“NAture Insurance value: Assessment and Demonstration”

NAIAD

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Deliverable 4.2

Costs of infrastructures: elements of method for their estimation

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EXECUTIVE SUMMARY

Life cycle costs (LCC) are also named Total Cost of Ownership (TCO), which considers “total cost of acquisition, use/administration, maintenance and disposal of a given item/service”. In relation to NAIAD task 4.1, the LCC methodology corresponds to the calculation of ‘implementation costs’. While Life Cycle Costs for grey infrastructures assets are greatly standardized and contractors and procurement authorities count with databases with context-specific cost figures per unit for different types of assets and expected distribution of Capital Expenses (CAPEX) versus Operative Expenses (OPEX); such level of knowledge is not yet in place for Nature Based Solutions (NBS). It is for this reason that in this deliverable, after introducing the general LCC methodology, we will focus on working out this generic methodology for NBS.

We will assess the life cycle costs of NBS by providing an overview of the temporal and spatial distribution of costs related to NBS. Compared to grey solutions, NBS are expected to have different types of maintenance and asset management tasks. Besides that, green options contain a share of nature’s volatility and adaptability, due to their biophysical characteristics, resulting in a different risk profile. Different costs and risks influence the structure of financial liabilities, requiring different types of partnerships between public, private and community actors.

LCC information can support an argument for cost-effectiveness, i.e. lower costs generating a similar functionality, compared to other infrastructure solutions, which stimulates investment. In this deliverable we tailor the general LCC methodology for the specificities of NBS and produce a general guideline for demo cases to calculate in a standardized way the TCO of NBS which could be then integrated in the cost-benefit analysis suggested in Task 4.1

Section 2 introduces the generic life cycle costing concept methodology and its relation with the bankability of infrastructure projects. Section 3 introduces how this methodology is applied to NBS, the challenges that may be encountered as well as the key cost generating activities and cost determining factors depending on the functions they are designed for, as well as other key design variables and design constraints (e.g. location where they have to be deployed). Section 3.6 presents the current available cost figures and empirical data for NBS implemented around the world. These figures could be used by the demo’s either to cross-check their initial calculations or to generate a first rough estimate of the TCO of these solutions.

Section 4 consolidates the cost drivers and elements into a single framework. Section 5 concludes and presents key methodological considerations when calculating LCC and TCO of NBS versus grey solutions.

1. GENERAL CONTEXT: NAIAD OBJECTIVES

NAIAD (Nature Insurance Value: Assessment and Demonstration) is a H2020 European project (started in December 2016) dedicated, to assess Nature Insurance Value. The **NAIAD** project aims to operationalize the contribution of ecosystems to society's resilience concerning water risks, and giving particular attention to extreme-water-related disasters in Europe and beyond. The goal is to develop a methodology based on gathering existing knowledge and developing new knowledge and methods (operational objective), to characterize the resilience of ecosystems including uncertainty in assessment to inform decision processes on mitigating risks. In relation with other partners, the proposed holistic approach will integrate social, economic, environmental issues in spatial evaluation of the protective role of ecosystems that consider the effectiveness to reduce risks, their vulnerability and long term sustainability.

NAIAD focuses on the insurance value of ecosystems, i.e. "the value of the sustained capacity of ecosystems to maintain their functioning and production of benefits despite any disturbance"[1,2] specifically on benefits regarding water-related disaster mitigation. Ecosystems protect but are also impacted[3] by storms, wildfires, diseases, climate change, etc. Specific management operations might increase their resilience, although possibly involving operation and management costs[4]. NAIAD aims to **bring evidence of the ecosystem protection roles, provide integrated hazard assessment methods, inclusion of social risk perception and preferences, and tailor innovative business models and finance to consider the insurance value of**

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[1] "The system itself having the capacity to cope with external disturbances and includes both an estimate of the risk reduction due to the physical presence of an ecosystem (e.g. area of upstream land/number of downstream properties protected) and the capacity to sustain risk reduction (i.e. the resilience of the system)" (EC, 2015). "An ecosystem's ability to maintain its basic functions and controls under disturbances, is often interpreted as insurance: by decreasing the probability of future drops in the provision of ecosystem services, resilience insures risk-averse ecosystem users against potential welfare losses". Baumgärtner and Strunz (2014).

[2] Definition retained by the European Commission in the document: "Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities", 2015.

[3] It worth being stressed that storms, wildfires and other "catastrophes" are an integral reset mechanism, a natural ecosystem management measure that enables the transition from one succession stage of an ecosystem to the next or even helps keep an ecosystem healthy by eliminating old, diseased or exotic elements from the system.
From an ecological point of view, they are not catastrophes, but rather mere essential processes that sustain the dynamic equilibrium and diversity of natural ecosystems and consequently their resilience, since natural resilience is drawn from diversity of functions and interactions of abiotic and biotic elements.
When using ecosystems for protection, we rely on specific functions of specific succession stages of that ecosystem and we aim to artificially maintain that succession stage which offers the most protection or the ecosystem services that we require. The disturbance brought by storms, wildfires, diseases and climate change may curtail some key ecosystems services and are consequently perceived as negative from a societal point of view. Further works of NAIAD, for example on forest wildfire will bring elements on the protective service perturbation, best way to deal with them and best ways to manage ecosystems and risks sustainably: Nature-based solutions must integrate these aspect of ecosystem dynamics.

[4] Please note that at present there is little data on the differences in terms of O&M costs of nature based solutions as compared to standard (hard) infrastructure.

ecosystems. NAIAD is organized in 10 work packages (WP). The present document is the first deliverable of WP4: Economic approaches to the insurance value of ecosystems.

WP4 - Economic approaches to the insurance value of ecosystems [Months: 1-36]
Partners involved: SIWI, BRGM, ERCE, GeoEcoMar, IRSTEA, Deltares, CCR, ISKRIVA, UPCT, UNS, and ICA. The objective of this WP is to gather and adapt state-of-the-art methods and knowledge to evaluate with economics the insurance value of ecosystems. It will build on existing approaches (including insurance industry methods) and data when they are relevant to estimate the global insurance value of ecosystems in case of water related risks.

2. OVERVIEW OF TASK 4.2 ESTIMATION OF LIFE CYCLE COSTS FOR DIFFERENT ALTERNATIVES

Objectives: WP4 is organized in 5 tasks, the present document is the deliverable for Task 4.2.

Task 4.2. Estimation of Life Cycle Costs for different alternatives (grey, green and hybrids) (Lead: Deltares, Collaborators: ICA) (Month 1-12)
This task will look at the Life cycle costs (LCC) assessment of measures and total costs of ownership (TCO) (BAU, green, grey and hybrid) and the differences in their distribution along the entire Lifecycle. Given the rather different type of "maintenance" and "asset management" tasks involved when working with nature - also is expected that different types of partnerships and risk allocation between Public, Private and Community actors will be required for a successful implementation and continuous service delivery. In this deliverable we concentrate on the negative cash flows that make part of the overall "Cash profile" of different measures; which are the ones calculated via a Life Cycle Costs Analysis. To the extent possible we will also take into account the financial consequences of liabilities; green options bring about other types of risk and if these risks are materialized they will be reflected as additional costs. Positive effects stemming from NBS can be referred to in order to illustrate their comparative cost-effectiveness NBS versus grey alternatives. The methodology for Life Cycle Costs calculation will serve as a guideline for demo cases to calculate in a standardized way the costs of the alternative Nature Based Solutions and Disaster Risk Reduction measures they are considering to implement. In this deliverable, after introducing the general LCC methodology, we will focus on working out this generic methodology for Nature-Based Solutions.

3. LIFE CYCLE COSTS OF NBS FOR WATER SECURITY

LCC METHODOLOGY

Sustainable delivery of infrastructure service requires financial means to keep the infrastructure operational over time. In order to assess the financial viability and affordability of alternative measures for DRR, understanding of the costs of the entire life-cycle of an infrastructure asset is required. LCC entails all costs to be incurred during the lifetime of a product, work or service.

Fonseca et al. (2011) provide six definitions of cost components used in the LCC methodology:

1. Capital expenditure: The capital required for constructing infrastructure, including costs such as design, procurement, delivery, installation etc.

2. Operating and minor maintenance expenditure: this includes regular, recurrent expenditures on maintenance to ensure the infrastructure operates at design performance. Major repairs or renewals are not included as they are not defined as recurrent. In practice, distinguishing between recurrent and non-recurrent can be difficult.

3. Capital maintenance expenditure: these costs include activities that go beyond 'regular' routine and maintenance related to keeping the system operational, *e.g.* asset renewal, replacement and rehabilitation. Estimating these costs may be based upon the risk of infrastructure failure.

4. Cost of capital: costs related to financing a project, *e.g.* interest or dividends.

5. Expenditures on direct support: costs related to support activities directed to local-level stakeholders, users or user groups. For example, capacity building at the local government level to ensure adequate planning, investment and monitoring.

6. Expenditures on indirect support: costs related to support activities not directly linked to an asset. For example, costs for setting up sector-wide regulation standards.

Besides these components, **environmental externalities** could be included, which contain effects on the environment surrounding the infrastructure that imply costs, *e.g.* habitat destruction or ecosystem disturbance. For estimating externalities system boundaries need to be defined to determine which effects will be included or excluded in the financial analysis. These effects can be particularly relevant for the LCC of NBS, since NBS can operate in better harmony with ecosystems vis-à-vis grey infrastructure and are expected therefore to incur in lower environmental costs.

Environmental externalities will become part of TCO if these are captured and internalized. According to a pricing mechanism, externalities can materialise into a monetary compensation that the implementing entity needs to transfer to another entity which is then invested in mitigation measures, *e.g.* mitigation banking.

Whether an environmental externality does translate in an additional cost item or not will depend on the national regulation. Take for example the Port of Rotterdam extension project: Masvlakte 2. The construction of Maasvlakte 2 resulted in a loss of natural environment, for which parties were legally required to compensate. As a consequence, a new sea bed protection area of 25,000 ha, several rest areas for birds and 35 ha of new dunes were constructed (Port of Rotterdam, 2008). The advantage of implementing a NBS versus a grey alternative can be that negative environmental externalities will be lower, which can reduce the compensation costs.

A number of factors influence the magnitude and distribution of LCC along these seven categories.

Firstly, infrastructure functionality can vary (*e.g.* flood protection, drought prevention), implying differing cost profiles. Secondly, the desired level of risk reduction or the level of service required (in case other functions beside DRR are required) influences design standards, which are related to different cost levels (*e.g.* the highest the level of protection desired, the highest the quality and costs of the infrastructure).Thirdly, activities necessary to build and maintain the infrastructure asset depend on the type of infrastructure (*e.g.* green, grey) and method for performing these activities (*e.g.* construction methods, types of materials, etc.).

Fourthly, location specific components are relevant, even more for NBS versus grey infrastructure as these solutions concern relatively more open systems and require often larger areas of land for their implementation. For example, identical infrastructure assets can have different costs due to different labour or land acquisition costs. Also depending on local specific conditions such as soil types, terrain and hydrologic conditions the implementation and operation of a green/grey infrastructure project may involve a different mix of risks; which will require additional investments or “risk control measures” to mitigate them.

A correct identification of LCC provides the information needed to keep systems functioning permanently. Creating a temporal distribution of expenditures will help in the generation of a ‘cash profile’ for a NBS project, at least the negative ones. The cash profile can subsequently be completed to include all forms of income, *e.g.* tariffs or debt, something is dealt with by Work Package 7. The cash profile of a project gives an indication of the profitability of investing in a project (i.e. Project Internal Rate of Return) as well as an indication on whether the project company undertaking the implementation of the NBS will be able to make all necessary payments while making the necessary operational and maintenance investments to ensure that the infrastructure remains operational and delivering the required level of service.

Using LCC for an adequate management of cash out- and inflows related to infrastructure can underpin bankability. Bankability implies the distribution of costs and revenues for a borrower are sufficiently balanced for lenders to finance the project. If LCC are determined correctly one can estimate future financial risks and prepare appropriately by developing a proper funding strategy (*e.g.* earmarked taxes, tariffs or transfers) and a risk mitigation strategy to limit the financial consequences of project downsides.

3.1 LIFE CYCLE COSTING OF NBS: A METHODOLOGICAL GUIDE

This section aims to describe the different methodological elements that are important for determining the LCC of a NBS. Firstly, one can employ existing data on the LCC of NBS to develop an estimation. However, discrepancies exist regarding information availability per type of NBS, which is described in section 5.3.1. Secondly, the desired degree of functionality of an NBS and the accompanying cost generating activities influence the LCC, details and examples are presented in section 5.3.2. Thirdly, section 5.3.3 illustrates how decisions made regarding the design and location of an NBS create different LCC profiles.

3.1.1 Methodological choices for the development of the guidelines

As previously explained there are a number of important factors that influence the magnitude and distribution of LCC along the seven categories: 1) Capital Expenditure (CAPEX), 2) Operating and minor maintenance expenditure (OPEX), 3) Capital maintenance expenditure, 4) Cost of capital, 5) Expenditures on direct support, and 6)Expenditures on indirect support.

Our objective with these guidelines is rather than to develop from scratch guidelines for LCC for infrastructures in general, as this is a much researched and developed field; to provide support in the application of the generic LCC methodology to NBS and allow the bridging of the practices used in the grey infrastructure world with that of the green infra community, like the methods used for cost-effectiveness analyses. This requires taking into account the specificities of NBS versus grey infrastructure and, the most important ones being:

Firstly that NBS are nearly always multifunctional while grey infrastructures are mono-functional, accordingly we place on our methodology great emphasis on the explicit definition of the hierarchy of functions and the levels of service per each of these functions a NBS is required to fulfil. The logic behind this operational choice is that the main function represents the main lens through which the NBS asset performance will be assessed, and that allow for first point of comparison of green and hybrid green-grey strategies with purely grey ones. As for grey infrastructure, the main function the NBS is supposed to fulfil will be operationalized in terms of a “level of service” experienced by the clients (*e.g.* a water utility or other public procurement agency). As explained before the LCC calculation needs to take this level of service into account as a higher level will possibly require higher LCC.

Additionally it is important to define the secondary functions as these functions will result in co-benefits, which not necessarily concern DRR, but which can be crucial for financial and institutional support. Creating awareness about the need for an explicit agreement on the hierarchy of functions per NBS is necessary to bridge the 'green' and 'grey' infrastructure worlds.

Secondly, and in accordance to the hierarchy of functions; in our listing of cost generating activities we report not all possible activities but the ones that are more specific to the particular NBS and the main function(s) for which is being designed. These activities provide an indication of costs to be expected along the NBS asset's lifetime.

Thirdly, NBS are in most cases relatively more open systems and require often larger areas of land for their implementation than grey DRR solutions. As open systems their performance is more dependent on the circumstances in the wider (environmental) system due to ecological interaction. They are consequently often also more vulnerable than grey infrastructure. Accordingly in our methodology context specific variables receive a greater importance than could be the case in LCC for grey infrastructure and we have listed per NBS the context-specific variables we believe most influential in explaining either cost levels and/or risks to NBS long term performance.

Last but not least although for the development of these guidelines we have kept the needs and specific NBS being considered in each of the demo's, since our intention is that the guidelines serve also for future demonstration cases in Europe and elsewhere; we have included also NBS such as mangrove restoration and others not being considered in our demo's. These NBS are to be identified by the grey shade in the table rows.

3.1.2 Information availability

Based on the literature review of the available cost figures, there appears to be a relationship between data availability and clarity of function to be fulfilled by the NBS. NBS with a clear main function, seem to have a larger degree of implementation history. NBS that have been commonly implemented typically have a short causal chain to achieve their main function, which improves comparability to grey alternatives. For example, the water retention capacity of green roofs. Understanding of life cycle costs and a clear comparison of the LCC of green versus grey options enables public and/or private parties to implement the NBS based on added value, as they can build the financial Business Case of such measures or at least perform a Cost Effectiveness Analysis.

For example, private companies provide green roofs as a substitute for cisterns to prevent pluvial flooding. Green roofs can be applied on small scale – house or building- and without running against regulatory barriers. Therefore, its application is widespread, stimulating data collection (see table 4). Wetland solutions as a substitute for waste water treatment plants are being offered by companies such as Bauer (Bauer, 2012). The scale and applicability of wetlands in different situations are aspects more complex to assess, which makes costs more variable compared to green roofs.

However, given the private buy-in and companies' ambition to be profitable, one can assume the information on costs and benefits is available for these measures. Companies would need data on life cycle costs to justify a positive financial business case of green versus grey solutions, requiring data on costs compared to benefits, which is confirmed by the availability of cost figures for green roofs and constructed wetlands in table 4[5]. Water harvesting, through NBS, is another measure with a clear function and a clearly coupled grey alternative for which data availability is relatively large, as shown by table 4.

Data availability also seems to be stimulated by previous widespread application in (public) activities, as is the case of re/afforestation and green spaces. These NBS do not have a clear single main function, see table 2, and are therefore harder to compare to grey infrastructure alternatives. Widespread application combined with public financial accountability has resulted in ample data, as shown by table 4. Moreover, recent attention to CO2 emissions and the acknowledgement of forests' and green spaces' carbon sequestering characteristics stirred their development and thereby knowledge on their costs.

Mangrove restoration is another NBS for which data seems to be relatively plentiful. This could be explained by the consensus on mangroves flood protection capacity (Bertule et al. (2014); Contrary to green roofs and wetland construction mangrove restoration has not been extensively commercialized due to a diffuse allocation of direct benefits. Mangroves for flood protection have become an attractive solution for developing regions, where public funds and technical capacity to undertake large civil engineering structures for flood protection are scarce.

In places where such large grey infrastructure is not yet in place and/or for which long term maintenance cannot be guaranteed by public fund; mangroves seem as a more sustainable alternative to ensure a certain level of flood protection. These factors have probably stimulated their implementation and explain current data availability.

Based on the analysis of scientific literature, data on NBS for which there is no clear consensus on their main function, their equivalent grey alternative, and/or that are ecologically complex to design and implement, seem to lack data on costs. For example, riparian buffers have a multitude of functions, with a focus on improving water quality. Additionally, short-term benefits can be hard to pinpoint and costs are assumed to be highly location specific. Overall, data availability seems relatively scarce.

Meanwhile, developing coastal marshes can be an ecologically complex endeavour (Fagherazzi et al., 2012), complicating the causal chain of direct benefits and creating an uncertain cost

[5] The cost figures show the range of a multitude of cost figures found in the underlying literature.

profile. Moreover, no consensus seems to exist regarding the degree of protection against floods provided by salt marshes'. Narayan et al. (2016) indicate that their function is mostly as wave attenuation and evidence about the protection they give against high water levels is limited.

Similarly, for oyster reef restoration/construction exact functionality seems debatable, which can also be explained by the complexity of ecological processes involved, making it harder to predict the ultimate level of service provided by the NBS.

Ambiguity with respect to main functions and the level of service that can be provided complicates effective cost comparisons with grey infrastructure alternatives and discourages implementation, hampering data creation.

3.1.3 Evidence from demo sites

Contact persons involved in the analysis of the NAIAD demo sites have been consulted in order to add empirical evidence and test preliminary findings concerning guidelines for the determination of LCC of NBS. Several key issues influencing the LCC of NBS were addressed such as cost activities, design variables, location-specific variables and the temporal distribution of costs. Besides that, cost figures based on demo site developments were retrieved if available, table 1 below lists the demo sites consulted.

Table 1. DEMO sites consulted.

BRAGUE	(FRANCE)
General description	The Cannes – Antibes – Nice area is a mountainous range located along the Mediterranean coast. Urban areas are located along the coast, where all mountain catchments finish their way to the sea. One of the rivers flowing from the mountains to the coast is the Brague river.
Main hazard(s)	1. (Torrential) flood risk: The mountains located near the French Mediterranean coast are regularly subject to severe rainfalls, and consequently to torrential floods. On 3rd, Oct. 2015, a dramatic flood occurred in the region between Cannes and Nice (20 casualties, 550-650M€ of losses, spread over 3 rivers). 2. Wildfires: Wildfire can aggravate the impact of a flood due to altered hydrology and soil erosion.
Measures being considered[6] and their functions	Nature Based Solutions: From the experience of the basin agency and ongoing studies, and according to the http://nwrm.eu project inventory several NBS have been identified, see below for a list including their function(s): • Floodplain restauration and management: Restoring floodplains, their retention capacity and ecosystem functions, by reconnecting them to the river. • Wetlands restauration and management: Improve the hydrological regime of degraded wetlands and generally enhance habitat quality. Creating artificial or constructed wetlands in urban areas can also contribute to flood attenuation, water quality improvement and habitat and landscape enhancement. • Stream bed re-naturalization: Bank re-naturalization is a stabilisation technique used to correct mild erosion problems. • Removal of dams and other longitudinal barriers: Allowing re-establishment of fluvial dynamics, as well as sedimentary and ecological continuity. • Natural bank protection: Decreased water flow, erosion control and biodiversity increase. • Forest riparian buffer: Water quality improvement and flow moderation. The trees in riparian areas can efficiently take up excess nutrients and may also serve to increase infiltration. Riparian buffers serve to slow water as it moves off the land. This can decrease sediment inputs to surface waters.

[6] The preferred strategy and hybrid –green/grey- combinations will be selected by demo's later in the process.

	Grey solutions: Large retention basins, riprap bank protections, concrete channelization and heavy maintenance of vegetation are the techniques used in the historical approach.
Context specific variables	• Hydrology of the river influences which type of vegetation is most suitable for reaching NBS functionality, *e.g.* ephemeral or perennial. • Some NBS need more space compared to (existing) grey solutions, therefore land prices are important. • Some areas of the Brague are relatively inaccessible, influencing construction and O&M costs.
GLINŠČICA CATCHMENT	**(SLOVENIA)**
General description	Glinščica catchment is situated within the borders of the Municipality of Ljubljana that spans roughly 275 km2 and has a population of 284,000 inhabitants. The demo site covers 7.01% of Ljubljana's surface area, includes 5 of its districts (Dravlje, Šiška, Rožnik, Vič, Šentvid) and accounts for 8.17% (23,200) of its population.
Main hazard(s)	(Torrential) flood risk: Originating at 409 m.a.s.l., the headwaters in the steep hill slopes of Toško Čelo give the Glinščica Stream a torrential character which, together with climate change (less frequent, but higher intensity rainfall) and land use change, results in regular flooding of the Vič and Rožna dolina districts of Ljubljana. With the expansion of urban areas in the lowlands of the river basin, the hydrological regime of the river basin has changed. By increasing the proportion of impervious surfaces (sealing, road surfaces) the rate of water runoff has increased.
Measures being considered [7] and their functions	The NBS that are appropriate for this demo site still need to be selected as part of the NAIAD project. Different NBS will be considered first for the hilly and wooded areas around the source, second for the agriculturally developed middle reaches and third, for the semi- to fully urban areas as the stream reaches the city of Ljubljana. The NBS primary function should be flood risk reduction. Besides that, the Glinščica catchment is an important source for Ljubljana's aquifers recharge and irrigation, ideally NBS also address this issue as a secondary function. The NBS that address flood risk mentioned above for the Brague can also be applicable to this demo, *e.g.* natural bank protection, floodplain and wetland restoration.
Context specific variables	• Proximity to Ljubljina could change land value. • People can try to maximize their selling price of land if they know it will be bought by municipality. • Some areas are already owned by the municipality.

[7] The preferred strategy and hybrid –green/grey- combinations will be selected by demo's later in the process.

LOWER DANUBE SECTION	(ROMANIA)
General description	The Lower Danube Demo site is located between Zimnicea and Calafat cities. It covers a stretch of approximately 250 km long of the Lower Danube River. This area has a moderate population level with strongly anthropomorphised areas that fall under different administrations.
Main hazard(s)	1. Flood risk: Some urban areas were developed on the Danube riverbank, in close proximity to the water, being susceptible to flooding. 2. Riverbank erosion: Where no engineering works (riverbank stability) have been performed, riverbanks face the risk of collapsing.
Measures being considered [8] and their functions	No NBS have been developed yet, the main methods that are being proposed include: • Artificial insemination (planting) of reed populations: They can provide a strong stability pattern and can help in the sediment accumulation processes for catastrophic riverbank collapses caused by erosion. Other NBS need to adhere to the ambition of continuous durable development of a green Danube, while ensuring a safe and continuous navigation on the Danube river.
Context specific variables	• Land can be private or belong to municipality, affecting the price. • Willingness to relocate can affect costs. • Marginal benefit of NBS is affected by proximity of other green or natural areas. • Occurrence of previous hazards can create incentive to implement/finance NBS. • Proximity of urban areas to NBS can affect willingness to invest.
ROTTERDAM	**(THE NETHERLANDS)**
General description	The Rotterdam Demo consists of an urban neighbourhood Spangen, located in the west of the city of Rotterdam, where a nature based solution (urban water buffer) will be implemented to expand rainwater retention without losing rainwater to the sewage system.
Main hazard(s)	1. Pluvial flood risk: Spangen has a shortage of aboveground rainwater retention capacity, facing flooding during extreme precipitation events. 2. Drought risk: A prolonged lack of precipitation can lead to (local) water scarcity.

[8] The preferred strategy and hybrid –green/grey- combinations will be selected by demo's later in the process.

Measures being considered [9] and their functions	In this demo a combination of green and grey solutions (Urban Water buffer concept) will be implemented to collect rainwater runoff in built areas and after temporary storage in the underground, rainwater will be recovered for reuse, the hybrid solution contains three main features, followed by their function(s): • Bio retention: Expand the retention capacity of the neighbourhood by adding 50 mm discharge capacity to the current sewage infrastructure. • Bio filtration: Contaminants and sedimentation are removed from storm water runoff. • Aquifer Storage and Recovery: Creating a new source for freshwater, as replacement of potable water for the irrigation of the sport fields of the Sparta stadium.
Context specific variables	• Availability of space. • Land price. • Original function of area, *e.g.* parking space or walking area. • Aesthetic preferences of surrounding inhabitants.

[9] The preferred strategy and hybrid –green/grey- combinations will be selected by demo's later in the process.

3.1.4 Typology of Nature-Based Solutions: functionalities and cost generating activities

The main function an NBS is meant to fulfil is a crucial determinant for LCC calculations as it affects the standards the NBS needs to adhere to over its lifetime. The level of service the NBS should provide for that function will pose constraints to its design and therefore influence the capital and operative expenses required for its implementation. Moreover, having clarity on the main function allows for comparisons on cost-effectiveness with grey infrastructure options. Table 2 below provides an overview of the main and secondary functions for a selection of NBS. The main function describes the ecosystem services provided by green infrastructure that are relevant to the problem it aims to address or the risk it aims to mitigate. These services can complement, augment or replace services provided by grey infrastructure.

The secondary function describes those additional ecosystem services that are provided by NBS and not captured in the main function defined; in other words the co-benefits. Co-benefits may often not be included in traditional appraisals on cost-effectiveness, since options are compared based on reaching the desired effect or “level of services” with the lowest LCC, leaving often aside the additional effects. Although not necessarily the best approach to select the best alternative, this is often the case except for cases where a co-benefit translates into reduced compensation costs as choosing an NBS will result in a lower environmental impact of the overall project. Meanwhile regular cost-benefit analyses to compare alternative infrastructure investments often include co-benefits. The challenge here is that in many cases the costs and benefits are considered at the local scale and/or scale of the project which may still translate into important co-benefits at system scale (i.e. the watershed) not being considered.

For each NBS a number of cost generating activities are listed. These activities provide an indication of costs to be expected along the asset’s lifetime. The list is not exhaustive; in our listing of cost generating activities we report not all possible activities but selected the ones that are more specific to the particular NBS and the main function(s) for which is being designed. As presented in more detail later in table 3, the absolute cost figures of each of these activities and the total LCC per type of NBS will be determined by design choices as well as by external factors which are context specific. Design choices relate to the level of service the NBS is supposed to fulfil (*e.g.* capacity), the location and the “construction” and/or “maintenance” methods chosen, among other things.

Context-specific circumstances are factors that cannot be influenced by the stakeholders planning or designing NBS, and that translate into a number of additional design constraints. Their relative impact on LCC costs and on system performance (for the NBS functions defined) over time is often not easy to be predicted or standardized. These factors add variability and uncertainty to cost estimations as they often relate to additional and unexpected implementation and operational risks. These context-specific factors are also often the ones that, given the nature of NBS solutions, are more exposed to, and dependent on the dynamics of their natural environment; introducing significant uncertainty in performance.

Table 2. NBS functions and cost generating activities[10]

NBS	Main function	Secondary function	Cost generating activities
Re/afforestation	(Ground) water supply regulation [1, 7], water purification [1, 7], erosion control [1, 7] biological control [7], water temperature control [7], flood control [1, 7].	Food production, raw materials, medicinal resources, carbon sequestration, pollination, species habitat, maintenance of genetic diversity, recreation, tourism, aesthetic value, spiritual experience [7], air purification [own].	Cost of seeds and plant, soil preparation, planting type, labour and machinery, regulation requirements, land acquisition [1]. Ungulate removal, weed control[11], training and education [2]. Land acquisition.
River bank protection	Erosion control [1].	Species habitat [1].	Bio-engineering, boulders placement, planting vegetation and design. Maintenance [1].
Wetland restoration	Water supply regulation, water purification, biological control, water temperature control [7], flood control [1].	Food production, raw materials, medicinal resources, carbon sequestration, pollination, species habitat, maintenance of genetic diversity, erosion control, recreation, tourism, aesthetic value, spiritual experience [7].	Mowing, grazing, clearing trees, increasing open water by removing aquatic vegetation, extending area of mosaic habitats, improving hydrological conditions, shrub clearance [6], long-term management/monitoring to ensure recovery [7].
Wetland construction	Water supply regulation [7], water purification [7], biological control [7], water temperature control [7], flood control [1]. Biological wastewater treatment ‘technologies’, nutrient pollution control (reduce eutrophication risk) of wastewater, reduce flow velocity, remove nutrients and sediments, mitigate surface run-off [7].	Food production, raw materials, medicinal resources, carbon sequestration, pollination, species habitat, maintenance of genetic diversity, erosion control, recreation, tourism, aesthetic value, spiritual experience [7].	Site assessment and design, excavation and layout, materials, inlet and outlet structures, pipes, pumps, and vegetation. Substrates [1]. Land acquisition. O&M can include activities such as the regular checking and repairing of pumps, inlet and outlet structure for water level, hydraulic loading, pollution loads of influent and effluent, odour control, removing sediment, harvesting the vegetation (optional), plant protection (*e.g.* pest or disease vector control) and checking filter bed for clogging [1].

10 The gray shaded cells describe NBS functions and cost generating activities that are not found in the NAIAD demo sites, they are included for completeness.

11 Removal methods include pulling, basal application of herbicide, and frilling. All methods have low material costs but are labour intensive [2].

NBS	Main function	Secondary function	Cost generating activities
Green spaces (*e.g.* parks)	Water supply regulation, water purification, water temperature control (shading), urban storm water runoff, bio retention, infiltration, [7]. Protect aquatic environments from impacts of surrounding land use [9].	Food production, erosion control, habitat for species, recreation, aesthetic value [7].	Planting vegetation, building materials, labour costs, planning, design, [6] Land acquisition.
Water harvesting (hybrid)	Water supply regulation, moderation of extreme events [7].	Erosion control, aesthetic/cultural value [7], urban heat prevention, air quality, cooling effect, spatial quality/recreation, co2 capturing [4].	Site assessment and design, construction, labour, wide variety of techniques, land acquisition. Placing pipes, underground system, and retention crates, excavation of soil, depleting sand, planting vegetation, drilling for infiltration, placing pumps [4].
Riparian buffers	Temperature control, moderation of extreme events, water purification, biological control [7].	Food production, raw materials, medicinal resources, carbon sequestration, pollination, habitats, genetic diversity, recreation, tourism, aesthetic/spiritual value [7]. *Biodiversity, cultural ES, recreation, tourism, nature preservation [2].*	Land acquisition, planting of buffer zones [7], and substrate.
Green roofs	Moderation of extreme events.	Food production, temperature control, pollination, habitats for species, aesthetic value.	Watering, weeding, pruning, application of organic fertilizer and occasional removal of invasive or undesirable plants and replanting as needed. Drains and gutters must be inspected and cleared more frequently than on a roof without a garden, due to the build-up of plant debris [3].
Mangrove restoration	Moderation of extreme events [7].	Food production, raw materials, medicinal resources, temperature control, erosion control, pollination, biological control, habitat, genetic diversity, recreation, tourism, aesthetic/cultural value, spiritual value [7].	Land purchase (if any), seeds and seedling growing costs, transportation and labour costs, Problem and system analysis, design of restoration plan, process of recreation of abiotic conditions (*e.g.* construction of groynes)

NBS	Main function	Secondary function	Cost generating activities
			Setting up monitoring system.
Coastal/salt marches	Moderation of extreme events [7].	Food production, raw materials, medicinal resources, temperature control, erosion control, pollination, biological control, habitat, genetic diversity, recreation, tourism, aesthetic/cultural value, spiritual value [7] CO2 sequestration [7].	Land purchase (if any), seeds and seedling growing (saltwater tolerant grasses, shrubs and other vegetation) costs, transportation and labour costs. Extensive planning and monitoring regarding; restoration of the tidal hydrology, the proper mix of freshwater with saltwater, nutrients, and sediments to tolerable concentrations of toxic materials [7]. Problem and system analysis, design of restoration plan, process of recreation of abiotic conditions (*e.g.* construction of groynes) setting up Monitoring System.
Restoring oyster reefs	Moderation of extreme events [7].	Food production, erosion control, biological control, habitat, genetic diversity, recreation, tourism, aesthetic/cultural value, spiritual value [7] Nitrogen removal [7].	Problem and system analysis, design of restoration plan, process of recreation of abiotic conditions (*e.g.* construction of groynes) Setting up a monitoring system.

As can be observed in table 2, the implementation of NBS involves a great variety of activities; which also implies that a great variety of skills and technical capacities –rather different than the ones required for the development of grey infrastructure- will be required. This variety in technical expertise required needs to be taken into account in the choice of implementation arrangements and the allocation of risks, responsibilities and rewards along the life cycle of the project between public sector, private sector and communities. This is necessary to guarantee the governance structures and financing mechanisms chosen to implement the NBS are the ones that are best able to ensure a steady quality in service provision, which in the case of NAIAD concerns levels of protection against flood or drought risks. We will elaborate further into the relationship between the required expertise in green versus NBS infrastructure projects and the partnerships required for their successful implementation in the concluding section.

3.1.5 NBS cost determining factors

Table 3 below provides an overview of NBS and accompanying cost determining factors. The life-cycle of an NBS describes the relative temporal distribution of costs over the life time of an NBS, reflected by the ratio between CAPEX and OPEX, which occur in an earlier or later phase of the NBS lifetime respectively. Furthermore, the location of implementation, design variables and context variables are described. Design variables are often related to the service level of NBS, which depends on the desired degree of functionality. Context specific characteristics are cost components that will be influenced by environmental and socio-economic conditions related to the asset location. Assessing these characteristics prior to NBS implementation can assist in determining and steering the outcome of LCC.

Table 3. NBS characteristics[12].

NBS	Life-cycle	Location	Design variables	Context specific variables
Re/afforestation	CAPEX/OPEX ratio varying, expected to be over 10/1 based on table 4. Dependent on inclusion of fences; The initial installation cost is high, but maintenance costs are relatively low with the exception of wire replacement every ten years [2].	Watershed [7].	Inclusion of fences, size, forest maintenance method [2].	*Location specific:* resilience of plant growth (lack of resilience would cause need for planting more mature trees instead of seeds, more expensive); weather/soil circumstances. Prevalence of animals that eat small trees and harm reforestation process, would cause need for a fence [2]. *Socio-economic:* Costs of land acquisition [17], other potential land uses (opportunity costs) [7], prevalent wages.
River Bank protection	Most costs in the beginning, maintenance of the NBS is comparable to the maintenance of a park (so small costs later on). To create NBS you need to reshape banks, which can be tougher work that costs more [16].	Watershed [1].	Bio-engineering method, sheer stress factor [16].	*Location specific:* Sediment transport conditions [16], hydrology of river, and accessibility of field site [16]. Availability of local materials (trees/plants already growing in river) [17] *Socio-economic:* Prevalent land-use and wages.
Wetland restoration	Russi et al. (2013) found that restoration costs can be high, requiring investment not only in the physical restoration works, but also in long term management, to ensure, often slow, recovery [7].	Watershed, Floodplain, Urban [7].		*Location specific:* Degree of degradation, spread of vector borne diseases, upstream pollution. [7]. *Socio-economic:* Prevalent land-use and wages.
Wetland construction	Table 4 indicates a CAPEX/OPEX ratio of around 20 to 1.	Watershed, Floodplain, Urban [7].	Size, structure (*e.g.* damming is cheaper than digging), purpose (re-use or safe discharge).	*Location specific:* Slope of area, hydrology [7]. *Socio-economic:* Prevalent land-use, wages [7], land acquisition costs.

12 The gray shaded cells describe NBS features that are not found in the NAIAD demo sites, they are included for completeness

NBS	Life-cycle	Location	Design variables	Context specific variables
Green spaces	In general OPEX is considered 'low' [7], mostly monitoring of density of vegetation cover and infiltration capacity. CAPEX probably much larger than OPEX in urban setting where land is scarcer/opportunity costs might be higher.	Urban [7].	Filtration/retention capacity, size.	*Location specific:* Land acquisition costs, concentration levels of water contaminants upstream [7]. *Socio-economic:* Prevalent land use, opportunity costs, wages.
Water harvesting (grey-green)		Watershed, Floodplain, Urban [7].	Bio retention; above or below ground, capacity, performance level, infiltration rate, type of vegetation**.** [19]	*Location specific*: Local preferences, surrounding land-use [19] *Socio-economic:* salary, cost of land [19]
Riparian buffers	Lifetime is over 25 years [10], For now the information on CAPEX vs. OPEX is limited.	Floodplain [7].	Size, with or without a fence [5]. Peak discharge reduction [17]. Volume reduction [17].	*Location specific:* Land acquisition costs, resilience of plant growth (lack of resilience would cause need for planting more mature trees instead of seeds, more expensive); weather/soil circumstances. Prevalence of animals that eat small trees and harm reforestation process, would cause need for a fence [2]. Land use of surrounding area. *Socio-economic:* Land acquisition costs [17], wages.
Green roofs	Between 20:1 and 6:1.	Urban [7].	Size and complexity of the installation. Use of special features for enhancing aesthetics and safety of accessible green roofs (*e.g.* edging, walking paths, safety fencing) [6].	*Location specific:* Local availability of materials. Availability of labour-reducing technologies (*e.g.* growing media blower truck) [6]. *Socio-economic:* Market competition, salaries [6].

NBS	Life-cycle	Location	Design variables	Context specific variables
Mangrove restoration	CAPEX/OPEX ratio of around 10:1.	Coastal [7].	*Design:* Water depth is a crucial factor, with mangroves showing an increase in cost effectiveness at higher depths, due to the relatively steep increase in breakwater construction costs. [4]. Intended degree of restoration.	*Location specific:* Ecological conditions, Land use of surroundings (pollution, opportunity costs). *Socio-economic:* Labour and material costs [7].
Coastal/salt marches	Limited information.	Coastal [7].	*Design:* Size, vegetation, need for elevation of the site [11].	*Location specific:* Surrounding land use, land acquisition costs, potential dyke breaching [7]. *Socio-economic:* Labour and material costs [7].
Restoring oyster reefs	Limited information.	Coastal [7].		*Location specific:* Surrounding land use, land acquisition costs, potential dyke breaching [7]. *Socio-economic:* Labour and material costs [7].

3.2 CURRENT EMPIRICAL DATA ON NBS LCC

Table 4 below provides an overview of the existing data on cost figures for NBS, capital expenditures (CAPEX) and operational expenditures (OPEX) are listed separately.

Naumann et al. (2011) find several drivers for discrepancies in costs of green infrastructure. Firstly, per hectare costs typically decline as size increases for nature conservation projects. Secondly, parks and green spaces in an urban environment can become costly due to the involvement of work related to gardening and buildings. Thirdly, labour intensity influences costs. Fourthly, the level of detail of design or level of desired outcomes, *e.g.* targeted species conservation tends to be positively related to costs. Fifthly, the degree of direct support costs depends on the existing institutional setting, *e.g.* some contexts require more awareness raising than others.

For 6 green infrastructure projects related to environmental restoration/conservation studied by Naumann et al. (2011) annual OPEX amounted to 6% of CAPEX (bot OPEX and CAPEX are cumulative for all projects). 68% of these costs were spent on the management and maintenance of land and buildings. Another large share of OPEX was based on project management and administration, at 25%. Therefore, depending on the life time of an NBS, total OPEX can outgrow the initial CAPEX over time.

Costs for re/afforestation seem to have high variability. For example, a study on 127 European green infrastructure projects resulted in a range of 1000$ per hectare (Bertule et al., 2014). The range of costs can be explained by the wide range of design variables elaborated in table 3. For example, the resilience of plant growth, since a lack of resilience requires planting mature trees instead of seeds. Besides that, in some cases reforestation required a fence around the site in order to prevent animals from eating saplings. Moreover, initial soil and weather conditions play a role in costs, among other location specific variables.

The figures on wetland restoration from Naumann et al. (2011) indicate a decrease in costs per unit as size increases. Be aware that the nature of restoration activities differed per location as well; therefore it remains difficult to compare activities as they vary between relative ‘simple’ shrub clearing (3368$ per ha) to mowing, grazing, clearing trees, removing aquatic vegetation, improving hydrological conditions and extending the area of mosaic habitats (6209$ per ha).

Table 4. CAPEX and OPEX figures of NBS

NBS	CAPEX	Unit	OPEX	Unit
Re/afforestation	230-460 [1] 1266 – 7675 [2] 997 [6] 1953 [6]	€/ha $/ha (NPV) €/ha €/ha	120-130 [1]	€/ha/year
River bank protection	130€ [16] 70€-140€ [16] 300 € [16]	€/Bank meter €/Bank meter €/Bank meter	0.5€ [16]	€/m/5 years
Wetland restoration	6209 [6] 3368 [6] 2500[6]	€/ha €/ha €/ha	n/a	n/a
Wetland construction	25-65 [1]	€/m2	0.4-0.5 [1] 8-10 [1]	€/m2/year €/m2/year
Green spaces	942 [6] 321 [6] 24 - 100 [7] 32-65 [7] 3-9 [7]	€/ha €/ha $/m $/m2 $/m2		
Water harvesting (grey)	10-30 [7] 40 -200 [7] 1.3 - 1.5 [7]	$/m3 $/m3 $/m3	0.27 - 0.47 [7]	$/m3
Riparian buffers	3100 [5] 9900 [5]	$/km $/km	N/a	n/a
Green roofs	6-21[3]	$/sq.ft.	0.25 – 4.10 [3]	$/sq.ft./year
Mangrove restoration	25 - 180 [1] 9,318 [7] 0.05 - 6.43 [4] 8812–9318 [8]	€/ha $/m2 $/ha $/ha	5 [1] 50 [7] 118 [5]	€/ha/year $/ha/year $/ha ..
Coastal/salt marches	0.01 - 33 [4]	$/m2	n/a	n/a
Restoring oyster reefs	107 - 316 [4] 93.75 [7]	$/m2 $/m2/year	n/a	n/a

However, costs for re/afforestation seem to have high variability. For example, a study on 127 European green infrastructure projects resulted in a range of 1000$ per hectare [7], which can be explained by the multitude of design variables elaborated in table 3.

The variation in costs for wetland construction is relatively limited. Figures are based on numbers from Tanzania, India, Nepal and Costa Rica. For Tanzania, the investment costs consisted of 61 euro/m2, of which 36% is the cost of the substrates, 25% is for the construction materials, 21% for the site assessment, planning and design, 16% for labour cost, and 2% for the vegetation plantation [1].

In general, it should be noted that not all authors reported explicitly whether their reported cost figures incorporated land acquisition costs. An educated guess would be to assume that most NBS were implemented on publicly available land, and therefore did not include land acquisition costs, which is definitely the case for the river bank protection figures.

3.3 LIFE CYCLE COSTING OF NBS: METHODOLOGY IN ACTION

In order to draft an estimation of LCC for a proposed NBS, one would need to link the aforementioned LCC components to cost elements and the drivers affecting their magnitude. Table 5 below exemplifies this link between different factors and exemplifies with an empirical example from the NAIAD demo sites where possible.

Table 5 can be used as a framework to make a projection of expected life cycle costs per NBS. Firstly, one can project the cost elements relevant to the NBS based on the life-cycle phase in which they are expected to be incurred, taking into account empirical examples. Secondly, one can estimate the future costs based on potential cost drivers that affect the cost elements.

Moreover, life-cycle costs can be controlled partly by altering the cost drivers, *e.g.* by choosing a particular location or design. When the estimation of costs over the entire life cycle of an NBS are complete, they can be used in an appraisal to find the optimal infrastructure solution.

See Appendix A for the demonstration of how these LCC Guidelines for NAIAD demo sites can be used, making use of the Brague Basin Demo.

Table 5. LCC components, cost elements and cost drivers for NBS.

LCC component	Cost elements	Cost drivers
Capital expenditure	*Planning, design and construction:* Hydrological assessment, bio-engineering, earth removal and recharge with machinery, concrete channelization, bed widening [16].	*Function & level of service design:* Sheer stress determines level of service, bio-engineering method [16]. *Location specific conditions:* Hydrology and climate conditions [16, 17, 18, 19]. *Socio-economic conditions:* Property prices [16, 17, 18, 19], salaries [16].
Operating and minor maintenance expenditure (OPEX)	*Maintenance, monitoring, operations:* Vegetation maintenance, water quality monitoring environmental quality monitoring [16].	*Function & level of service design:* Sheer stress factor that determines level of service [16]. *Location specific conditions:* Hydrology and climate conditions [16, 17, 18, 19]. *Socio-economic conditions:* Salaries [16].
Capital maintenance	*Asset renewal, replacement and rehabilitation:* Post-disaster riparian vegetation reconstruction River bed cleaning [16].	*Function & Level of Service Design:* Sheer stress factor that determines level of service [16]. *Location specific:* Probability of hazard occurring [16]. Measures to reduce vulnerability of NBS to hazards[13] [16]. *Socio-economic conditions:* Salaries [16].
Expenditure on direct support	*Activities directed to local-level stakeholders, users or user groups:* Increase hazard knowledge and risk awareness [16].	Existing technical and institutional capacity.
Expenditure on indirect support	*Activities not directly linked to an asset:* Risk awareness in urban planning [16].	Institutional environment- existing legal/economic barriers for implementation.
Cost of Capital	*Financing costs:* Interests, dividends.	*Risk profile of project:* Capability of implementing actor to mitigate risks (past experience).

[13] A different hazard than the one the NBS is supposed to mitigate may apply here (e.g. afforestation is susceptible to forest fires, while the forest is meant to mitigate other hazards such as rainfall variability).

3.4 NATURE-BASED SOLUTIONS VERSUS GREY INFRASTRUCTURE: KEY CONSIDERATIONS IN TERMS OF LCC AND IMPLEMENTABILITY

3.4.1 Cost-effectiveness of NBS versus grey infrastructure

Another key methodological aspect to be considered for the calculation of LCC and a proper comparison of NBS versus grey solutions is that "green infrastructure design and performance is generally more context-specific than grey infrastructure. NBS solutions for DRR need to be designed and built to fit the soil, terrain and hydrological conditions of each individual site" (American Rivers, 2012, p.9). This translates in greater complexity and uncertainty in ex-ante cost estimations and cash profile of NBS projects, but also often on a greater value as they may address local concerns and values.

Infrastructure costs need to be considered in a broad sense. The cost-efficiency of green versus grey solutions can be improved by making all cost savings explicit, and quantifying the reduced "opportunity costs". Let's take the example of storm management structures. This requires a consideration of overall project costs beyond the ones involved directly in storm water management structures. "Green streets in Seattle require less pavement, reducing pavement costs by 49%. " (American Rivers, 2012, p.12).

The adoption of green infrastructure measures – especially for storm water management- has an impact on volumes that need to be managed and are expected to result in reduced or avoided investments in grey infrastructure (American Rivers, 2012).

It needs to be taken into consideration that putting in place NBS and green infrastructure at full scale will require a change not just in system but a paradigm change in the existing O&M approaches of most public (infrastructure) agencies. For instance in the case of storm water infrastructure, *managers will need to shift to a new maintenance paradigm and plan for regular, low capital rather than episodic, high capital approaches (*page 13).

3.4.2 Cash and risk profiles of green versus grey alternatives

All in all, in a cost-effectiveness comparison made of NBS solutions versus grey infrastructure for storm water management the following TCO advantages have been discovered (American Rivers, 2012, p.9):

• Reduced built capital (equipment, installation) costs.

• Reduced operation costs (*e.g.* energy costs).

• Reduced land acquisition costs.

• Reduced repair and maintenance costs.

• Reduced external costs (off-site costs imposed on others).

• Reduced infrastructure replacement costs (potential for longer life of investment).

Altamirano et al. (2013) also find that in the long term, operation and maintenance costs of NBS are expected to be lower compared to grey solutions, due to the adaptive and regenerating capacities of ecosystems. Figure 1 below illustrates the investment levels of traditional and hybrid measures; for the specific case of mangrove restauration (making use of groynes) versus a seawall in Indonesia, indicating a more 'smoothened' curve for hybrid measures.

"*Properly functioning green infrastructure practices are premised on using natural processes rather than built systems, which requires a shift away from capital intensive, infrequent maintenance to less-invasive tasks that may be more frequent but less expensive overall. As grey infrastructure systems require increased operations and maintenance over time as equipment and materials wear down, green infrastructure practices are designed to increase in resilience and function as vegetation matures and adapts to local resource cycles. While green infrastructure solutions can become more effective over time, extending the infrastructure's life cycle and even performance level, it should be noted that performance may eventually diminish without proper maintenance. Coupled with the flexible, adaptable nature of green infrastructure, O&M efforts devoted to these systems can increase a community's ability to more resiliently respond to changing conditions, like increased precipitation or growth*" (American Rivers, 2012, pp.12 – 13).

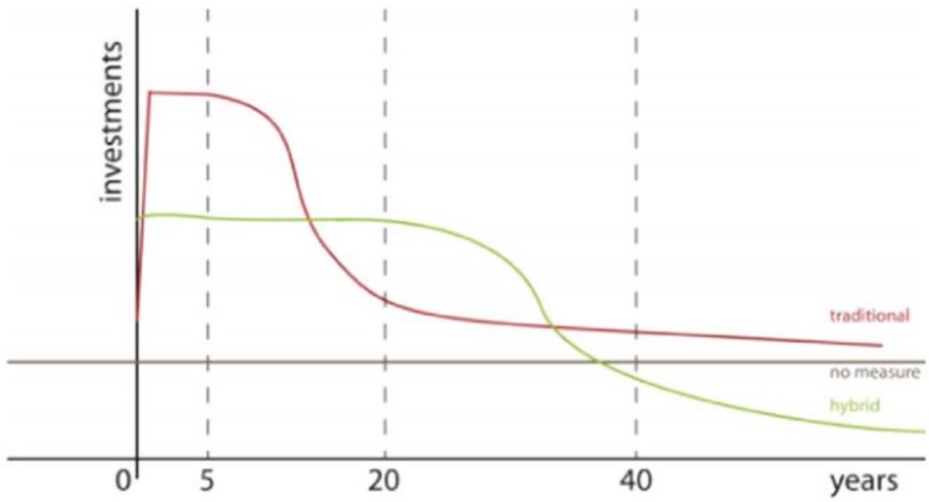

Figure 1. Grey versus Green infrastructure qualitative capital investment and operational expenses required. (Altamirano et al., 2013).

Nonetheless, NBS have unique financing challenges inherent to their cash profile. Benefits can be unique, delayed, dispersed, non-guaranteed and non-financial, complicating the estimation of an internal rate of return. With respect to costs, capital expenditure is often spread over a longer term, in comparison to grey solutions. The spread in costs is inherent to the longer 'building' times of NBS regarding the achievement of functionality (Altamirano et al, 2013). This has been confirmed, for the NAIAD Brague demo site, were target functionality is achieved after 3 years.

While TCO are expected to be lower for NBS versus grey infrastructure in the long term, it is also important to consider the differences in the "perceived" risk profiles of green versus grey and the impact that will have on cost of capital and on the "risk premium" to be charged by implementing parties to the procurement agency when opting for green versus grey. This will be specially the case in the first years of transition towards a hybrid infrastructure market; when risk perception will remain high and companies engaging in providing these NBS solutions won't have the required track record to prove to financiers that they are in total control of construction and performance risks.

While in the one hand "financing" of NBS solutions at scale may prove challenging; the characteristics of NBS that often impact positively on-site aesthetic and provide other co-benefits could prove beneficial to generate new funding sources as it could increase willingness to pay of people in the immediate vicinity of these solutions. For example, in Portland, Oregon, residents were more willing to invest in those on-site storm water projects that provided additional scenic and other direct benefits (American Rivers, 2012). Such aspects will be further worked out in the deliverables of WP7.

3.4.3 New partnerships and expertise required

In order to ensure a successful implementation of NBS as well as to guarantee stable levels of service over time; it is key to consider not only LCC costs and their distribution over time but even more the skills and expertise required to undertake the activities identified at the lowest costs, higher quality and minimizing risks. By considering these aspects, the implementing agencies can be guided in their choices of who should take care of which life cycle phases of the project. In other words, this understanding of cost elements and cost drivers can guide the process of allocation of risks, responsibilities and rewards between the key implementing actors that could be either from the public sector, the private sector or the community.

An in depth analysis of the strengths of PPP (Public, Private, People) actors' is required to guide this risk allocation decision. Given the differences in implementation models and actors between NBS and grey infrastructure solutions up until recently, to find suitable implementing parties for large scale NBS projects may prove challenging.

Until recently NBS projects have been often undertaken by community volunteers coached by NGO's and/or environmental government authorities; and more often than not these projects have a piloting function and are of limited scale. In these projects often social objectives are equally important as those related to biophysical conditions or risk reduction; which influences significantly the design of NBS measures, the methods for their construction and the emphasis given to monitoring and data collection systems. This means all in all a very different project management style than the one normally applicable to grey infrastructure projects.

Meanwhile the provision and procurement of regular grey infrastructure is a relatively more formalized process where (large) construction companies and public infrastructure agencies are key players. In this sector risk based asset management along the entire useful life of the asset is the new norm. Additionally, due to public procurement rules in this sector; risk allocation and the related liabilities carried per implementing party need to be clarified and agreed upon way in advance before project implementation.

One could expect that the mainstreaming of NBS as DRR measures will require NBS projects to pass the same standards as the ones required for the built environment or grey infrastructure. A question that needs further investigation is therefore how this process of formalization will affect the current cost estimates and cost categories identified by NBS. For example, to guarantee risk reduction levels, the share of monitoring in operation and maintenance costs of NBS could increase to counteract ecological uncertainty.

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5. APPENDIX A: LCC GUIDELINES FOR NAIAD DEMO SITES

Findings of D4.2 have been transformed to a hands-on guide with guidelines for NAIAD DEMOs to determine their LCC.

Firstly, 6 steps have been defined for demo's to develop an initial assessment:

1. Determine main function(s) (*e.g.* water supply, erosion control, flood protection)
2. Determine service level of main function or per function (*e.g.* volume of water stored)
3. Determine activities that need to be performed in order to construct NBS and maintain service level
4. Determine cost elements per activity, incl. volume required (*e.g.* materials, working hours)
5. Estimate frequency and cost of activities over NBS life-time
6. Perform step 3-5 per LCC category

The LCC categories are as follows:

1. Capital expenditure: The capital required for constructing infrastructure, including costs such as design, procurement, delivery, installation etc.

2. Operating and minor maintenance expenditure: this includes regular, recurrent expenditures on maintenance to ensure the infrastructure operates at design performance. Major repairs or renewals are not included as they are not defined as recurrent.

3. Capital maintenance expenditure: these costs include activities that go beyond 'regular' routine and maintenance related to keeping the system operational, *e.g.* asset renewal, replacement and rehabilitation.

4. Cost of capital: costs related to financing a project, *e.g.* interest or dividends.

5. Expenditures on direct support: costs related to support activities directed to local-level stakeholders, users or user groups.

6. Expenditures on indirect support: costs related to support activities not directly linked to an asset.

Deliverable 4.2 provides examples of NBS, their main and secondary functions , and possible cost generating activities (Table 2).This can enable demo's to find suggestions of cost generating activities that coincide with the life-time of their NBS, which can be incorporated in step 3-5.

The guidelines also provide an example of the guidelines' application to the Brague DEMO, see below:

Brague Basin, France

- **Main function:** Erosion control, to prevent breaching
- **Service level:** Shear stress level that the bank is able to resist
- **Selection of activities:**
  - Capital expenditure: Fascine bio-engineering
  - Operation and maintenance: Vegetation maintenance
  - Capital maintenance: Post-disaster vegetation reconstruction
  - Direct support: Capacity building for local stakeholders
  - Indirect support: Sector-wide regulation standards.
  - Cost of capital: Interest rate payments.

Overview of costs

Action type	Features	Unit price [€ ex-Tax]	Quantity in the Brague	Units	Number for 10 yrs	Quantity on a 10 years period	Cost on a 10 years period
Capital expenditure							
Bank protection	Light Bioengineering Fascine	130 €	1.400	Bank meter	1	1.400	182.000€
Capital maintenance expenditure							
Post-disaster riparian vegetation reconstruction	Tree and bush plantation	15 €	5.500	Bank meter	1	5.500	82.500€
Operating and minor maintenance expenditure							
Baseline maintenance	Vegetation maintenance	0.5 €	11.500	River meter	2	23.000	11.500€
Direct support							
Capacity building	Increase hazard knowledge	68.000€	1	Session	1	1	68.000 €
Indirect support							
Regulation standards	Urban planning laws	115.000 €	1	n/a	1	1	115000
Cost of capital							
Interest rates	Payment of 1% per year	1820	1	%	10	10	18200

The Brague overview of LCC costs has been computed as follows:

Table 6. Potential drivers that could affect these costs in the future in La Brague Basin DEMO.

LCC component	Cost drivers
Capital expenditure **Operating and minor maintenance expenditure (OPEX)** **Capital maintenance**	*Function & level of service design:* Desired shear stress level determines level of service and bio-engineering method. *Location specific conditions:* Hydrology and climate conditions. *Socio-economic conditions:* Salaries, property prices (CAPEX only).
Expenditure on direct support	Existing technical and institutional capacity.
Expenditure on indirect support	Institutional environment. Existing legal/economic barriers for implementation.
Cost of capital	Risk profile of project. Capability of implementing actor to mitigate risks (past experience).