REGREEN

NATURE-BASED SOLUTIONS

FOSTERING NBS FOR SMART, GREEN AND HEALTHY URBAN TRANSITIONS IN EUROPE AND CHINA

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COST-EFFECTIVENESS OF NBS IN THE URBAN ENVIRONMENT

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WP N°2 Challenges and NBS

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Executive summary

In this report, we provide an overview of costs for nature areas that can serve as NBS. We provide cost estimates for green and blue spaces in urban and peri-urban areas. We also provide cost estimates for de-pavement projects, street trees, green roofs and green walls. We show that these cost estimates can be applied in cost-effectiveness analysis in three different examples. We furthermore discuss how the cost-effectiveness analysis can be expanded to account for the potential multiple benefits provided by nature in urban and peri-urban areas that are in line with the spatial planning policy objectives by local authorities. We argue that a stepwise ranking of policy objectives in a cost-effectiveness analysis is a viable approach that will enable policymakers to make an informed choice over competing solutions.

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1 INTRODUCTION

In this report, we refer to Nature-Based Solutions (NBS) as deliberate actions or interventions that involve, enhance or copy nature in order to provide solutions to a wide range of urban societal challenges such as air pollution, flood risks, and urban heat islands. The report covers diverse types of NBS, including various forms of green and blue spaces, street trees, de-pavement projects, and green roofs.

The purpose of the report is to address the knowledge gap related to the cost and effectiveness of NBS. Cost measures are derived thorough literature review of the development and maintenance of nature and designed nature areas in urban and peri-urban regions. The cost measures are reported for different urban green and blue spaces, green roofs, green walls, small-scale de-pavement projects, and street trees. The information on cost was extracted from scientific literature and grey literature published by consultancy firms and public authorities. The literature on the cost of nature areas in an urban setting is not well-developed. This apparent knowledge gap is contrasted by the amount of literature that focuses on quantifying the benefits of ecosystem services both in monetary and non-monetary terms (e.g., Chee (2004), Turner et al. (1993), Tietenberg & Lewis (2018)). Throughout our literature search, we found only a few studies that focus on the cost-effectiveness of NBS, with Blackhurts et al. (2010), Jiangyi et al. (2020), and Qiu et al. (2020) being notable exceptions. Therefore, in the present report, the cost measures were extracted from the literature where cost calculations were secondary to the main objective of the publication. The implication was - among other things - that a structured literature review was not realistic. Instead, a snowball approach to the literature review of costs calculation of investing and maintaining new nature areas in urban areas was conducted using key publications and then following the trail of these key references. Aarhus municipality and Paris regional municipality – two of the urban living labs in the Regreen project – also provided cost measures based on previous projects conducted within their municipality.

In the report, we define NBS as constructed or designed nature areas located within urban or peri-urban regions. The nature areas are not per se NBS. However, nature areas can provide ecosystem services that solve or mitigate a problem or an issue that local residents experience. In this sense, nature areas are similar to other infrastructures or engineering facilities that are purposely built or implemented to solve a problem faced by people living in an urban environment. This report primarily defines NBS as intentional actions/interventions in an urban setting which solve a specific problem that technical construction and infrastructure also could have solved (see further Chapter 2). In this report, the notion of nature encompasses various forms – managed or modified nature areas and created ecosystems (e.g., green roofs).

We also attempt to provide an approach that builds on the strengths of cost-effectiveness analysis while still accounting for the multiple benefits provided by urban and peri-urban nature areas. The appeal of cost-effectiveness lies in its simpler approach and less demanding need for information compared to other analytical approaches such as cost-benefit analysis. Cost-effectiveness analysis only captures monetary cost information and can only be related to individual effects in non-monetary terms – see Chapter 3. As urban and peri-urban nature can solve several problems by providing multiple ecosystem services, a narrow focus on a singular effect in a cost-effectiveness analysis becomes less appropriate.

We discuss several options to expand the cost-effectiveness approach in order to account for more than one ecosystem service provided by urban and peri-urban nature. We discuss possibilities to provide a common effect scale for the benefits provided by the nature areas using equivalency analysis or economic valuation tools. However, such approaches would complicate the analysis and potentially conceal the decision-making practicalities in analytical technicalities. Instead, we propose an alternative approach that entails ranking of policy objectives by local decision-makers on specific projects and then provide cost-effectiveness analysis for each policy objective related to the construction of an urban or peri-urban nature area. We term this alternative approach the ranking cost-effectiveness approach. In this way, the decision-making process becomes transparent and political objectives can be prioritized where decision-makers can evaluate different solutions by comparing their possible advantages and shortcomings.

We provide several applications of the ranking of cost-effectiveness approach for a Mediterranean provincial city like the Urban Living Lab Velika Gorica in Croatia, a Central European city region represented by Paris region, and a northern European city represented by Aarhus municipality. The application of the approach provides an overview of the challenges and benefits of attempting to rank NBS provided by urban and peri-urban nature.

2 WHAT IS NBS?

NBS is a relatively new terminology within the environmental research and management discourse (Nesshöver et al., 2017) and a consensus on a commonly adopted definition of NBS is yet to be seen (UNEP, 2020). NBS have been dubbed an "umbrella concept", implying links and overlaps with other existing concepts, frameworks, and approaches for ecosystem management and biodiversity protection and promotion (see, e.g., Cohen-Schacham et al., 2016; Nesshöver et al., 2017; UNEP, 2020). In the context of climate change adaptation and disaster risk reduction, EEA asserts that as an "umbrella concept", NBS "encompass other established approaches, e.g., the ecosystem approach and ecosystem-based approaches, sustainable management, ecosystem-based management, sustainable forest management, green infrastructure, and blue-green infrastructure, ecosystem-based adaptation, natural water retention measures, and ecosystem-based disaster risk reduction" (EEA, 2021). To access the most recent overview of the literature pertaining to NBS definition, readers may refer to UNEP (2020). Nonetheless, for the purpose of this report, we take a departure at the definition of NBS following the EU Commission and IUCN.

International Union for Conservation of Nature - IUCN (Cohen-Schacham et al., 2016) defines NBS as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." IUCN (2012) underlines "the potential power of nature and the solutions it can provide to global challenges in fields such as climate change, food security, social and economic development." The notion of nature is highlighted to refer to "healthy and restored ecosystems". The overarching approach of NBS entails "a pro-active application of the sustainable management and conservation of natural resources to address major global challenges (food security, disaster risk reduction, economy)." Thus, the emergence of NBS concept signifies a crucial shift of paradigm that beyond deriving benefits from nature, people can take proactive, deliberate efforts on protecting, managing, and restoring natural ecosystems in order to tackle major societal challenges (Cohen-Schacham et al., 2016). NBS essentially encompass interventions that deliver cost-effective solutions to major global challenges while delivering biodiversity benefits, appeal to the wider range of communities beyond the typical conservation community, respect and reinforce communities' rights over natural resources, and target both public and private financing (IUCN, 2012; Nesshöver et al., 2017).

According to the EU commission[3], NBS encompass "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. NBSs must therefore benefit biodiversity and support the delivery of a range of ecosystem services." NBS draw on "the features and complex system processes of nature …". Embedded in this definition is the notion of designing and implementing sustainable solutions to address various environmental, social and economic challenges by using and working with nature as well having nature as a source of inspiration for developing innovative solutions. NBS deliver numerous desirable outcomes for society, including better environmental risk management, increased resilience of ecosystems and flow of vital ecosystem services, enhanced human well-being, socially inclusive green growth, and greater community cohesion and people-nature connection. Compared to conventional approaches, NBS generate greater benefits and synergistic effects on reducing multiple risks (EU Commission, 2005; Nesshöver et al., 2017). This highlights the role and

[3] https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en

scope of NBS within a whole system perspective, simultaneously addressing multiple societal challenges, hence delivering synergies while ensuring that a solution to one specific challenge does not lead to triggering or exacerbating other challenges.

While the definition of NBS can be generic, its application or operationalization is context-dependent, varying by landscape characteristics as well as by spatial and temporal scales. To aid the application, a typology of NBS categories has been proposed by Eggermont et al. (2015). The typology can aid in deciding what does and does not constitute a NBS. The typology classifies NBS in relation to two key determinants:

1) the intensity of engineering contribution into a NBS; and
2) the extent of increase in ecosystem services as a result of deploying the NBS.

According to this typology, NBS can be grouped into three categories:

1) solutions that involve making better use of existing natural or protected ecosystems (e.g., measures to increase fish stocks in an intact wetland to enhance food security);
2) solutions based on developing sustainable management protocols and procedures for managed or restored ecosystems (e.g., re-establishing traditional agro-forestry systems based on commercial tree species to support poverty alleviation); and
3) solutions that involve creating new ecosystems (e.g., establishing green buildings (green walls, green roofs)) (Cohen-Schacham et al., 2016).

3 WHAT IS COST-EFFECTIVENESS ANALYSIS?

The purpose of cost-effectiveness analysis is to provide decision-makers with a tool that can compare different approaches to solve a specific objective. In cost-effectiveness analysis, this is done by comparing costs relative to the effect of different solutions to reaching a predefined objective. In this way, decision-makers can make informed choices to efficiently distribute resourses to projects that are in line with policy objectives (Garber & Phelps, 1997).

Cost-effectiveness analysis can take two forms depending on the decision situation. In the first situation, the budget is fixed, and the purpose of the cost-effectiveness analysis is to point to the solution that provides the greatest benefit at the lowest cost, hence benefit maximization. In the second situation, the objective is fixed, and the purpose of the cost-effectiveness analysis is to point to the solution that achieves the objective at the lowest cost, hence cost minimization (Murray et al., 2000). In real life, budgets and objectives might not be fixed but may be endogenous to the proposed approaches. In this case, the two situations can serve as corner solutions that explore the extent of the outcomes.

In cost-effectiveness analysis, the proposed solutions are ranked according to their effectiveness using the ratio, *R*, between cost, *C*, and the effect, *E*, for individual, *i*, approaches (Sartori et al., 2014).

$$R_i = C_i/E_i \quad (1)$$

Cost-effectiveness analysis originated in the health care sector. The original purpose was to assess different clinical treatments, e.g., treatment for heart failure (Rich& Nease 1999) or treatment of diabetes 1 (Pease et al., 2020). Still today, cost-effectiveness analysis is most widely applied in the health care sector - a simple google scholar search on recent publications using cost Cost-effectiveness analysis as keywords confirms this. Nonetheless, cost-effectiveness analysis is today also applied to other sectors such as the education sector (Hollands et al. 2014), or in policies related to traffic safety (Mak et al. 1998) and air pollution (Cropper et al. 2014) or the built-out wind turbines (Menezes et al., 2018). Cost-effectiveness analysis has also been applied in a NBS context; however, only in a few cases, e.g., Blackhurst et al. (2010) analysis of green roofs or Jiangyi et al. (2020) analysis of different types of wetlands.

3.1 The importance of project scale in cost-effectiveness analysis of NBS

In the assessment of NBS using cost-effectiveness analysis, the delimitation of the effect of NBS can pose a challenge. Unlike, say, a clinical treatment, a NBS is often part of a greater system that solves one or more challenges. For instance, a green urban water drainage system is part of the larger urban water management system that might both solve issues to nearby properties but also solve issues further downstream in the system (Zhou et al., 2013). In essence, the sustainable urban drainage system is part of a greater system, making it difficult to assess the implementation of such a project in isolation. In a scenario where the sustainable urban drainage system is not implemented, other flood risk reduction measures will have to be implemented, and these solutions can take various forms. It is therefore not evident if it makes sense to assess the sustainable urban drainage system, in this example, separately or whether it is better to perceive the drainage system as part of a broader system perspective.

The example with sustainable urban drainage system is related to urban hydrology and rainwater management, but similar arguments can be provided for other NBS, e.g., the construction of peri-urban nature to preserve biodiversity. From a landscape ecology point of view, such a project will be part of a network of biotopes that, collectively, ensures the preservation of vulnerable species (Naveh & Lieberman, 2013). In many circumstances, NBS are part of a system that responds discretely and nonlinearly to changes. In such a system, a narrow focus on single elements is likely to be suboptimal. Cost-effectiveness analysis on a NBS should therefore take a broader system perspective. Thus, looking into the cost-effectiveness of different systems rather than specific projects.

The system characteristics of many NBS also entail that the solutions are not mutually exclusive. The choice is not between one or the other NBS. Instead, a combination of NBS in a common project might be the relevant scale to apply the cost-effectiveness method.

While the application of cost-effectiveness analysis in the health care sector seems straightforward, the opposite is often true in projects based on NBS. The scale of what to assess will not be straightforward, and the analysis will have to make judgment calls based on sound reasoning on a case-by-case basis.

3.2 The context-specific nature of NBS

The services and potential solutions provided by an ecosystem are specific to the context. The same type of NBS does not necessarily deliver the same kinds and magnitude of effects in different settings. To illustrate this, a green space located in an urban area can, under particular circumstances, reduce flood risk from extreme precipitation events. Under other circumstances, a green space can provide habitat for an endangered species (see Chapter 2). However, it is doubtful that a green space both can alleviate flood risk in an urban area and give sanctuary to endangered species. The implications are that a cost-effectiveness analysis of the solutions provided by an ecosystem will have to be case-specific. In the same vein, the work in this report will not result in a generalized cost unit for different NBS.

4 ASSESSING THE MULTIPURPOSE BENEFITS/EFFECTS USING A METHOD DESIGNED FOR SINGULARITY

Cost-effectiveness analyses were originally developed to assess the effect of different courses of treatments in the health care sector. The cost-effectiveness analysis is, in this setting, a straightforward methodology to apply. Patient recovery or survival is compared to the cost of specific treatments.

NBS do not have a simple causal relationship between treatment and effect. NBS are provided by ecosystems and biotopes. A key characteristic of ecosystems is that they provide multiple services, e.g., green space can provide recreation, improve biodiversity and water quality, reduce flood risk, and mitigate noise and air pollution. The implication is that a cost-effectiveness analysis of an ecosystem that focuses on a specific solution will be an analysis with blinders.

The cost-effectiveness analysis method will have to be developed further to account for the multiple services ecosystems provide. Suppose the cost-effectiveness analysis is not adapted to encompass the multi-beneficial effects of NBS. In that case, such an analysis is likely to deliver results that misrepresent more than represent the potential of NBS. In such a case, the problem of underestimation of the benefits is likely to occur.

4.1 Stepwise-singularity

NBS are a solution to a specific policy problem, e.g., air pollution removal, noise mitigation, urban heat mitigation, water quality mitigation, water flow management, carbon sequestration, biodiversity, or demand for wellbeing and recreational experiences (see Chapter 2). Projects may not be initiated to solve multiple challenges, but initiated to solve one specific problem or societal challenge. Public authorities or private organizations come to realize that there is a problem and then decide that the problem needs to be solved. However, in the design phase of the project, additional policy challenges could merge or be integrated into the project. The implications are that a single-purpose perspective cannot entirely be rejected as an approach to an assessment of a NBS.

An extension of the single purpose perspective could be a ranking of the different challenges that the NBS address. The social engineer might want to base the ranking on welfare economic values related to each of the challenges that the NBS deals with. This approach would require that the challenges can be welfare economically quantified, which is likely not realistic. Environmental economic valuation is a well-established field with well-developed methodologies and valuations of distinct environmental goods (Garrod & Willis, 1999). However, it would be relatively resource-intensive to apply appropriate valuation techniques to NBS or even to conduct an appropriate benefit transfer exercise. Also, suppose the welfare economic impact of a proposed NBS is known. In that case, a classical welfare economic cost-benefit analysis would be preferable to a cost-effectiveness analysis as a tool to inform decision making. The main appeal of cost-effectiveness analysis is the relatively little information required relative to other decision-maker tools.

The ranking of different benefits of a NBS project could possibly be done more pragmatically. Decision-makers could rank NBS of specific projects based on existing policy objectives. Suppose a municipality in a southern European country, like Velika Gorica in Croatia, considers a new roof on one of their more prominent public buildings. In that case, the main concern is likely to be cost-related. The municipality official might be concerned with the comfort of the user of the building, the construction and maintenance cost of the roof, and possible energy savings. And the decision-makers in the municipality are likely to be concerned with the project objectives in that specific order. The construction cost will influence the municipality investment budget, while maintenance cost and energy savings will influence the municipality budget as ongoing expenses. From an economic point of view, the focus on the construction cost makes sense as the future flow of benefits and expenses are attributed less value given people's time preference. Except for the comfort consideration, the cost and the energy savings can be relatively easy to calculate in monetary terms and to account for the general time preference priorities (see Section 5.1).

For simplicity, the municipality considers two possible roof types: an extensive green roof and a cool roof with a white reflective coating. Given that the municipality is located in southern Europe, the main energy consumption concern is cooling - making a cool roof an obvious first choice. The municipality may also have policy objectives regarding aesthetical and recreational benefits for the municipality's citizens, preservation and enhancing of biodiversity, CO_2 mitigation, air quality improvement, and risk reduction from extreme precipitation events. A municipality council in municipality could rank the cost and benefits of the two roof types as described in Figure 1.

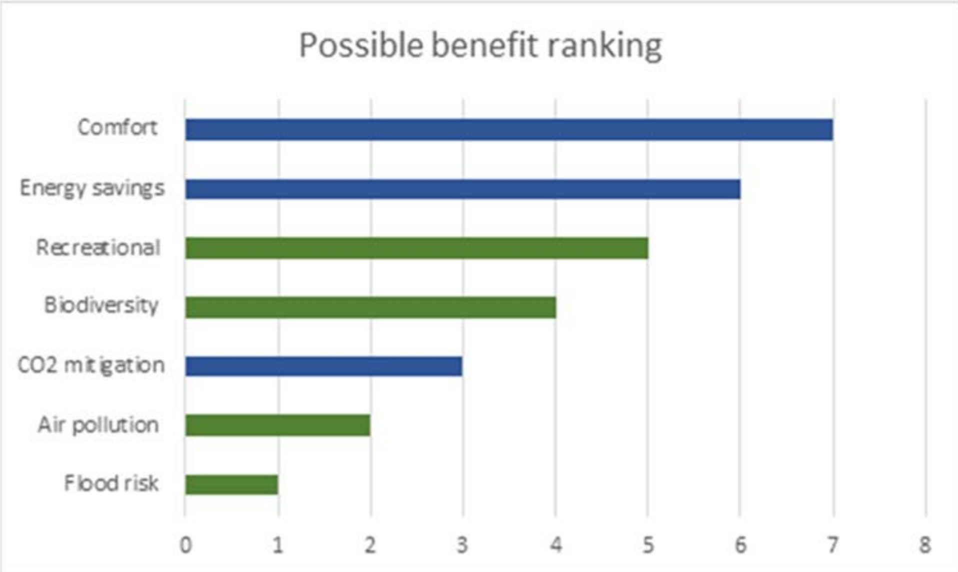

Figure 1. Illustrative ranking of potential benefits for green roofs and cool roofs. The Green column is specific to the green roof, while the blue column represents shared benefits with cool roofs.

Several of the ranked benefits are shared between the roof types, including the comfort of users of the building, energy savings, and CO2 mitigation, while recreational potential, biodiversity protection, air pollution mitigation, and flood risk reduction are benefits that are exclusively related to green roofs.

A single-purpose perspective using cost-effectiveness analysis would likely focus on comfort or energy savings. As the comfort of a green roof and a cool roof is likely the same, a cost-effectiveness analysis could look solely on the cost side. If we adapt the numbers from Berto et al. (2018) on green roofs and cool roofs for an Italian city, an extensive green roof will cost approximately 140.88 EUR/m^2 to construct, and a cool roof will cost 81.588 EUR/m^2. Berto et al. (2018) estimate the maintenance cost to be 2 EUR/m^2 and 2.86 EUR/m^2 for extensive green roofs and cool roofs, respectively. If we assume a lifetime of 40-years for the green roof and a 20-year lifetime for the cool roof, in addition to a non-convex discount rate of 3%, the green roof costs less than the cool roof. A green roof of 400m^2 will cost 76,443 Euro over a 40-year period, while a cool roof will cost 77,100 Euro over a 40-year period. The result is sensitive to the assumption of the lifetime, the discount rate, and maintenance cost. Small changes in the assumption can alter the results. Given the minor difference in mean value and potential variation in the assumptions, the municipality should be indifferent to the choice of type roof if comfort were the only benefit they are considering.

Going one step down, the municipality's policy ranking to energy saving (see Figure 1), the choice of the roof may become clearer. Francis & Jensen (2017) provide an overview of building energy-saving due to reduced cooling requirements as a result of green roof refurbishment. They find that there is an energy-saving ranging from 2.3% up to 90 % based on 21 studies. Most of the green roof studies document energy savings of less than 30%. In contrast, the energy savings of a cool roof are easier to calculate with much higher precision. Rawat & Singh (2021) find that cool roofs can reduce energy consumption by 17% in dry, hot climates. Energy consumption can be reduced even further to 32% and 35% in temperate and tropical regions, respectively. The cooling effect of green roofs and cool roofs are nonetheless overlapping. In this case, constructing a cost-effectiveness ratio would be nonsensical. Thus, the southern European municipality is left with no apparent preferred option.

The municipality council is forced to look further down their ranking, and here the green roof outperforms the cool roof. The green roof is likely to have additional aesthetic and recreational values for people who can see the roof, while the cool roof is just a roof. Similarly, a green roof can possibly enhance or preserve existing biodiversity, which the cool roof does not provide. The green roof can also, to some extent, mitigate air pollution by absorbing air pollutants and reducing pressure on sewerage systems in situations with an excessive amount of rainwater (Francis & Jensen, 2017). While these benefits are relatively small, the cool roof does not provide any of these benefits. Finally, the uncertainty surrounding energy consumption related to green roofs will also be reflected in the potential CO_2 reduction that both roof types provide.

In the example of green roof versus cool roof, the ranking of benefits relative cost showed that green roof is the preferable choice. The ranking approach where each benefit is assessed using the classical cost-effectiveness method provides a pathway where the multipurpose characteristics of NBS can be accounted for while utilizing the simplicity of the cost-effectiveness approach. The example can serve as inspiration for an approach to decision-making. However, the ranking and singularity of the proposed approach does not ensure decisions will result in welfare economic efficient solutions. A determining factor of the outcome is the ranking along with the types of benefits included in the ranking. Suppose the ranking was done in a way that matches the welfare economic value of the benefits. In that case, it is more likely that the ranking and singular testing of benefit will result in a welfare economic, efficient choice. However, this is not by any means given, that decision-makers will rank benefits according to their welfare economic value. If, in the example, biodiversity was ranked above comfort, then the conclusion would have been clearer cut. However, potentially also flawed from a welfare economic point of view – as comfort is, in general, more important to people than the rather marginal biodiversity effect of green roofs.

4.2 A common scale approach

The challenge of the multipurpose characteristics of NBS can also be addressed if the benefits are translated into a common scale. The most obvious solution would be to translate the benefits into monetary values. This can be estimated by doing economic valuation of the specific benefits related to the constructed nature or peri-urban nature, employing revealed and stated preference techniques. A less challenging approach would be to do a benefit transfer exercise where numbers from previous valuation studies are adapted to the specific context of the NBS of interest. However, such an exercise where a range of benefits is translated into monetary value can be rather resource-intensive and time-consuming. Depending on project size, this approach is likely to be outside the scope of available resources for projects where a NBS is under consideration (Bateman et al., 2002).

Alternatively, and perhaps more realistically doable is the use of resource equivalency approach. In this method, the benefits of a project are not quantified in monetary terms. Instead, the researcher then has the challenge to describe or identify projects that can provide similar benefits and document the cost of these projects. The cost of these projects then reflects the “value” of the bundle of benefits provided by the original project (Scemama & Levrel, 2016). The resource equivalence method evaluates benefits in terms of compensation costs relative to experienced benefits by residents. The resource equivalence method has, however, been criticized for providing conclusions that are not in line with welfare economic principles (Zafonte & Hampton, 2007).

Another challenge of the resource equivalence method is the necessity to quantify the entire bundle of benefits of the NBS and then find projects that can provide similar benefits. Given that the benefits of NBS are context-specific, similar projects can prove difficult to identify. Let's say that the municipality in southern Europe interested in a green roof on a public building is considering a building with a roof visible to many people due to terrain differences. In this case, the aesthetic and recreational benefits of the green roof are considerable, making another roof project with similar properties difficult to identify. Also, it is relevant to consider the question of being similar “to whom?” The benefits will have distributional impacts. It is likely not irrelevant to the people receiving the benefits, whether it is themselves or other people who will get access to NBS. For instance, spatial consideration is important for a project if biodiversity protection or biodiversity enhancement benefits are considered the primary benefit to be obtained from the project. Should comparable projects be located close to the original project, or could a national or global perspective be applied? In the latter case, biodiversity projects can become cheap as payment of even a small section of biodiversity-rich nature areas in the global South can provide a lot of protection for many species relative to a project on green roof on a public building in southern Europe.

5 COST FUNCTIONS FOR NBS

We set out to construct cost distributions for green and blue spaces in urban areas, green roofs, small-scale de-pavement projects, and vegetation alterations in urban areas. The cost distributions will be constructed based on a database of international scientific and grey literature. The literature in the database was collected using snowballing in the literature review. Key publications were identified, and these publications were used as the starting point for the literature review by looking at citations and references related to the publications. In this manner, publications with relevant cost information were identified following the literature trails of references and citations.

A systematic literature review proved to be infeasible as the information we seek has not been treated in the literature as the publication's focus. The cost parameters have been extracted from studies with other primary focal points. Information was extracted from scientific literature and grey literature using the general Google search engine, Google scholar, Web of Science, Scopus, and by reaching out to the REGREEN Urban Living Labs partners. L'institut Paris Region and Aarhus municipality were both able to contribute.

5.1 A generalized cost function of NBS

The cost of NBS is a function of the fixed one-time cost of the establishment (d), where the nature areas are constructed, and the ongoing maintenance cost (m), which will burden the project owners' budget going forward. Given that people and companies have a time preference where cost is rather endured in the future relative to the near future, the ongoing cost will have to be discounted with a discount rate (r) that weights the future cost over time (t) relative to the costs endured today.

The debate of discount rate is controversial as the way the weight is implemented in classical economic literature ensures that benefit and cost in the future are negligible. In the debate on sustainable development, the classical implementation of the discount rate has been heavily criticized for emphasizing near future issues relative to issues in the long future (Arrow et al., 2014). People have adjusted for this adverse implication of the classical discount rate by introducing a convex discount rate where the rate is lower as a function over time (Weitzman, 2007). In this report, we will, for simplicity, apply the classical discount rate.

The present cost (C) of a NBS can be calculated using the following equation, where opportunity cost (o) is added to the establishment cost and the net-present cost derived for the sum of discounted maintenance cost over time. The equation can be expanded to contain lifetime consideration - as some constructions will have to be rebuilt while other constructions do not have such temporal constraints.

$$C = o + d + \sum \frac{m}{(1+r)^t} \qquad (2)$$

Development and maintenance costs will vary depending on how mature the industry that constructs the nature areas is. Industry growth goes through different phases, starting with the startup phase characterized by high demand and little supply leading to high price relative to later phases. The demand will attract new companies that will ensure that the demand is met. In the later phases, competition increases as the market is saturated. Growth is slowing, and focusing on expenses and costs becomes a competitive advantage. The result is that prices drop. At the same time, companies consolidate by mergers to achieve economy of scale, preserve the experience, and ensure learning. The result will be even lower establishment and maintenance costs or better products. Small companies will be either bought out or go bankrupt, thus reducing possible cost outliers in the market (Klepper, 1997). The industries that develop around meeting the demand for NBS will be in different phases towards a mature industry. Given that NBS are restricted in geographical space, the industrial life cycle is likely to vary from country to country and region to region. The implications are that some countries will have well-developed industries that provide, e.g., green roofs, while other countries where the know-how is limited tend to have few actors and higher prices. Another explanation for the cost difference between countries and regions is material and labor cost, the latter being the most important for this difference (Jacobs et al. 2004). The implications are that the cost of labor-intense projects will vary more between countries than less labor-intense projects.

5.2 Land-use opportunity cost

Green and blue spaces that can serve as NBS often take up space that could have been used for other purposes. In urban areas where NBS are considered to achieve one or more policy objectives, the NBS will have to compete with other types of land-use, i.e., housing, service, and industrial activities, parking lots, sports activities, and so forth (see Buchanan (1991) for a theoretical introduction to the concept of opportunity cost). In general, the choice and implementation of a particular land-use exclude other land-uses, e.g., an intensively managed urban park cannot function as a parking lot and vice-versa. The forgone land-uses and the benefits that these land-uses provide can be described as a land-use opportunity cost. From a welfare economic perspective, the land-use opportunity cost of possible land-uses should be evaluated and weighed against each other in order to choose the land-use that provides the highest benefit relative to their cost (Buchanan, 1991). Such an exercise requires information about the sum of all the benefits and costs of all land-use types. This type of information is, in general, not available.

Still, the concept of land-use opportunity cost is useful as it underlines the demand for space in urban areas. The implications are that constructed nature areas and biotopes that provide NBS will have to provide obvious solutions to problems that people who live in the area are confronted with. Some might raise the concern that in such a setup, constructed nature areas that provide a NBS are likely to be outcompeted by urban-land uses such as housing or parking lots. However, this is not apparent looking at the literature, e.g., Panduro et al. (2018) find that the recreational benefit alone of having access to an intensively managed urban green park in a large inner-city outperforms housing or parking house projects in terms of the aggregated welfare effect.

In order to compete with other types of urban land-uses, the NBS will have to be able to solve several policy objectives. If the multipurpose characteristics of constructed biotopes are not recognized in the decision-making process, the choice is more likely to lean towards other land use types, such as housing or parking lots. Another implication of the land-use opportunity cost is that nature areas such as green and blue spaces in the urban environment are often found in places with on average lower opportunity costs, i.e., places where the cost of constructing a nature area is high or where land-use demand is low, i.e., in the outskirts of the city. Furthermore, another implication of opportunity cost related to NBS is that constructed biotopes with little or low land-use opportunity cost, such as green roofs, green walls, rain beds, or street trees, have a competitive advantage relative to green and blue spaces that take up larger space. Even though a green roof provides lower benefits on all possible policy objectives (see Section 6), the land-use opportunity cost can shift the conclusion of whether a green space or green roof is the most cost-effective. As demands for space increase, green roofs and other low land opportunity cost NBS will become more attractive to policy objectives relative to NBS that potentially incur a high land opportunity cost.

5.3 Characterizing the costs of different types of NBS

5.3.1 Urban green space

Urban green space is a term that captures a range of spaces in urban areas that serve a range of different services. Urban green space comes in many forms, including urban parks, peri-urban nature in the outskirts of the city, cemeteries, schoolyards, sports grounds, a local housing association playgrounds, or a scrape land buffering dis-amenities or unused building lots (Panduro & Veie, 2013). These green spaces have different facilities and will require different investment and maintenance costs.

The cost of establishing a green space in an urban environment will involve some if not all of these: treatment of contaminated soils or soil movement, soil management, soil preparation, landscape development, planting, and sowing vegetation, creating flowerbeds. Possible additional facilities will also have to be created such as benches, gravel roads, playgrounds, sports facilities and so forth. Some green spaces are small, and others will cover several hectares, depending on the type of green space. To some extent, the economy of scale will be important for the cost. The initial cost of getting people and equipment ready to develop a green space site will be evened out over large areas. Also, ambition-level related to facilities is likely to impact the cost of green space, and finally, labor-intensive activities will influence the cost of establishing a green space. In this respect, countries and regions with low labor costs will have an advantage relative to countries and regions with high labor costs.

In Table 1, we present cost estimates based on a comprehensive literature review that includes scientific literature and grey literature. Also, the Urban Living Labs that are part of the REGREEN project were asked to contribute based on their own historical numbers. All cost measures presented in the table are expressed in Euros 2021. The cost figures have been corrected for inflation to 2021 values in their local currencies and then translated into Euros. The cost measures presented in Table 1 represent numbers based on multiple projects, single projects, and general assessment. Since the cost figures were not the main focal point of the publications, the cost figures are not that well documented in the referenced literature. The implications are that the presented cost figures should be interpreted with care, not as an exact number but rather as an impression of the likely cost level of green spaces. For instance, some of the presented cost measures are likely to include activities not included in other cost measures.

Table 1 includes cost measures covering mainly measures for green spaces from Europe, the US, and China. The table covers small green spaces like wadis, swales, water retention areas, urban parks, urban forestry, and peri-urban nature. The mean establishment cost of green space is 65 €/m^2 with a median cost of 30 €/m^2. The cost distribution is right-skewed with a maximum establishment price of 323 €/m^2 and a minimum of 1.7 €/m^2. The establishment cost is in general higher for European and US sources and cheapest for Chinese sources. The establishment cost is the highest for schoolyards and intensively driven park areas which are likely to be found in inner-city areas. Smaller green spaces are less expensive, and peri-urban nature, located at the fringes of a city, like urban forest and extensively managed green spaces, is the cheapest type of green space.

The mean maintenance cost of urban green space is 1.44 €/m^2, and the median maintenance cost is 0.96 €/m^2. The maximum maintenance cost is 4.16 €/m^2, and the minimum maintenance cost is 0.05

€/m². Again, we find the lowest cost number for China and high maintenance cost for European countries and the US. It is likely that the higher maintenance cost is related to green spaces that are intensively managed, while the lower maintenance cost is related to areas with either low labor cost or low labor intensity like China or in the case of peri-urban nature.

Table 1 Cost overview of green spaces

Source	Short description	Country	Year	Establishment (EUR/m²)	Maintenance (EUR/m²)
NIRAS (2017)	wadi, swale-trench 1 m wide 0.4 m depth	Denmark	2017	69.26 €	3.47 €
	wadi, swale-trench 1 m wide 0.2 m depth		2017	76.25 €	4.16 €
	wadi, swale-trench 2 m wide 0.2 m depth		2017	48.55 €	2.425 €
Keating et al. (2014)	swales	UK	2015	13.13 €	
	swales		2015	19.71 €	0.13 €
	swales		2015	23.64 €	0.13 €
	swales		2015	26.27 €	0.13 €
Yu et al. (2017)	swales	US (New York)	2018	37.32 €	0.05 €
	swales		2018	122.21 €	1.78 €
Gordon-Walker et al. (2007)	swales	UK	2007	20.55 €	0.24 €
Zhang et al. (2012)	park - grass	China	2012		1.4 €
	park - grass		2012		0.93 €
	park - grass		2012		0.62 €
Qiu et al. (2020)	infiltration trench	China	2019	29.84 €	
	bioretention cell		2019	103.04 €	
	vegetated filter strip		2019	56.01 €	
De Sousa (2003)	brownfield conversion to parks	Canada	2003	36.49 €	
García de Jalón et al., (2020)	new green space	Spain	2019	23.29 €	
Li et al., (2019)	new green space to flood reduction	China	2019	2.16 €	
	new green space to flood reduction		2019	6.91 €	
DuMoulin et al. (2008)	park	US	2007	183.79 €	
Tempesta (2013)	park maintenance	Italy	2012		1.19 €
			2012		0.42 €
			2012		2.96 €
Escobedo et al. (2008)	urban forestry	Chile	2008		0,06 €

Source	Short description	Country	Year	Establishment (EUR/m²)	Maintenance (EUR/m²)
Chen & Jim (2008)	park extensive	China	2008	1.73 €	
			2008	25.9 €	
Reynaud et al. (2015)	wet-green park	Italy	2015	88.13 €	0.98 €
Liu et al. (2016)	green space depression for stormwater	China	2015	5.87 €	0.18 €
Foster et al. (2011)	urban forestry	US	2006	322.76 €	
Aarhus municipality (2021)	intensive park (city park)	Denmark	2021	80.69 €	4.03 €
	extensive parks (peri-urban)		2021	33.62 €	1.61 €
	amenity area- green schoolyard		2021	201.72 €	4.03 €
	peri-urban forest		2021	4.03 €	0.4 €
	wadi		2021	134.48 €	
L'institut Paris Region (2021)	conversion from wasteland to park	France	2018	6.8 €	
	Improvement of nature quality peri-urban nature		2019	7.5 €	
	creation of peri-urban nature		2016	13.9 €	
	schoolyard		2018	303 €	

5.3.2 Blue space

Blue space in urban areas can be lakes, ponds, streams, and rivers. In the outskirts of the city, blue spaces can also refer to wetlands. The cost of constructing and maintaining a blue space will, in many cases, require removal of existing land-use, excavation, soil removal, the addition of coarse material, creation of impermeable layers, creating possible pumping stations, landscape development, planting, and sowing vegetation at the blue space banks (Kristensen et al., 2021). In addition, possible facilities that can help improve the recreational experience of the blue space might also need to be installed, e.g., benches, bridges, floating pontoons.

The cost of construction will also be a function of the size of the blue space. In absolute terms, costs will increase with the size of the blue space. However, due to the economy of scale, the relative cost is likely to go down. Investment and maintenance costs will also be influenced by labor costs and the labor insensitivity of the projects. Depending on the specific context, the cost of constructing a blue space can be as little as stopping pumping groundwater. In other places in concentrated urban areas, costs related to land-use removal such as de-paving will drive the cost up.

The construction and maintenance cost of blue space is presented in Table 2. The cost estimates were extracted from scientific and grey literature. The urban living labs also provide numbers based on previous projects. All cost measures presented in the table are expressed in 2021 Euros. The cost measure has been corrected for inflation to 2021 values in their local currencies and then translated into Euros. The cost figures presented in Table 2 represent numbers based on multiple projects, single projects, and general assessment. The cost figures in Table 2 should not be taken as the exact numbers but rather as an impression of the likely cost level of urban blue spaces. Still, the figures provided in the table give valuable information about the cost level for different types of blue spaces and to what extent the costs differ costs worldwide.

Table 2 includes cost estimates covering mainly blue spaces from Europe, the US, and China. The table covers small blue spaces such as lakes, ponds, streams, rivers, and wetlands. The mean establishment cost of a pond or a lake is 102 €/m^3, and the median cost is 33 €/m^3. The establishment cost of lakes and ponds is especially high for the Danish sources and is extremely low for the references from a Brazilian case study. The Chinese cost figure in Table 2 is all above the mean values. The difference in cost is likely a result of the context-specific cost related to the level of urban development of the reported projects. The maintenance of lakes or ponds costs on average 2,586 €/basin with a median maintenance cost of 1,390 €/basin.

The cost of streams and rivers is also reported in Table 2. Especially, L'institut Paris Region has knowledge of several river-reopening and river-restoration projects. In these examples, previous piped or straightened streams and rivers are re-established as "natural" hydrological systems. The cost of reopening a river/stream ranges from 5.8 €/m to 13,650 €/m. This large difference is explained by the specific urban context of the reported project from a predominantly rural to a highly developed urban area. The reported Danish cost figures for small streams represent lower cost estimates (90-124 €/m) relative to the cost estimate from Paris region. The maintenance cost is reported to range between 2-5 €/m.

Table 2 also contains cost information on wetland construction from the US and France. The cost ranges from 0.04 €/m^2 to 4.28 €/m^2 with a mean cost of 1.63 €/m^2 and a median cost of 0.9 €/m^2. Even though the units differ between wetlands and the other blue spaces, it is evident that the cost of wetlands is much lower than the other types of blue spaces, e.g., ponds, lakes, and streams. The cost figures in Table 2, however, do not contain land opportunity costs. The implications are that even though the cost of wetlands is low, wetlands are possibly still the most expensive blue space in developed urban areas, while wetlands could be potentially more competitive in the fringes of large cities.

Table 2 Cost overview of blue spaces

Source	Short description	Country	Year	Establishment Euro/m^3	Maintenance Euro
NIRAS (2017)	Lake	Denmark	2017	277.36 € 69.34 € 554.73 €	554.73 €/basin 277 €/basin 1386 €/basin
Keating et al. (2015)	Pond	UK	2015	19.71 € 32.84 € 21.02 €	1320 €/basin 3960 €/basin 2640 €/basin
US EPA (1998)	Pond	USA	1999	19.6 €	

Source	Short description	Country	Year	Establishment Euro/m^3	Maintenance Euro
				26.14 €	
Narayanan & Pitt (2006)	Pond	USA	1996	11.11 € 24.98 €	1821.6 €/basin 12033 €/basin
Chui et al. (2015)	Pond	Hongkong	2016	132.09 € 138.62 €	469.67 €/basin 469.67 €/basin
Liu et al. (2016)	Pond	China	2015	117.35 €	3520 € /basin
Targino et al. 2019)	Pond	Brazil	2017	4.37 €	
Aarhus municipality (2021)	Pond	Denmark	2021	80.69 €	
NIRAS (2017)	Stream (1m*1m) Stream (0.5m*1m) Stream (0.5m*2m) Stream (1m*2m)	Denmark	2017	104 € 124 € 117 € 90 €	3 € (m) 5 € (m) 3.6 € (m) 2 € (m)
Tyndall & Bowman (2016)	Wetland	US	2016	0.94 € (m2)	0.07 € (m^2)
Aerts (2018)	Wetland	US	2016	4.28 € (m2)	
Leon et al. (2018)	Wetland	US	2018	0.04 € (m2)	0.5 € (m^2)
L'Institut Paris Region (2021)	River Re-opening River Reopening River Reopening River Reopening River Reopening Riverbank restoration Riverbank restoration Flood area expansion Wetland restoration Wetland restoration	France	2014 2012 2014 2014 2014 2018 2020 2019 2018 2018	5.8 € (m) 13,650 € (m) 126 € (m) 578 € (m) 1,051 € (m) 2,667 € (m) 695 € (m) 29.5 € (m2) 0.5 € (m2) 2.4 € (m2)	0.01 € (m2)

5.3.3 Green roof

Green roofs can be either extensive or intensive. The difference between the two types of green roofs is the thickness of the growth media. On average, extensive green roofs have 20 cm growth media, while intensive green roofs have a growth media around 0.5 cm (William et al., 2016). The difference in construction has the implication that extensive green roofs, in most cases, can be retrofitted to regular houses without strengthening the load-bearing elements in the building. The opposite is true for intensive green roofs that can only be retrofitted to buildings that have been dimensioned to withstand heavy loads or designed specifically for an intensive green roof. The other difference between extensive and intensive green roofs is that the latter can only sustain resilient drought-resistant plants growth, e.g., sedum plants, while the former can sustain regular plants much similar to plants growing on the land surface.

Green roofs are more similar to each other than, for instance, between green and blue space. Still, there will be a difference depending on building codes, knowledge base, and competition among the roof providers. A green roof consists of a plant layer, a growing media, a filter layer, a root barrier layer, and a protection layer. The cost of construction will vary according to the use of the material, the skillset of those who install the roof, and the general labor cost in the area. We find that extensive green roof establishment cost will, on average, be 107 €/m^2 with a median cost of 106 €/m^2 – see Table 3. The maintenance cost is on average 7 €/m^2 and on the median 2.6 €/m^2. The establishment cost of green roofs does not have a large variability relative to the green and blue space cost figures reported earlier.

Intensive roof cost on average 235 €/m^2 to construct. The median construction cost is 281 €/m^2. The construction cost figures describe a left-leaning distribution with a few relatively cheap cost figures and several cost measures above 300 €/m^2. Maintenance cost is on average 9 €/m^2, and on the median cost is 12.6 €/m^2. According to Table 3, the construction cost of an intensive roof seems to be between double and triple the cost of an extensive roof, e.g Bianchini & Hewage (2011) documenting cost for both extensive and intensive roofs find similar cost relationships.

The Urban Living Labs of Aarhus municipality and Paris region are also able to provide cost estimates for vertical greening of buildings in the form of green walls. It turns out that climbing plants are the cheapest green wall solution, while other types of green walls where plants grow above the ground are much more expensive.

Table 3 Cost overview of green roofs

Source	Short description	Country	Year	Development EUR/m^2	Maintenance EUR/m^2
Bianchini & Hewage (2011)	Extensive	Canada	2012	119.9 €	0.66 €
	Extensive			152.5 €	12.84 €
	Intensive			499.02 €	12.85 €
Wong et al. (2003)	Extensive	Singapore	2003		3.91 €
	Intensive		2003	192.43 €	4.24 €
GSA (2011)	Extensive	US	2011	19.57 €	0.25 €
	Intensive		2011	26.09 €	0.25 €
Armitage et al. (2013)	Extensive	South Africa	2013	38.39 €	
Keating et al. (2015)	Extensive	UK	2015	117.82 €	
	Extensive		2015	105.11 €	

Source	Short description	Country	Year	Development EUR/m²	Maintenance EUR/m²
Carter & Keeler (2008)	Intensive	US	2005	176.94 €	
Claus and Rousseau (2012)	Extensive	Netherlands	2008	127.94 €	1.16 €
Mahdiyar et al. (2016)	Extensive Extensive Extensive	Malaysia	2016 2016 2016	65.23 € 86.43 € 208.74 €	0.22 € 0.7 € 5.67 €
Shin & Kim (2019)	Extensive	South Korea	2019	96.84 €	1.27 €
Yu et al. (2018)	Extensive Intensive	US	2018 2018	112.03 € 503.72 €	0.94 € 27.04 €
Chui et al. (2016)	Extensive Extensive	Hongkong US-Seattle	2016 2016	145 € 235.5 €	14.56 € 54.59 €
Johnson et al. (2020)	Extensive Extensive	Austria	2018 2018	59.66 € 92.55 €	0.66 € 4.11 €
Manso et al. (2021)	Extensive Intensive	Several	2019	91.59 € 334.45 €	4.14 € 7.5 €
William et al. (2016)	Extensive intensive	US	2016 2016	195.44 € 293.56 €	 7.28 €
Qiu et al. (2020)	Extensive	China	2019	6.27 €	
Aarhus municipality (2021)	Extensive Intensive Green wall (climbing)	Denmark	2021 2021 2021	107.58 € 268.96 € 1.35 €	1.34 € 4.03 € 1.08 €
L'Institut Paris Region (2021)	Extensive	France	2015	63 €	11.77 €
	Semi-Intensive			108 €	12.64 €
	Intensive			185 €	14.01 €
	Green wall (tablecloth)			797 €	61 €
	Green wall (performed models)			474 €	42 €
	Green wall (gabion)			606 €	44 €
	Green wall (hanging)			572 €	42 €
	Green wall (climbing wall)			55 €	9.5 €

5.3.4 De-pavement

De-pavement project, where a small or large section of pavement is removed to give place for plants and increase rainwater infiltration and retention, can have many different forms. In some projects, small sections of pavement are removed to give way to flower rain-beds. In other projects, impermeable pavement is replaced by porous pavement or gravel for streets, parking lots, or schoolyards. The cost estimates provided in Table 4, for the more expensive sources, describe the cost of removing pavement and then replacing the pavement with an infiltration solution. Other cost figures in Table 4 do not account for the removal of pavement.

The cost of de-pavement projects ranges from 1815.49 €/m² for rain-beds in Denmark to 8.89 €/m² for porous pavement projects in China. The average de-pavement projects are likely to range between 50-500 €/m². Maintenance of de-pavement projects costs between 0.18 €/m² and 16.93 €/m². There is rather considerable uncertainty in the cost estimates related to de-pavement projects. However, the uncertainty is likely to lessen as more de-pavement projects get described and published in the coming future.

Table 4 Cost overview of de-pavement projects

Source	Short description	Country	Year	Establishment EUR/m²	Maintenance EUR/m²
NIRAS (2017)	Rainbeds - paved	Denmark	2017	1386.63 €	3.46 €
Siwiec et al. (2018)	Rainbed	Polen	2018	520.09 €	
Gordon-Walker et al. (2007)	De-pavement	UK	2007	90.85 €	0.62 €
Chui et al. (2016)	Porous pavement	Hongkong	2016	57 €	16.93 €
		US-Seattle	2016	62.26 €	12.16 €
Liu et al. (2016)	Porous pavement	China	2015	8.89 €	0.18 €
Qiu et al. (2020)	Porous pavement	China	2019	24.48 €	
Aarhus municipality (2021)	Gravel footpath - not paved	Denmark	2021		1.08 €
	Rain beds - not paved		2021	470.68 €	
	Rainbeds - paved		2021	1815.49 €	
L'Institut Paris Region (2021)	De-pavement	France	2019	96 €	
				394 €	
	Schoolyard		2018	303 €	

5.3.4 Street trees

The investment and maintenance costs of street trees placed along urban streets are presented in Table 5. The average investment cost in street trees is 1581 €/tree, and the median investment cost is 210 €/tree. The investment cost figures describe a heavy-tailed right-leaning distribution due to cost estimates provided by Aarhus municipality. The most relevant investment cost number is, therefore, the median cost of 210 €/tree. The difference in cost between Aarhus municipality and the other sources is partly due to the de-pavement cost that Aarhus municipality accounts for in their cost figures. The mean maintenance cost is 33 €/tree, and the median cost is 27 €/tree. A few references have presented the cost in square meters that have not been translated into a tree unit.

Table 5 Cost overview of street trees

Source	Short description	Country	Year	Unit	Establishment EUR/Unit	Maintenance EUR/unit
Yu et al. (2018)	Street trees in green space	US -New York	2018	m2	9.87 € 236.84 €	7.74 €
McPherson et al. (2005)	Street trees	US - Fort Collins	2005	trees	258.06 €	33.26 €
	Street trees	US - Cheyenne	2005	trees	80.24 €	19.27 €
	Street trees	US - Bismack	2005	tress	11.63 €	20.27 €
	Street trees	US - Berkley	2005	trees	183.73 €	72.56 €
	Street trees	US - Glendale	2005	trees	122.1 €	13.84 €
McPherson et al. (2006)	Street trees	US - California	2006	trees	168.66 €	
					618 €	
Maco et al. (2003)	Street trees	US - California	2003	trees	7.34 €	35.10 €
McPherson et al. (2017)	Street trees	US – California	2017			17.41 €
Johnson et al. (2020)	Trees	Austria	2017	m2		0.8 €
	Vegetation	Austria	2017	m2		3.99 €
Soares et al. (2011)	Street trees	Lisbon	2011	trees		43.51 €
Song et al. (2018)	Street forest	Review	2018	trees		22.44 €
Wang et al. (2018)	Street trees	China-Dalian	2018	trees		18.19 €
						30.80 €
Targino et al. (2019)	Trees in green space	Brazil	2017	m2	0.58 €	0.9 €
Foster et al. (2011)	Urban forestry	US	2011	trees	50.48 €	15.15 €
					504.84 €	65.62 €
Aarhus municipality (2021)	Street trees in green space	Denmark	2021	trees	1,075.85 €	53.79 €
	Street trees street				5,379.24 €	
	Trees paved area				13,448.09 €	

5.4 Summing up the cost estimates

The cost estimates presented in Tables 1-5 provide an overview of the cost of the construction of different urban and peri-urban nature areas. The cost figures presented in the tables show large variability in cost, which both reflect the different definitions of cost estimates, i.e., largely dependent on the elements of the cost that are included and or excluded from the cost figures reported by the different sources. The presented cost figures represent reviews of many projects or reflect only the cost of a single project.

It has not been possible to access primary cost data. The reported cost estimates are thus secondary sources and must be interpreted with caution. Another factor that drives the price differences is the specific context that has produced the cost figures. Elements such as labor intensity, labor cost, experience, competencies, industry maturity all affect the costs of constructing and maintaining nature areas that can serve as NBS.

Despite all the caveats, we argue that the cost estimates provided in Tables 1-5 are informative. The cost figures can be applied to different NBS projects as part of a scoping exercise that will inform further assessments.

Using equation 2, we have calculated one unit cost for green space, blue spaces, green roofs, and street trees (see Table 6). We use the median cost estimates of investment and maintenance costs. In addition, we use a discount rate of 3% and assume the project will run for 50 years. Furthermore, we assume a lifetime above 50 years for green space, blue space, and street trees. However, we follow Manso et al. (2021), Carter & Keeler (2008), and GSA (2011) assessments of green roofs and set the lifetime of an extensive green roof to 40 years.

Table 6 Median cost of different constructed nature types

Type	Lifetime	Unit	Net present cost
Green space	> 50 years	m^2	55 €
Blue space - pond	> 50 years	m^3	70 €
Extensive green roof	40 years	m^2	207 €
Street trees	> 50 years	tree	921 €

Given the functional form of equation 2 and the choice of the discount rate, the investment/establishment cost is more emphasized relative to the ongoing maintenance cost. A lower discount or a discount rate that decreases over time would give maintenance costs a higher weight (Weitzman, 2007). It is important to note that the calculated cost does not include land opportunity cost consideration, which would potentially change the cost estimates depending on the specific urban setting. The cost figures presented in Table 6 show that green spaces are the least expensive relative to an extensive green roof or a pond with a depth of one meter. It is difficult to compare street trees in terms of size to the other types of constructed nature areas as street tree coverage will vary from the foot to the tree's crown.

6 EFFECT ASSESSMENTS

Urban and peri-urban nature areas can mitigate or manage air pollution, noise pollution, heat, water quality, water flow, carbon emissions, biodiversity, and the wellbeing of people. The different possible nature areas can provide these different ecosystem services, however, not at the same level. In Table 7, the level of service is provided by different types of green and blue spaces, de-pavement projects, green roofs, and street trees. The level of services was assessed by lead scientists in the Regreen project. The nature areas are assessed on a scale starting from "Very high", "High", "Medium", "Low", and ends with "Negligible".

The services that urban and peri-urban nature provide - as a NBS - to a specific issue will vary depending on the specific context where the NBS is implemented. In dry, hot climates, a green roof will, for instance - in addition to contributing to the well-being of residents – alleviate and mitigate heat. In a cold wet climate, a green roof is likely to manage water flow in the city. The point is that the ecosystem services provided by urban or peri-urban nature will vary depending on the specific context. The implications are that the magnitude of the service will vary depending on the location. Nevertheless, the direction of the relationship between the different levels of services provided by urban and peri-urban nature is likely to hold. It also means that the effectiveness of a NBS cannot be captured by one number but will vary over a range of numbers. The scale provided by experts in table 7 is, therefore, an exercise that simplifies and translates the effectiveness of the NBS to address the challenges of local residents.

Table 7 shows that peri-urban nature in green space woodland provides the strongest ecosystem services across all types of service and will therefore also function as the NBS with the highest potential. In comparison, a green roof will provide a lower level of services on all accounts. Still, in some situations, green roofs are likely to offer the better option given the land opportunity cost connected with large green spaces.

Table 7 Expert assessment of the effectiveness of urban nature areas

Object category	Air pollution	Noise	Heat	Water quality	Water flow	Carbon	Bio diversity	Wellbeing
Woodland (other)	Very high	Very high	Very high	Very high	Very high	Very high	Very high	High
Green space - Pocket park	Low	Low	Low	High	High	Low	Low	High
Green space - Urban park	Medium	High	High	Very high	Very high	High	High	High
Green space - Sports field	Low	Negligibl e	Low	Negligible	Low	Negligibl e	Negligible	Medium
Street tree	High	Low	Medium	Low	Low	Medium	High	High
Green roof	Low	Negligibl e	Low	Low	High	Low	Low	Negligible
Green wall	Medium	Medium	Negligibl e	Negligible	Low	Low	Low	Medium
Permeable paving	Negligibl e	Negligibl e	Negligibl e	High	High	Negligibl e	Negligible	Negligible
Blue space Wetland	Medium	Low	Medium	Very high	Very high	Medium	Medium	Medium
Blue space River/stream	Low	High	High	Medium	Low	Low	High	Very high
Blue space Pond	Low	Low	Low	Medium	Low	Medium	High	Very high
Blue space Lake	Low	Medium	High	High	Medium	Medium	Very high	Very high
Blue space Reservoir	Low	Medium	High	High	High	Medium	High	High

7 APPLICATION OF COST-EFFECTIVENESS

In the following section, two applications of the pragmatic cost-effectiveness ranking approach are presented in order to exemplify the advantages and the shortcomings of the approach. The first case focuses on the increasing problem that Aarhus municipality and Aarhus utility company have with capacity problems in the sewerage system. The accelerating anthropogenic climate change is expected to alter precipitation patterns across the globe. In Aarhus, Denmark, the overall rainwater volume will increase and, at the same time, happen in more intense concentrated events resulting in a higher frequency of extreme precipitation events. The existing sewerage system in Aarhus is not dimensioned to the existing and the coming changes in the climate, thus, leading to capacity problems in the sewerage system and consequently flood risk in many parts of the city.

The second cases revolve around reducing exposure from flash flood events by the river Croult in the city of Gonesse, located in the greater Paris area in France. The flash floods are expected to increase, exposing the citizens of Gonesse to floods. The regional municipality of Paris recognizes the need to alleviate water pressure during flash flood river events along with the Croult river system, thus reducing exposure and risk to the citizens of Gonesse.

7.1 Reducing sewerage system pressure in Åbyhøj neighborhood in Aarhus municipality

Aarhus municipality and Aarhus utility company are in the process of increasing capacity in the sewerage system across the city. Parts of the older areas of the city need sewerage system separation, and other policy’s objective also influences the large-scale effort by Aarhus municipality and Aarhus utility company. The municipality seeks to create better urban spaces by improving the recreational and aesthetics of the city. The municipality also has focused on creating spaces that make people feel safe and stimulate social interactions in order to combat loneliness. Biodiversity and health are also on the municipality´s agenda and are duly considered in the investment by the municipality (Aarhus Kommune & Aarhus Vand, 2016).

In the Åbyhøj neighbourhood in the eastern part of Aarhus city, the municipality of Aarhus and Arhus utility company seek to reduce pressure on the sewerage system of about 2145 m3 water. They are considering increasing the capacity by constructing a closed rainwater basin or by constructing rainwater retention ponds with permanent water. Alternatively, the municipality also considers involving local housing associations and residents to alleviate pressure on the sewerage system by having citizens invest in green roofs. In fact, Aarhus municipality has a strategy to increase the number of green roofs to alleviate the sewerage system (Aarhus Kommune & Aarhus Vand, 2016). In this case, both the retention pond and the green roof have the possibility to work as a NBS.

Åbyhøj has a large green space, - “Klokkerparken” - which is about 4.5 ha. In the northern part of the city park, there is already some old depression which possibly could be the starting point for a retention pond with a capacity to handle 2145m^3 water influx in a short period. The retention pond will be designed to have a basin with permanent water covering 900m^2 (~ 270m^3) and a mildly slopping area covering 8050m^2 that can contain additional 2145m^3 water in a short period of time. In total, the retention pond with permanent water will cover 8050m^2 which equals about 2415m^3. The cubic meter assessment will, in this case, be an upper-bar assessment as the area already have an old landscape depression that functions as an overflow area. The assessment of the size of the retention pond was adapted from DANVA (2018) examples for permanent water basins.

The mean investment/establishment cost of blue space was calculated to be 102 EUR/m^3 and on the median 33 EUR/m^3 (see 5.3.2). The results indicate a right-leaning heavy-tailed distribution indicating that some references have rather high-cost estimates relative to the rest of the sample - especially the Danish source reported high establishment cost. The most appropriate number would be the median cost in many cases, thus reducing the impact of potential extreme outliers. However, in this particular case, with Danish source reporting high cost, the mean cost is the better choice as is likely to resemble the actual costs. The mean maintenance cost is reported to be about 2,586 EUR/basin, and the median maintenance cost is reported to be 1,390 EUR/basin (see Section 5.3.2). Again, the higher cost figure is likely the most appropriate and will enter into the cost-effectiveness calculation presented in Table 8.

An alternative to an open urban drainage system like the retention pond with permanent water is a closed retention basin located underground. Experience numbers provided by NIRAS (2007) - that have been inflation corrected and translated into Euro - show a construction cost of 1248 EUR/m3 and a maintenance cost of 5.5 EUR/^{m3} for a midsize, closed retention basin in Denmark.

Finally, green roofs are also considered as a potential solution. Aarhus municipality focuses on green roofs as a possible solution to alleviate stress on the sewerage system. Sewerage overflow due to extreme precipitation events is a dynamic problem that occurs as the dimensions of sewerage pipes in a short period of time are exceeded. In cold, wet climates, green roofs have the functionality as a retention space for rainwater which is slowly released to the sewerage system, thus alleviating the risk of sewerage system overflow (Johannessen et al., 2017). We assume that a green roof can absorb about 20 mm of rain per hour, similar to Hamouz et al. (2018) results. Furthermore, we assume that Aarhus utility company wants their sewerage system to handle extreme precipitation events of 1 mm rain per minute in 30 minutes. The implications are that there would need to be installed 214,500m^2 extensive roof to have a retention capacity of 2145m^3. We use the calculated median establishment cost of 106 EUR/m^2 and the maintenance cost of 2.66 EUR/m^2 in the cost-effectiveness analysis.

In Table 8, the ranked cost-effectiveness analysis is presented for a 2,145m^3 water retention in the sewerage system in Åbyhøj, Aarhus. The calculation is reported for a retention pond, green roof, and closed basin solution. The cost is evaluated over a 50-year period and follows equation 2 to evaluate costs in the future, assuming a stable discount rate across all years of 3%. Policy objectives other than the retention capacity are not quantified but are based on the qualitative expert assessment in Table 7. The calculations show that a retention pond with recreation potential is by far the cheapest solution. The retention pond is also able to provide services that are relevant to the policy objectives defined by Aarhus municipality. The green roof solution and closed basin solution are not attractive alternatives. A closed basin is directly compatible with a retention pond as its key function is to hold water for a short period. The main objective of a green roof is to provide shelter and well-being for the people living in houses with a green roof. The implications are that a cost-effectiveness exercise like this one sets the green roof at a considerable disadvantage. The point is that green roofs are only relevant to consider if the main problem is roof renovation – like in the example in Section 4.1.

Table 8 Ranked cost-effectiveness for NBS in Aarhus

	Retention pond	Green roofs	Closed basin
Costs investment/ establishment	246,330 EUR	29,707,183EUR	2,676,960 EUR
Maintenance cost	68,533 EUR	15,121,050 EUR	312,653 EUR
Lifetime	75 years	40 years	75 years
Total costs	314,863 EUR	44,828,233 EUR	2,989,613 EUR
Cost-effectiveness ratio	146 EUR/m^3	20,899 EUR/m^3	1394 EUR/m^3
Ranked policies			
Reducing pressure on the sewerage system	Solved	Solved	Solved
More recreational space	Medium	Negligible	Negligible
Improved aesthetics	Medium	Negligible	Negligible
Reduced loneliness	Medium	Negligible	Negligible
Increased health	Negligible	Negligible	Negligible
Improved biodiversity	Medium	Low	Negligible

7.2 Reducing risk of flash floods for Croult River in Gonesse, Paris

To reduce the risk from flash floods from the river Croult for the citizens in Gonesse, a flood expansion zone was created with a capacity to store 55,000 m3 of water. The expansion zone consists of a series of wetlands and ponds that, in addition to flood risk reduction, promote biodiversity and recreational experiences among the citizens in Gonesse. The alternative to wetland and ponds construction would likely be a series of open concrete basins that, under flash floods from the river, would alleviate the risk of flooding.

The flood expansion area covers 12ha. We assume two-thirds consist of newly established wetland, and the rest of the areas are ponds and walkable pathways. We apply the mean establishment cost for wetlands of 1.6 EUR/m^2 and a maintenance cost of 0.5 EUR/m2 for 2/3 of the 12 Ha. We assume that this area will have the capacity to contain 37,000m^3 of the project volume 55,000m^3. The last 18,000 ^{m3} is assumed to be covered by nine smaller basins, each with a capacity of 2,000m^3. We apply the median establishment cost for wet basins at 33 EUR/m3 and maintenance cost of 1390 EUR per basin.

The alternative to the wetland flood zone solution is assumed to be a series of open concrete basins that are assumed to have an establishment cost of 693 EUR/m^3 and a maintenance cost of 5.5 EUR/m^3. The numbers are adapted from NIRAS (2017) cost assessment of concrete open basins.

The municipality has additional general planning policy objectives that have been important in the decision process. It is seen as an important objective to increase biodiversity and at the same time create places where people can have recreational experiences from nature. These objectives will enter into the stepwise ranking of the cost-effectiveness analysis.

In Table 9, the ranked cost-effectiveness analysis is presented for a 55,000m^3 water flash flood reservoir. In the table, the wetland solution is compared to large concrete basins. The costs are evaluated over a 50-year period. We use equation 2 to evaluate costs in the future, assuming a stable discount rate across all years of 3%. Policy objectives other than the retention capacity are not quantified but follow the expert qualitative assessment in Table 7. The calculations show that the wetland solution is by far the cheapest. The wetland also provides services that are relevant to the general policy objectives, which the concrete basins solution does not.

Table 9 Ranked cost-effectiveness for NBS in Gonesse, Paris

	Wetland + ponds	Concrete open basins
Investment/establishment costs	722,000 EUR	38,115,000 EUR
Maintenance costs	1,391,602 EUR	8,016,751 EUR
Lifetime	> 50 years	>50 years
Total costs	2,113,602 EUR	46,131,751 EUR
Cost-effectiveness ratio	38 EUR/m^3	838 EUR/m^3
Reduced risk of flash floods	Solved	Solved
Improved biodiversity	Medium	Negligible
More recreational space	Medium	Negligible

8 DISCUSSION AND CONCLUSION

In this report, we provide an overview of costs for nature areas that can serve as NBS. We provide cost estimates for green and blue spaces in urban and peri-urban areas. We also provide cost estimates for de-pavement projects, street trees, green roofs and green walls. We show that these cost estimates can be applied in cost-effectiveness analysis in three different examples. We furthermore discuss how the cost-effectiveness analysis can be expanded to account for the potential multiple benefits provided by nature in urban and peri-urban areas that are in line with the spatial planning policy objectives by local authorities. We argue that a stepwise ranking of policy objectives in a cost-effectiveness analysis is a viable approach that will enable policymakers to make an informed choice over competing solutions.

We attempt to define NBS so as to make the concept operational in a policy setting. We find that NBS have been defined in various ways. In some cases, NBS has been dubbed “an umbrella concept” that relates to other more established concepts, including nature and ecosystem services. However, clear operationalization of the concept remains scarce. In other cases, people have focused too much on the "solution" in NBS without clearly defining the problem. For there to be a solution, there needs to be a problem to be solved. Cost-effectiveness analysis helps to focus on the challenges and thus identify the problem that needs solving. Multiple policy objectives are likely to be competing. However, all projects start with one specific problem that needs solving, after which other policy objectives can be incorporated into the solution.

Costs of NBS seem to vary both between different categories as well as within a category of NBS. To illustrate, the cost of de-pavement projects ranges from 8.89 €/m^2 for porous pavement projects in China to 1815.49 €/m^2 for rain-beds in Denmark. Variations in the costs are due to a number of factors, including the inconsistency in the reporting of cost components by different sources and the fact that that the influence of the contexts where the NBS are implemented. High variation in the cost figures for certain NBS inevitably poses considerable uncertainty. Overall, comprehensive, harmonized information on the costs of NBS remains scarce, although this is expected to change in the coming future as more reports and publications containing cost data become available. In the same vein, a detailed, quantitative assessment of the effects of different NBS is also lacking. Nevertheless, it is worth noting that this report is among the first attempts to compile the cost figures and to evaluate the cost-effectiveness of different NBS

The applications of NBS in the Aarhus case and the Gonesse/Paris case underline that NBS can outcompete classical infrastructure solutions – sometimes by a lot. However, available cost figures from the literature and from the two Regreen cases do not account for land opportunity costs. NBS involving green and blue spaces in urban settings most likely have to compete with other possible uses, including, for example, residential areas, industrial infrastructures, parking spaces etc. The use of urban space for establishing nature based-solutions inevitably excludes other land-uses with an inevitable consequence of forgone alternative land-uses and the associated benefits that these land-uses provide - known as a land-use opportunity cost. This implies that the use of space for NBS will have to provide obvious solutions to pressing problems that people who live in the area are facing. Furthermore, to be competitive with other types of urban land-uses, the prioritization of urban space use for NBS will have to fully consider the capacity and potential of these solutions to address multiple policy objectives. Otherwise, the totality of the desirable impacts of NBS is likely to be underestimated, and the choice for NBS is likely to be outcompeted by other land-use types, such as housing or parking lots. Another implication of the land-use opportunity cost is that nature areas such as green and blue spaces in the urban environment require larger spaces, hence likely incur a high land opportunity cost.

Consequently, other NBS that are less demanding in terms of space requirement, despite the lower benefits, are likely to receive greater preference in the policy decision-making process. In short, in densely populated urban areas, land opportunity costs will reduce the competitiveness of NBS provided by green and blue spaces as these types of nature areas take up too much space. Future research should explore the relationship between land opportunity cost and NBS.

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