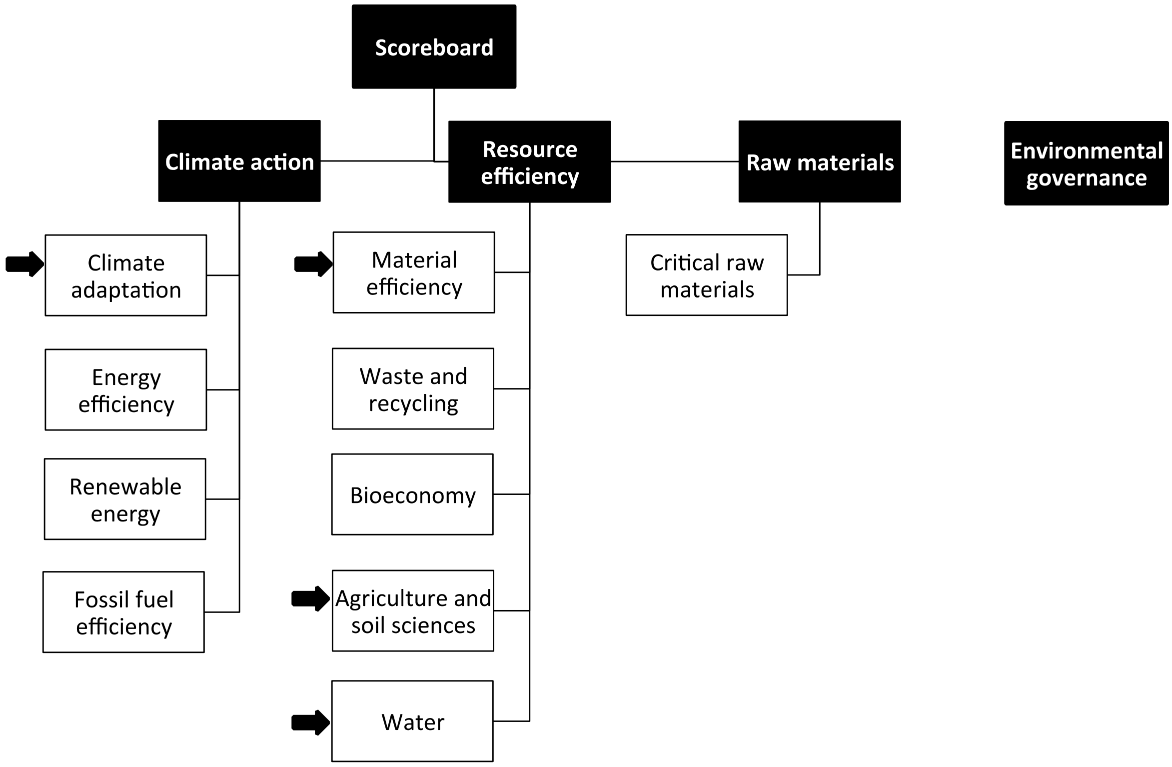
  This dedicated stakeholder workshop on "Nature Based Solutions and Climate Services for coastal and water adaptation in cities – opportunities for growth and employment" was organised by Martin Drews (DTU), and Ina Krüger (Ecologic), on behalf of RECREATE during the European Climate Change Adaptation Conference 12-14 May 2015 in Copenhagen. More information on this workshop may be found in the annexes of the narratives on nature-based solutions.

- **Session on Climate Information Services at the 2nd RECREATE Strategic Workshop**
  Date: 24.09.2015, Time: 11:30 - 12:45
  Location: Diamant Conference centre Brussels

  At the 2nd strategic RECREATE workshop in Brussels, the narrative on climate information services in support of urban adaptation projects were presented and discussed, suggestions for improvement were collected and parallels with the other three narratives produced within the RECREATE projects so far (see preceding sections) were identified.

Finally, we include here results collected during the Copenhagen Climate Solutions Annual Conference 2015 on 5 October 2015 organized by the City of Copenhagen and the Confederation of Danish Industry.

Links with RECREATE Scoreboard:



Climate action:
Reduced flood risks in cities, reduction of heat island effects

Resource efficiency:
Improved urban land use (e.g. green urban spaces) for multiple economic benefits

Note: Links are marked with an arrow.

5.1 The Narrative

Reliable and actionable climate information services, which integrate climate data and models with socio-economic assessments, are expected to scale-up the cost-effectiveness of climate change mitigation and adaptation solutions (European Commission Directorate General for Research and Innovation, 2015). Such services are also expected to facilitate improved decision-making for example on efficient mitigation policies, resilient infrastructures, novel business opportunities, and future investments. The vision of the European Union and a main pillar of Societal Challenge 5 is to enable European leadership in this emerging market and to stimulate its development globally, which in turn will contribute directly or indirectly to the European economy in terms of growth and job creation.

The urgency for cities to reduce emissions and build resilience to climate change is well recognized and strongly enhanced by the rapid growth of urban areas worldwide both in terms of population and economic importance (e.g. European Environment Agency, 2012). For this reason alone the specific market potential for climate information services in cities is expected to be high and this will overlap the need for improved urban planning tools stimulated by non-climatic drivers such as the growing global trend towards greener, smarter and more sustainable cities with a high quality of life. The current market for climate information services in urban areas however seems largely immature. Business opportunities are growing only at a slow pace and mostly within the existing sector for consultancy and engineering due to little sustainable demand from users. A main reason could be that approximately 72% of European cities are only in the initial stages of planning for adaptation (Reckien et al., 2015), and that main consumers and investments derive almost entirely from the public sector and local governments. In addition efforts are mostly disaster-driven with a primary focus on managing the risk of urban flooding due to heavy rainfall, rivers or sea water (Resilient Cities, 2014).

This specific narrative focuses on the use of climate information services to facilitate climate resilient urban planning in Copenhagen with a focus on nature-based solutions and to enable robust cost-benefit analyses for optimizing environmental, social, cultural and economic benefits of planned investments. A GIS (Geographical Information System) tool was developed to facilitate the screening of flood risk by integrating different sources of information in a spatially explicit form e.g. present and future climate data, urban topography, dynamical flood modelling and socio-economic factors. The tool presented here was instrumental in bringing together different administrative areas and competences, and in collecting the necessary funds for implementing the Copenhagen Climate Adaptation Plan from different parts of the city's budgets.

In the following we analyse the costs and (co-)benefits of using climate information services to support the development of the Copenhagen Climate Adaptation Plan, which is generally hailed as one of the world's most ambitious examples of urban adaptation and a model to learn from. Thus climate adaptation in Copenhagen will enable investments exceeding 1.5 billion EUR, and generate an estimated 15.000 new permanent jobs (City of Copenhagen, 2014). The tools and techniques tested in Copenhagen including the climate information services described here have so far demonstrated a significant potential for commercialization and are in the process of being transferred to a number of other cities including the city of New York.

To identify some of the drivers and barriers for further development of the market for urban climate services we have organized several workshops and also interviewed with a small number of key actors in Copenhagen representing a plethora of stakeholders from the private and public sectors. The interviews confirm a market currently dominated by consultancy/engineering companies and report reluctance from current market actors to change this business model – at least in the short term. The interviews attribute this in parts to the lack of real incentives for engaging in extensive collaborative research & development activities experienced by some commercial actors, who – unlike their academic partners – report that they are often not eligible to receive external funds but are mainly required to contribute to such projects by their own resources. In addition, the traditional opposition towards a general policy of open access to data and data products i.e. as a limiting factor to business development is found to be alive and well amongst existing commercial actors within the market of urban climate information services. Policy recommendations suggested include the need to further promote collaboration and build new modes of collaboration between commercial actors, academia, and end-users e.g. by providing a different set of incentives for businesses to enter co-production and co-development with academia and users; to set up city-scale demonstrators to help generate real-life market cases to generate narratives and best practices to be shared between cities; and to highlight and support the development of different financing models to stimulate adaptation action in European cities including the uptake of dedicated climate information services.

5.2 Understanding the Innovation System

The Innovation

Within a period of only five years, reoccurring cloudbursts, including the rare extreme events in August 2010 and in July and August 2011, have caused severe flooding and considerable damages in Copenhagen amounting to more than a billion euros in insured losses. In response the city recently initiated a comprehensive set of trans-disciplinary analyses to form the basis for implementing enhanced and cost-effective levels of protection against such future events in a changing climate (Cloudburst Management in Copenhagen, 2014). While the principal aim is pluvial flood protection, the City of Copenhagen has an ambition to increase the blue and green infrastructure in the urban space and hence an important secondary goal of these analyses were to pave to the way for the increased use of innovative blue and green infrastructure i.e. in terms of serving as a living laboratory and as an engine for sustained green urban growth.

The abovementioned analyses (cf. Table 32) were carried out along four main "tracks" and involved collaboration and co-production by a suite of different actors from the public, commercial and academic sectors, each track contributing one or more components to the overall adaptation assessment as outlined in Figure 26.

Table 32. Tracks of the adaptation assessment

Track	Main contributors
Rainfall, sea level	• COWI* (urban flood modelling, flood maps, digital elevation map) • Danish Meteorological Institute** (observed and projected data on climate and sea level) • University of Copenhagen** (projections of sea level rise)
Urban heat island effect	• DHI-GRAS* (remote sensing estimates of the urban heat island effect) • University of Copenhagen** (models)
Groundwater	• Rambøll Consulting* (modelling, observations)
Economy	• Technical and Environmental Administration*** (Municipality of Copenhagen) • COWI* (general valuation of assets, spatial mapping of assets) • University of Copenhagen** (models of costs and benefits of different adaptation options/green infrastructure with respect to e.g. biodiversity and amenity values)

Note: *commercial provider, **academic provider, ***user

Based on the above, a spatial planning tool and novel climate information service was commissioned by the City of Copenhagen and innovated by COWI Consulting Group in collaboration with several partners. Though focusing on flood risk the tool is designed to accommodate the screening of different planning and adaptation options and thereby to facilitate the optimal use of different elements of adaptive measures into the wider local master plans and urban development projects in Copenhagen. The tool was successfully used and has played a central role in developing the Cloudburst Management Plan of Copenhagen, forming the basis for outlining a portfolio of nearly 300 individual projects across each of seven catchment areas in Copenhagen. It is planned that the 300 projects will be implemented gradually over a period of 20 years, based on a prioritization to be amended as new knowledge (e.g. based on new or improved climate information services) or new technological innovations become available.

Urban adaptation assessments

Urban adaption assessments generally involve a series of steps as outlined in
Figure 26. Figure 26, connecting climate scenarios with socio-economic factors by means of different standalone tools ranging from physical models e.g. of urban drainage systems through impact assessments and cost-benefit analyses on e.g. health, bio-diversity or amenity values in the urban area.

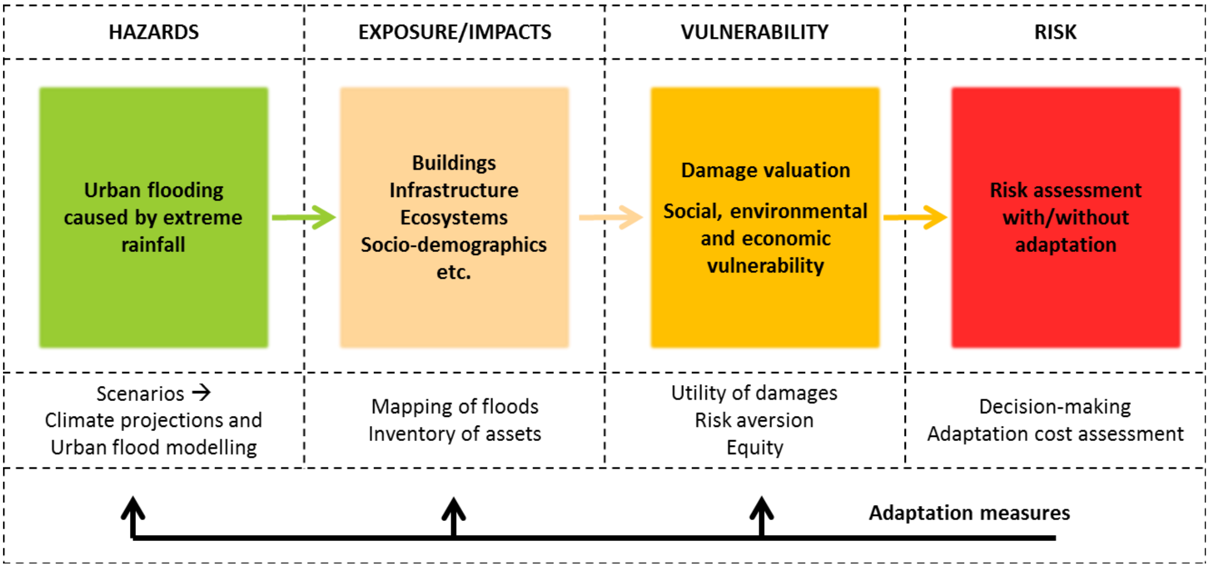


Figure 26. Schematic flow of an adaptation analysis

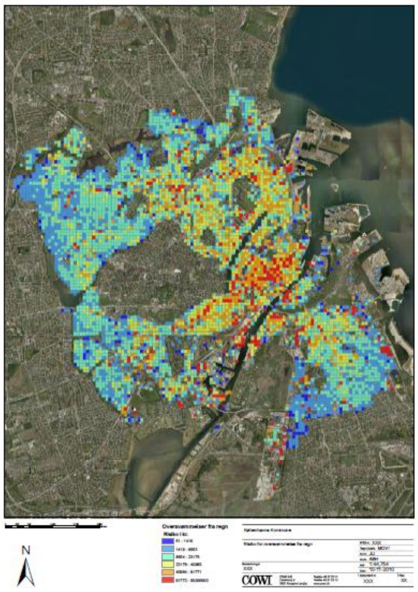
In such a framework, the relevant data or models for evaluating the increased risk due to climate change (Cardona et al., 2012) is a function of climate-related hazards through an inventory of elements in an area in which hazard events may occur (exposure) and their vulnerability to such adverse events. Typically, data and models are provided by different actors and experts including both commercial and academic entities. As a result high levels of expertise are often required to carry out the combined analyses needed by urban planners and adaptation decision-makers. The climate information service developed for the City of Copenhagen is inherently a visualization tool whose principal objective is to bring together different data sources and to make it feasible for e.g. the Technical Administration of Copenhagen to overlay different data layers and to carry out simplified screening analyses in terms of facilitating decision-making and implementation. The system is based on a Geographic Information System (GIS), which is a highly standardized technology readily available to urban planners and fully compliant with existing data systems across different administrative areas in Copenhagen. Similar visualization tools of ranging complexities have been developed by both academic and commercial institutions hence arguably the innovative value in Copenhagen lies in the depth of the data and in the penetration of the tool into the organization.

Data sources

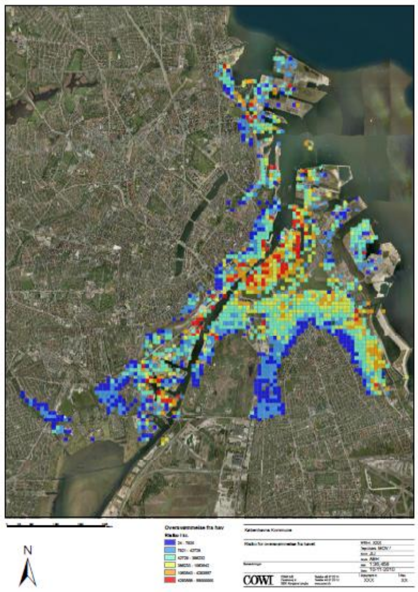
Climate data underlying the GIS platform has so far been provided by the Danish Meteorological Institute based on regional climate projections from the open repositories of the FP6-ENSEMBLES project (van der Linden & Mitchell, 2009) and observations and reanalysis products from the European Centre for Medium-Range Weather Forecasts (ECMWF). The resolution of these data products varied both spatially (from point measurements to 25 km horizontal grid resolution) and temporally (from daily to seasonal and annual means). Remote sensing data were provided by DHI-GRAS (a commercial operator) based on data products from the European Space Agency (ESA). Socio-demographic data were provided by the city of Copenhagen, Statistics Denmark and other sources.

Technology

COWI has developed a unique concept for screening of flood risk. The concept combines information of the topography (Digital Terrain Model), the sea level rise, the storm surge, the rainfall/runoff distribution in the area and knowledge of the economic values of property etc. in the area. The idea uses flood risk defined as vulnerability (in this case strictly economic value) times the probability of flooding in a given area according to risk assessment framework indicated in Figure 26 . The flood risk was first assessed by screening methods followed by prioritized detailed dynamic modelling of floods and economic consequences over the next 100 years.



Risk map for flooding caused by rain until 2110



Risk map for storm surges from the sea until 2110

Note: GIS maps illustrating the spatial extent and depth of the floods can be viewed together with areal maps showing economic values of properties, infrastructure etc. The GIS tools combine climate statistics, floods extent and damage cost etc. on a 100x100m grid. A series of planning options and adaptation activities were screened in this manner, and the most feasible in economic terms were demonstrated. The flood risk maps points out areas and spots which are most beneficiary to protect, and hence highlights which areas should be given highest priority for the most cost-efficient climate and climate change adaptation (COWI, 2011).

Figure 27. Exemplary risk map showing flooding from extreme rainfall

Current Market

Cities are generally recognised as key players in global and European adaptation efforts – in parts because the majority of people live in cities. Cities are also characterized by very high concentrations of assets, critical infrastructure and economic activities. In 2007 major urban areas generated about 60% of global GDP where about half came from 380 cities in developed regions (Dobbs et al., 2011). Cities themselves emphasize the urgent need for adaptation action (e.g. Resilient Cities, 2015). That said a recent analysis of the urban response to climate change in Europe – a highly urbanized region perceived as a world-leader in terms of environmental policies – reveals that 72% of large and medium-sized European cities have no dedicated adaptation plans in place and 35% no mitigation plans (Reckien et al., 2015). Part of this has been attributed to lack of clarity on how to implement these plans. For example, cities are unsure about the difference between disaster risk management and adaptation, which have different funding streams (Resilient Cities, 2015). Hence there is an urgent need for integration and comprehensive frameworks to make implementation easier and clearer for cities. The availability of climate information services to support urban adaptation plays an important role and will help to increase resilience by facilitating reductions in exposure and sensitivity and an increasing adaptive capacity of a city.

Based on the above it is clear that cities, as well as private companies and investors, represent a huge unrealized market potential. There are currently only few studies, which have tried to estimate the actual value of the global market for climate information services, and none, which have focused specifically on urban issues. According to recent analyses by Environmental Business International (EBI, 2014), the global market in 2012 for climate information services defined here as (i) Climate Risk Assessment & Analysis, (ii) Climate Adaptation Planning, (iii) Analytical & Information Systems was in the order of 729 million $ (650 million EUR). Conversely, the Government of the United Kingdom (2013) have estimated that the global market for commercial weather and climate services related to both adaptation and mitigation in 2010/2011 reached a value as high as 26.6 billion pounds sterling (36.5 billion EUR) of which 46% alone accounted for dedicated climate services. The two estimates are not directly comparable as they are based on an entirely different set of assumptions and rely on different methodologies yet each in its own right suggests a global market of considerable size.

The current market specifically related to different aspects of urban adaptation and mitigation is mainly found to be dominated by traditional engineering/consulting companies and SME's providing turn-key solutions to cities (Smith Innovation, 2012; Environmental Business International, 2014; kMatrix, 2011). This includes the development of dedicated urban climate information services, which typically is embedded into the already existing services delivered to cities. This is also true in the case of Copenhagen: for the development of the novel GIS screening tool COWI received a combined framework contract worth approximately 1.4 million EUR from the City of Copenhagen (source: COWI), which also included traditional consultancy, data collection and detailed dynamic modelling of flood risk.

The findings from existing market studies were confirmed by the results from our workshops and by stakeholder and expert interviews. It was also evident from these sources that major market actors do not consider the market for climate information services related to urban areas (as well as to a number of other sectors) to be "new" or "emerging" *but to be an integral component in already existing business models and services offered commercially for many years* to cities. In addition, it was pointed out that many cities maintain long-lasting economic relations with specific commercial actors, which is likely to play an important role for the current immature state and volume of the market for urban climate information services. In the case of Copenhagen leading Danish consultants such as COWI, Rambøll and DHI play this role. This can be seen as a market failure in the sense that newcomers will find it difficult to penetrate the market even with superior products.

5.3 Estimation of the Investment Case

Investment Strategy

As stated above, climate information services relevant for urban adaptation decisions to a high degree are already included into existing packages of "adaptation services" offered to cities and ultimately commissioned by public authorities or local governments. Within such a framework, innovating or improving these services are therefore not necessarily aimed at yielding a return-on-investments on their own but are typically linked to a larger portfolio of products offered by the provider.

In the case of Copenhagen, a number of large consulting companies dominate the market, including international consulting groups such as COWI and Rambøll, however, the commercial eco-system also supports a high number of SME's (Smith Innovation, 2012), typically within the water sector, which deliver different kinds of complementary services either directly to the city or through subcontracting. This market setup is not specific for Denmark, but takes on largely similar forms throughout Europe (Smith Innovation, 2012; kMatrix, 2011). Accordingly, the commercial development and exploitation of urban climate information services has so far mainly taken place within this arena and often within the confines of the larger companies. This may take place in collaboration with partners from academia or the public sector such as the Danish Meteorological Institute, and possibly co-funded by research and/or innovation funds provided by public donors at the national (e.g. by national research councils) or European levels.

As mentioned in preceding sections, the climate information service/GIS tool innovated in Copenhagen was originally developed as part of a large investment related to the Copenhagen Cloudburst Management Plan (Drews et al., 2015). The sole investor was the City of Copenhagen, whereas the main incentive was to ensure the cost-effectiveness of future investments in adaptation solutions i.e. through a "combined solution" which makes optimal use of sustainable urban drainage system as opposed to more traditional (and expensive) pipe-based solutions whenever feasible. In this picture the direct return-on-investment in terms of e.g. jobs and economic growth is not applicable; rather the return-on-investment follows from the massive co-benefits incurred by implementing the cost-effective adaptation e.g. as exemplified in Table 33, which in the case of Copenhagen are expected to yield expected "profits" in the range of 700 million to 900 million EUR.

Table 33. Economic assessment of costs and benefits of climate adaptation in Copenhagen

Flooding from heavy rainfall	Traditional urban drainage solutions	Combined solution (traditional + nature-based solutions)	Combined solution (Ministry of Finance method)
Damage costs without adaptation	2.2	2.2	2.4
Costs of adaptation	2.7	1.5	1.4
Reduction of damage costs	2.2	2.2	2.3
Profits	-0.5	0.7	0.9

Note: Investments in billion EUR (converted from DKK, 2013-prices, Copenhagen, November 2014). Values shown are estimated market prices including a net tax factor of 17% and a tax distortion loss of 20% based on prior economic analyses of the cloudburst and adaptation plans. Solutions are assumed to be implemented over a 20 year time frame with an additional 0.5% added in terms of operating expenses. The exception to this relates to private investments within property boundaries, which are assumed implemented over a time frame of 70 years. Numbers in the first two columns use a 3% discount rate. Conversely, the rightmost column uses the 2013 guidelines by the Danish Ministry of Finance, describing a decreasing discount rate.

In addition to the above, indirect returns-of-investment will be secured in terms of using the climate information services as part of an overall narrative aimed at strengthening the brand of Copenhagen and thereby to attract investors to the city in a broader perspective. This includes promoting the business proposition of the city's commercial partners (COWI, Rambøll, etc.) in order to facilitate new business opportunities to stimulate economic growth and job creation with the partners – and ultimately increased tax revenues for the city. As part of this strategy, Copenhagen co-founded the very successful "Copenhagen Cleantech Cluster" supported by European Union Structural Funds and Cohesion Funds, which is now part of the Danish CLEAN innovation cluster[81].

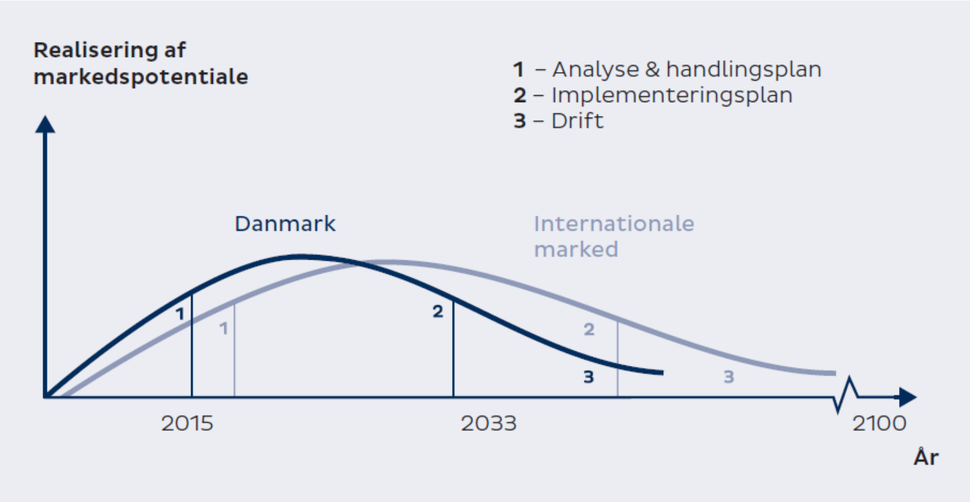
Future Market Potential

According to data from the World Bank about 75% of Europe's population of 508 million live in cities. For comparison the global average is about two thirds and in key markets such as the United States, China and Japan the numbers are 81%, 54% and 93% respectively (2014 numbers, web: data. worldbank.org). While the reduction of emissions presently seems to be the main concern for most cities, an increasing number of serious floods events and extreme heat waves throughout Europe in recent years have turned the spotlight also to adaptation. This is strengthened by and overlaps the trend towards green and sustainable cities and vice versa i.e. building climate resilience is generally also considered as a strategic part of sustainable urban development. As a result, many cities and local governments as well as private citizens and companies have started to invest in the development and implementation of adaptation measures at different scales, though most are only in the very early stages of adaptation planning (e.g. Reckien et al. 2015).

As already mentioned above (see "Current Market"), estimates of the global market potential for climate adaptation – not to mention the arena for climate information services on its own – are highly uncertain even for present day conditions. According to Environmental Business International (2014), the global market is expected to continue to grow towards 2020 by as much as a factor of three compared to the present. On the longer term a review by Smith Innovation (2012) based on a variety of international sources indicates that the size of the market for storm water management alone, which is a main concern for cities worldwide is expected to peak around the 2030's, and that services related to the implementation phase are likely to carry the highest potential. In this survey the following central markets are identified:

- High potential: The northern parts of west Europe (including Scandinavia) has a high economic density, in many places larger cities have grown together creating extensive urban areas dominated by large impervious surface fractions, a strong public sector and climate projections indicates significant increases in extreme precipitation events.
- Medium potential: Climate projections also indicates significant increases in extreme precipitation events however the northern parts of east Europe has a lower economic density than in the western parts of Europe and the largest cities are smaller.
- High potential: Parts of North America, particular along the east coast and west coasts, are dominated by extremely high economic densities and high (and increasing) levels of urbanization while climate projections suggest severe increases in the frequency and intensities of extreme precipitation. The public sector in general is weaker than in Europe, however, various case studies have not found this to negatively affect the market for climate adaptation in these areas.
- High potential: Large parts of Asia, in particular along the coasts of Japan, China, South Korea, and India, are dominated by urban areas, which generally are growing at a very rapid pace (except for Japan) and the economic densification in these areas is also extremely high and increasing.

[81] http://cleancluster.dk/



Note: Based on estimates from a variety of sources e.g. World Bank, UNFCCC, Environmental Business International, etc. Figure 29 from (Smith Innovation, 2012) reproduced with permission (in Danish). The x-axis shows the projected year, the y-axis the expected realization in market potential. The dark blue curve outlines the expectations for the Danish market, the light blue curve expectations for the global market. The three phases indicated by numbers are: 1 – Analysis & strategic planning, 2 – Implementation & planning, 3- Operations

Figure 28. Expected structural development of the global market potential for storm water management over time

Climate change and in particular extreme weather events impose severe risks on a wide range of critical assets in cities, including houses, business buildings, hospitals, roads, infrastructure, harbour facilities, health, ecosystems, historical and cultural values etc. As a result, the development and subsequent proofing and monitoring of adaptation plans are in general very complicated processes. Adaptation is also costly and high political local priorities are at stake in relation to city life, health, economics, etc. Climate information services can be expected to play a key role in all these aspects, which generally involves combining and disseminating highly trans-disciplinary information including detailed technical information e.g. future climate scenarios, hydrological modelling, physical planning, vulnerability models, and economic valuations of damages and of the costs and benefits of adaptation.

Employment Effects

In this study there is very limited evidence of new jobs being created as a direct result of establishing the climate information service discussed above. That said, COWI as well as many of their Danish and international competitors report (Confederation of Danish Industry, personal communication) that over the last few years they have had to expand their specialist staff considerably in order to accommodate increasing demands for their expertise and tools to assist cities worldwide with adaptation to climate change. Since however this increase is tightly embedded into more general business and market developments, no absolute numbers are available with respect to direct job creation effects due to climate information services.

Evidently, new jobs will be created as Copenhagen fully enters the implementation phase of the 300 planned interventions in the city. It is clear that the vast majority of these cannot be directly related to the innovated climate information services but to the implementation of the overall strategy made possible by this tool. The planned investments in climate change adaptation i.e. through traditional pipe-based and nature-based solutions are expected to create up to 13.000 new jobs within the time frame of its implementation ~ 20 years (Copenhagen, 2014). For comparison the total number of jobs in the private sector in Copenhagen in 2014 was ~230.000 (Data: Statistics Denmark). Also counting new jobs related to improvements and development of urban spaces this total amount increases to 15.000 new jobs. Most of these jobs will be created in the construction and engineering sectors, followed by the consultancy sector.

An estimated 13.000 respectively 15.000 new jobs will yield increased tax revenues in the order of 200-300 million EUR in Copenhagen. Interestingly, if one would generalize these estimates to future non-European markets with high potentials like North America and Asia, this would seem to imply that the majority of new jobs and tax revenues created, e.g. in the construction and engineering sectors, as a result of improved and more cost-effective decision-making on adaptation (and mitigation) in all likelihood will also be created locally in these regions.

Environmental and Social Benefits

The dominant characteristic of this climate information service – or at least the way it has been used in Copenhagen – is to promote the use of Sustainable Urban Drainage Systems as opposed to traditional pipe-based solutions; and more generally, to facilitate the "greening of cities" by the use of nature-based solutions. A comprehensive analysis of the environmental and social benefits of Sustainable Urban Drainage Systems can be found in Chapter 4, Section 4.3.

It is well documented (e.g. Gill et al., 2014; Hair et al., 2007; Naumann et al., 2014; Naumann et al. 2011) that the use of nature-based solutions in cities generally can be associated with a large number of environmental and social benefits e.g. in terms of ecosystem services, biodiversity and human welfare. For example green-blue solutions have the potential of reducing the "urban heat island" and to reduce pollutants for the benefit of human health. In a holistic context the type of climate information service developed in Copenhagen can also lead to improved urban planning by integrating aspects of urban development, socio-economic and demographic data with climate information e.g. paving the way for an improved social development in the city while at the same time building resilience towards the impacts of climate change and extreme weather events.

Risk maps produced through the use of the GIS tool have served as an anchor for interactions between the city's administration and members of the local government in Copenhagen and thus have helped to support the political and democratic process. Likewise, the climate information service has played an important role in disseminating the contents of the Climate Adaptation Plan to citizens of Copenhagen. The latter is particularly important due to the Danish financing model, where the largest part of the investments will be provided through increased water taxes made possible through national legislation (Copenhagen, 2014). Internally the use of the GIS tool as a common platform has helped to bring together different parts of the city administration and to frame adaptation efforts in Copenhagen around a holistic view on urban planning, as mentioned above, and to coordinate and optimize the use of funds across the different parts of the city's administrative areas.

Finally, the climate information service has contributed in the way of branding Copenhagen as an innovative and "green city". By facilitating the economic valuation of the city's blue-green solutions this climate information service has helped strengthen the image of Copenhagen and its ambitious climate plans, which according to the Confederation of Danish Industry has helped attract considerable global investments, and which have also in turn had a positive impact on Danish exports, in particular in the clean-tech sector. In this manner the brand of the Copenhagen Climate Adaptation Plan can arguably be said to promote a "greener" agenda also globally (e.g. Resilient Cities, 2015).

5.4 Innovation System Functioning

In the following we evaluate the seven functions comprising the framework of technology innovation systems (TIS) proposed by Hekkert et al. (2007) i.e. to highlight some of the drivers and barriers towards urban climate information services inferred from Copenhagen narrative. Each function has been scored by means of a five-point scale (1 – very weakly developed, 2 – weakly developed, 3 – developed, 4 – strongly developed, 5 – very strongly developed) based on the author's assessment.

Function 1. Entrepreneurial Activities (EA)

Many European cities have like Copenhagen experienced serious flash floods or urban flooding within recent years. As a result urban adaptation and decision-support is currently addressed by a considerable number of research and innovation actions both at the Member State level and by recent EU Framework Programs. Quite a few of these research and innovation actions have developed planning and/or visualization tools similar to the GIS tool used in Copenhagen and should be considered climate information services in their own right. Entrepreneurial activities concerning urban climate information services are however not restricted to academia. Interviews and workshop results confirm that operational tools for urban planning and adaptation have already for several years been developed by major engineering companies and tested within real-life projects. In this context climate information services which integrate climate data and models with socio-economic assessments are not really novel although it may be argued that existing tools in most cases are far from replicating the scientific state-of-the-art. Such tools are often bundled with traditional consulting services as part of a holistic 360° planning solution, exchanged between companies and cities in a market, which to some extent is influenced by the fact that a lot of cities like to maintain collaborations with specific suppliers. Hence it may presently be difficult to penetrate the market even with superior products. For this aim there is a clear absence of large-scale demonstrators to serve as best practice cases i.e. demonstrating the added value of climate information services as means to facilitate climate resilient urban planning with a holistic focus, including nature-based solutions. **Score: 3**.

Function 2. Knowledge Development (KDev)

Climate information services inherently depend on the (i) quality and availability of e.g. the physical and socio-economic data and models they are driven by; (ii) their ability to provide the user with the information (including about uncertainties) in a form which is easily accessible to him; and (iii) knowledge about the user's needs and objectives. The general availability of climate information e.g. in terms of climate model projections, impact models, observations, remote sensing, and reanalysis products have increased dramatically within the last decade. This development is expected to continue under the open source policies adopted by the European Union and a large number of Member States. Experts and stakeholders interviewed for this study jointly pointed out a general need for improving the general quality, accuracy and relevance of the different data sources and the models they rely on if climate information services are truly to become the "reliable and actionable" tools they are envisioned to be. The need for better interpretation of primary model output and for reducing the inherent uncertainties e.g. in climate and urban projections were highlighted by both the supply and demand side. Clearly, this will require sustained long-term investments in both applied and basic research within a number of different areas, including climate modelling and socio-economics. One research area was particularly highlighted in virtually all the interviews and both by commercial and academic actors: the need for standardized and improved valuation tools for assessing for example the economic value of implementing traditional "grey" infrastructure vs. blue-green infrastructure in a city, including both tangible and non-tangible values such as amenity value. The lack of suitable international consensus on how to carry out such analyses is found to greatly reduce the legitimacy of cost-benefit analyses and to pose a serious challenge for decision-makers in identifying the most cost-effective adaptation and mitigation solutions.

The experts and stakeholders also pointed out that in terms of urban climate information services the access to socio-economic data is also frequently a great challenge. Due to legal issues like data privacy, confidentiality or commercial interests it is in many countries often difficult to gain access to the relevant socio-economic and demographic data needed to make informed decisions, even when in anonymized form. **Score: 2**.

Function 3. Knowledge Diffusion through Networks (KDiff)

Cities have a long tradition of sharing information through networks and partnerships. For example the cities of Copenhagen and New York have recently signed a partnership agreement aiming to bring technologies developed in Copenhagen to New York and vice versa. European and global networks like the Covenant of Mayors and ICLEI (Local Governments for Sustainability) also provide excellent means for knowledge diffusion and market stimulation worldwide. Finally conferences, workshops and exhibitions both at a national, regional and international level like the bi-annual European Conference on Climate Adaptation (ECCA) plays an important role in knowledge diffusion.

The City of Copenhagen has a very active dissemination strategy, which is realised through these and other international networks. The dissemination strategy includes Master Classes in Climate Adaptation, which are taught to other cities in collaboration with leading Danish engineering companies, which again contributes to the commercial exploitation of services implemented in Copenhagen. Finally, Copenhagen also takes active part in European and nationally funded research and innovation projects. **Score: 5**.

Function 4. Guidance of the Search (GoS)

Large-scale innovation in the field of urban climate information services is unlikely to take place in the short term without public funding to support research and development activities (see Resources Mobilization). In 2015 the European Commission Directorate General for Research and Innovation published "A European research and innovation Roadmap for Climate Services". The roadmap outlines a number of planned policy initiatives and funding opportunities to be implementing through e.g. JPI Climate, Horizon 2020 (Societal Challenge 5), and the Copernicus Climate Change Service, to enable the growth of a sustainable climate service market, including its urban context.

In 2013 the Danish Government in agreement with the Local Governments in Denmark committed all Danish municipalities to carry out local analyses of the risks towards pluvial flooding due to extreme precipitation and based on this to develop climate adaptation plans. As a consequence of this policy intervention consulting companies including SME's delivering climate screening services have experienced significant growth and new jobs have been created to the extent that there is at the moment a shortage of skilled experts in Denmark within the area of climate change adaptation (Confederation of Danish Industry, private communication). **Score: 4**.

Function 5. Market Formation (MF)

As mentioned in previous sections the market for urban climate services is currently embedded into the much larger and well-established market for urban adaptation and presently dominated by traditional engineering/consulting companies. Based on several interviews it is quite likely that current market actors will therefore be reluctant to opt for different and more open business models to facilitate actual co-development and co-production as recommended in the Roadmap for Climate Services (European Commission Directorate General for Research and Innovation, 2015). A prerequisite for the formation of a new market structure is therefore likely to depend on policy interventions at least to some degree.

Another issue is related to scalability. Since climate information services related to urban adaptation by nature are highly customized products, some solutions are unlikely to be replicated in large scale. This will evidently affect the return of investments and hinder their entrance on the market. It will also serve to consolidate the current market structure dominated by consultancies. **Score: 2**.

Function 6. Resources Mobilization (RM)

Previous and current research on climate information services has mainly been funded by public sources including regional, national and European-funded actions, and mainly in the context of research. As more and more cities will begin to reduce emissions and adapt to climate change it is highly likely that the demand for urban climate information service will increase dramatically, which in turn should stimulate investments by the private sector. At the present however only few frontrunners – mainly larger European cities – are investing or are planning to invest large funds in adaptation, and many must adopt more or less "exotic" financing schemes to ensure sufficient funds for the implementation. In the case of Copenhagen approximately 90% of the funding will be procured through increased water taxes, whereas the last 10% will be found within the city's operation budgets in terms of savings due to the implementation of blue-green infrastructure (as opposed to pipe-based solutions) and by pooling resources from different administrative areas i.e. considering adaptation as an integral part of the city's sustainable urban development. With the exception of the insurance industry, investments from the private sector have so far mainly been restricted to philanthropic donors such as REALDANIA (Smith Innovation, 2012) and to internally R&D funded activities.

It is evident that this picture may be changing. New funding schemes have recently become available through Horizon 2020 (Societal Challenge 5), JPI Climate, Copernicus Climate Change Service, and other funding instruments also at the national level now specifically aim at stimulating the growth of new and existing commercial markets for climate information services across all sectors with a much higher share of consumption by the private sector (European Commission Directorate General for Research and Innovation, 2015). When asked about how they embrace these new opportunities, most of the stakeholders from the private sector interviewed in this study however stressed that in practical terms it is difficult for commercial actors to take part in these actions. This was attributed by some of the commercial actors we interviewed – mainly larger companies - to the lack of real incentives for engaging in collaborative research & development activities as they (unlike academic partners) frequently did not find themselves eligible to receive funds from public sources but in most cases were required to provide significant co-funding for such projects. Moreover when eligible for grants the amounts received did not prove to cover salaries. Some of the smaller SME's interviewed noted that the complex and time-consuming process of writing a grant proposal alongside the low rates of success in general deterred them from participating in externally funded research and innovation actions, as they simply could not fund nor had the expertise to do so within their limited budgets. **Score: 2**.

Function 7. Creation of Legitimacy (CoL)

The creation of legitimacy is one of the most important factors preventing the uptake of climate information services in the cities. Although positive results from cities like Copenhagen, Amsterdam, Hamburg, etc. have received a lot of attention there is still considerable concern amongst policymakers about the validity of climate projections and the value of analyses based thereof at the urban scale. To a large extent this seems to derive from the present state of knowledge (see Knowledge Development), where improvements in terms of quality, relevance and dissemination of the available information to stakeholder is needed. As a result in many places the usefulness of integrated cost-effectiveness and cost-benefit analyses to facilitate improved decision-making is highly questioned (e.g. Resilient Cities, 2014), and results collected by Local Governments for Sustainability (ICLEI) - a global network of more than 1,000 cities - recently indicated in some cities such analyses are disregarded entirely as part of urban planning.

Another crucial issue of legitimacy reported both by companies, researchers and customers is the need for assuring the validity of climate information services delivered commercially. COWI and other sources reported that customers often call for independent researchers, e.g. a professor at the local university, to be involved at least in the proofing of commercial end-products. Notable exceptions were those cases where the work itself was co-developed together with academic researchers or the commercial actors themselves possessed the status of a renowned research institute. Likewise most of the researchers who were engaged in this study have promoted the need for a scheme to assure the validity of climate information services based on the fact that most commercial actors and in particular SME's rarely possess the skills and expertise internally to ensure that innovations in the field of climate services are valid and developed in accordance with state-of-the-art and proper scientific practices. The creation of a quality assurance scheme for climate services is also promoted by the Roadmap for Climate Services (European Commission Directorate General for Research and Innovation, 2015). **Score: 1**.

Summary: Barriers and Drivers

Figure 4 summarizes the present state of the innovation system for urban climate information services inferred from the study of Copenhagen (as assessed by the author) based on the seven innovation system functions (as discussed above). The main findings are detailed below.

- Although the market for urban climate information services has clearly not yet matured it is beyond question that there will potentially be a larger demand for such services as cities worldwide have begun to invest more extensively in climate adaptation and mitigation. This in turn could be expected to lead to more investments from the private sector.
- Currently, the market for urban climate information services is dominated by consultancy/engineering companies. In this context climate information services, which integrate climate data and models with socio-economic assessments is not really an innovation. Similar services have been in place for many years, and major market actors including non-profit organisation like e.g. Tecnalia from Spain and Deltares from the Netherlands already offer holistic 360° planning solutions, which bundle this together with traditional consultancy. There is currently considerable reluctance from commercial market actors to change this business model in favour of a more collaborative model, and companies take advantage of long-lasting relationships with their customers.
- Highly customized climate information services may be difficult to replicate across cities for example due to differences in e.g. access to or availability of local socio-economic data caused by national legislation. This affects their ability to be upscaled, lowers the return of investments and hinders their market uptake.
- The diffusion of knowledge and best practice between cities is well developed and facilitated by extensive city networks both at global, regional and local scales.
- Some policy instruments like the Roadmap for Climate Services and national legislation are already in place to strengthen the uptake of climate information services also in an urban context.
- Some commercial actors find it difficult to engage in collaborative externally funded research & development activities, since they are often not eligible to receive funds but are required to contribute to projects largely by their own funding.
- There is still need for considerable knowledge development and research to create legitimacy and underpin the validity and relevance of climate information service to stakeholders and customers. This

will require sustained long-term investments in both applied and basic research within a number of different areas and sciences (and their interactions), including climate modelling and socio-economics.

- To ensure the legitimacy of (urban) climate information services it is necessary to develop an internationally acclaimed quality assurance scheme.

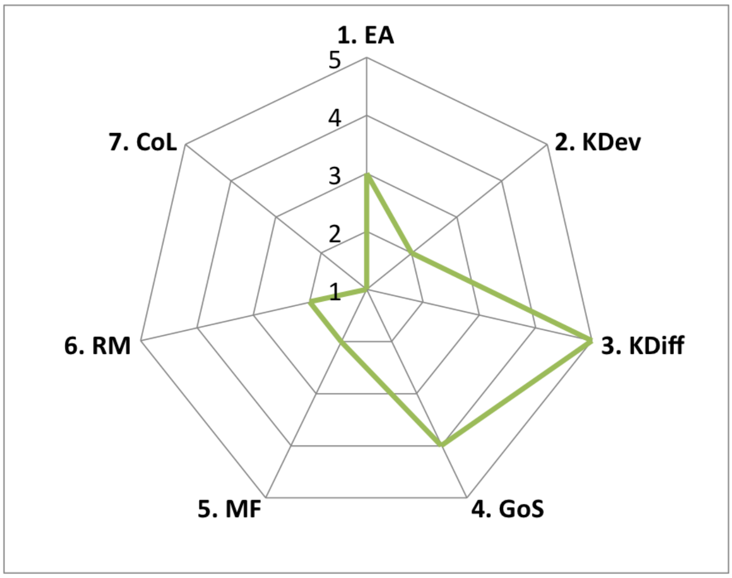


Figure 29. Fulfilment of Innovation System Functions: Urban Climate Information Services—Copenhagen

5.5 Further Evidence on the Innovation System

An issue, which was brought up both in the interviews and in the workshops and not captured by the innovation system functions is the well-known dilemma of intellectual property rights vs. open access, which is highly relevant in terms of climate information services. Several stakeholders made the strong point that intellectual property rights could play a significant role for the commercial exploitation of these services. At the present incentives for business actors to engage in co-development and co-production of climate information services with academia and users are often valued to be low, since they do not generally obtain exclusive rights to the outcomes, which can make the products difficult to commercialize. Another limiting factor mentioned is the notable differences in objectives in between academia and industry. It was suggested that the "academic business model" where success is measured primarily in terms of e.g. publications in leading journals in some cases prove detrimental to commercial objectives. One of the interviewed experts reported from a collaborative research project, where joint results were academically embargoed for more than a year due to the requirements of the scientific journals, where results were to be published. In this example it was impossible for the commercial partner in the project to fulfil their contractual obligations with a third-party customer, and hence the partner had to put together an entirely new product based on outdated information. Overall to attract more funding and interactions with the private sector several stakeholders recommended that new modes of collaboration between commercial actors, academia, and end-users could be developed to better accommodate both academic and commercial objectives.

5.6 Policy Implications

The European research and innovation Roadmap for Climate Services published in March 2015 aim at developing climate information services in all sectors and to make Europe a world market leader. The development of actionable climate services also comprises a main component of the Horizon 2020 work program for Societal Challenge 5 and of the Copernicus Climate Service program.

The urgency for cities to adapt (and mitigate) to climate change is high on the political agenda following the repeated instances of extreme weather events throughout Europe, in particular related to flooding. Thus current economic incentives in terms of avoided costs are already considerable and are very likely to grow with climate change. Some European cities like Copenhagen are frontrunners and provide hard evidence of the economic benefits by combining climate adaptation and mitigation with sustainable urban development. The development of tailor-made climate information services integrating climate information with socioeconomic data and models is crucial in order to facilitate improved decision-making in cities e.g. towards urban planning, resilient infrastructures and future investments and such tools will be needed to realize the full potential. Urban climate information services may also serve as an important factor in the large-scale uptake of nature-based solutions in cities, e.g. by helping to assign value to these innovations as opposed to more traditional solutions.

Some of the main drivers for innovation and uptake by the market are:

- Increased risk levels as climate change impacts in cities accelerate and are enhanced by the growth and increased densification of people and assets in urban areas.
- Rapid diffusion of knowledge and narratives between cities.

Conversely, some of the main barriers are:

- This is not a new market, the offering of adaptation services of varying complexity are already offered commercially by consulting and engineering companies worldwide, and at the same time there is a trend for cities to maintain long-lasting relationships with specific market actors.
- The legitimacy of urban climate information services needs to be created through further knowledge development and certification systems to ensure potential customers that services comply with state-of-the-art and proper scientific practices.
- The demand for urban climate information services is almost entirely dominated by the public authorities. While this demand could be expected in increase in the coming years as prompted by national and international policies, increased risk levels and increased public demand new funding schemes will be needed both in terms of procuring additional funding from the public sector, through public-private partnerships and from the private investors.

A series of policy recommendations at the European level has already been proposed by the European Commission in the Roadmap for Climate Services developed by the Directorate General for Research and Innovation; most of policy interventions identified in this study confirm or elaborate these previous findings:

- There is a need to highlight and support the development of new and existing financing models to stimulate further adaptation action in European cities including the uptake of dedicated climate information services.
- There is a need for sustained long-term investments in both applied and basic research within a number of different areas related to urban issues, including climate modelling and socio-economics.
- To help mature the market for urban climate information services it is recommended to set up city-scale demonstrators to generate market cases, narratives and best practices to be diffused between cities.
- To stimulate true co-production and co-development between commercial actors, academia, and end-users in the light of the existing market dominated by consulting companies it is suggested to create additional incentives and to analyse how existing barriers for collaboration between research institutions and commercial entities come into play and how this might impact the implementation of H2020.

Lastly, it is strongly recommended for the policy level to establish international standards for climate information services for example in the form of an internationally acclaimed quality assurance scheme. This should be done to ensure that services delivered commercially conform to what at any point in time may be described as sound scientific and engineering practices, e.g. in terms of interpreting correctly the results of climate model simulations and socio-economic models, and to ensure fair competition between market actors.

References

- Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh (2012). Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.
- Cloudburst Management in Copenhagen, report by City of Copenhagen, November 2014.
- COWI (2011). Copenhagen Climate Adaptation Plan. Web: http://www.cowi.dk/menu/project/Vandogmiljoe/spildevand-og-klimatilpasning/Klimatilpasning/Documents/CopenhagenCCAplan-juli2011.pdf (Accessed 22-10-2015)
- Dobbs, R., Smit, S., Remes, J., Manyika, J., Roxburgh, C., Restrepo, A. (2011). Urban world: Mapping the economic
- power of cities. Report, McKinsey Global Institute, March 2011.
- Drews, M., Kropp, J., Krummenauer, L., Lázaro Ruiz, J. M., Halsnæs, K (2015). Evidence-Based Narratives: Climate Information Services. Report produced by the REsearch network for forward looking activities and assessment of research and innovation prospects in the fields of Climate, Resource Efficiency and raw mATErials (RECREATE), March 2015.
- European Environment Agency (2012). Urban adaptation to climate change in Europe. Challenges and opportunities for cities together with supportive national and European policies. EEA report No 2/2012.
- Environmental Business International Inc. (2014). A Climate Change Industry Business Segment Review. EBI Report 4800: Emerging Business Opportunities in the Climate Change Adaptation Industry. Climate Change Business Journal. San Diego, USA.
- European Commission, Directorate General for Research and Innovation (2015). A European research and innovation Roadmap for Climate Services.
- Furrer, B., Hoffmann, V., Swoboda, M. (2009). Banking & Climate Change – Opportunities and Risks. An Analysis of Climate Strategies in more than 100 Banks Worldwide. Report. ETH Zurich, ZHAW Zurich University of Applied Sciences, SAM.
- Klimatilpasning og investeringsredegørelse (Climate adaptation and investments), report by City of Copenhagen, November 2014 (in Danish)
- kMatrix Ltd (2011). Global Weather and Climate Services. Commercial After Market 2010/11. Report, December 2011.
- Gill, S., Handley, J., Ennos, A., and Pauleit, S. (2007). Adapting Cities for Climate Change: The Role of The Green Infrastructure. Built Environment 3 (1): 115-133.
- Hair, L.; Clements, J.; Pratt, J. (2014). Insights on the economics of green infrastructure: A case study approach. Water Economics Federation, WEFTEC 2014: 5556-5585.
- Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., 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
- IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.
- Máñez, M., Zölch, T., Cortekar, J. (2014): Mapping of Climate Service Providers - Theoretical Foundation and Empirical Results: A German Case Study, CSC Report 15, Climate Service Center, Germany
- Naumann, S., Kaphengst, T., McFarland K, Stadler, J. (2014): Nature-based approaches for climate change mitigation and adaptation. The challenges of climate change - partnering with nature. German Federal Agency for Nature Conservation (BfN), Ecologic Institute, Bonn
- Naumann, S., Anzaldua, G., Berry, P. et al. (2011): Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2. Brussels; European Commission.
- Reckien, D., Flacke, J., Olazabal, M., & Heidrich, O. (2015). The Influence of Drivers and Barriers on Urban Adaptation and Mitigation Plans—An Empirical Analysis of European Cities. PLoS ONE, 10(8), e0135597
- Resilient Cities (2014). European cities adapt to climate change. Open European Day at Resilient Cities 2014 – Conference Report, 2014.
- Resilient Cities (2015). Global developments in urban adaptation and resilience. Resilient Cities Report 2015 (based

on the proceedings of the 6th Global Forum on Urban Resilience and Adaptation 8 - 10 June 2015 in Bonn, Germany.

- Rogers, D.P. & Tsirkunov, V.V. (2013). Weather and Climate Resilience. Effective Preparedness through National Meteorological and Hydrological Services. World Bank, 2013
- Scoping Paper for Horizon 2020 Societal Challenge 'Climate Action, Environment, Resource Efficiency and Raw Materials'. Annex 14 (2014). Working document presented to the Programme Committee for the Horizon 2020 Specific Programme
- Skybrudsikring betaler sig - økonomi for skybruds- og regnvandshåndtering af København (Protection against cloudbursts pays off – economic considerations for handling cloudbursts and rain water in Copenhagen, report by City of Copenhagen, November 2014 (in Danish)
- Smith Innovation (2014). KØBENHAVNS KLIMAKARRÉ. Idékatalog. Behovsafdækning og løsninger del 1 og 2 (Copenhagen Climate Block. Ideas. Requirements and solutions part 1 and 2). Report by Smith Innovation, December 2014 (in Danish).
- Smith Innovation (2012). Markedets vej. Analyse af markedspotentialet for klimatilpasning (An analysis of the market potential for climate adaptation). Report by Smith Innovation, November 2012 (in Danish). Contribution to the Klimaspring" initiative (see http://www.klimaspring.dk/in-english)
- Smith Innovation (2012). Nye løsninger. Virksomhedernes vilkår og muligheder for udvikling (New solutions. Potentials and conditions for company growth). Report by Smith Innovation, November 2012 (in Danish). Contribution to the Klimaspring" initiative (see http://www.klimaspring.dk/in-english)
- The Government of the United Kingdom (2013)). Space Innovation and Growth Strategy. Leadership in Climate Technologies & Services. Executive Summary (p. 16). London, UK.
- United States Agency for International Development (USAID) (2013). The value of climate services across economic and public sectors. A review of relevant literature. Washington, USA.
- van der Linden P, Mitchell JFB (eds.) (2009) ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK. 160pp
- World Meteorological Organization (WMO) (2011). A global framework for climate services – empowering the most vulnerable. Report of the high-level taskforce for the global framework for climate services. WMO No. 1065.