AN INSTITIÚID UM THAIGHDE EACNAMAÍOCHTA AGUS SÓISIALTA
ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

ESRI Working Paper No. 794

September 2024

Nature-based solutions for climate adaptation: Review of barriers to adoption and guidelines for policymakers

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Funding: This research received support under the Irish Environmental Protection Agency Research Programme 2021-2030 and co-funding from the Irish Department of Transport. The opinions con-tained within this paper are personal to the authors and do not necessarily reflect the policy of the Environmental Protection Agency or the Department of Transport. Farrell acknowledges funding from the ESRI Energy Policy Research Centre.

Declaration of Competing Interest: The authors declare no conflict of interest. The funders pro-vided the research focus but had no role in the design of the study; in the collection, analysis, or interpretation of the material; in the writing of the manuscript; or in the decision to publish the results.

CRediT statement:
Anita Vollmer: Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing, Visualization; Stefano Ceolotto: Conceptualization, Methodology, Writing - Original Draft, Writing -Review & Editing; Niall Farrell: Conceptualization, Writing - Review & Editing, Supervision, Project Administration, Funding Acquisition

Acknowledgements:
For useful comments, the authors would like to thank Niamh Garvey, Ruth Wolstenholme, Jodie Colgan, Sean O'Leary, Fintan McGrath, Maurice Harnett, Anne Mason and Andrea Staccione.

ABSTRACT

Nature-based solutions (NBS) for climate adaptation encompass a range of approaches that work with nature to increase resilience to climate change whilst providing ecological and social co-benefits. These solutions have frequently been put forward for application in urban contexts, such as the creation of urban forests, but can likewise be applied to rural contexts where they may, for example, prevent soil erosion. However, NBS face numerous barriers to being considered on equal footing with technical climate adaptation interventions. Previous research that has sought to address this issue has focused on conceptual frameworks, on the one hand, and practical guidance on how to quantify the benefits provided by NBS, on the other. In this article, we supplement these existing frameworks by providing practical recommendations for the whole decision-making cycle, from identification of objectives to the monitoring and scaling up of chosen interventions. We draw from a wide range of literature to, first, outline the barriers to the inclusion of NBS and, second, present policy recommendations for each step of the climate adaptation process. We find that policy recommendations which span across all decision-making steps are: Choosing a participatory decision-making approach, involving a wide range of experts, considering social justice implications, and creating a legal and regulatory framework which can accommodate NBS. While we put an emphasis on climate adaptation, most of the recommendations presented here are not limited to this context.

Keywords: Climate adaptation; Nature-based solutions; Ecosystem services; Policy decision-making; Planning

1 Introduction

Recent extreme weather events across the globe as well as urgent calls by low-income countries (Khadka, 2021), the scientific community (IPCC, 2022, Intergovernmental Panel on Climate Change) and international organizations (Global Center on Adaptation and Climate Policy Initiative, 2023; UNEP, 2023, United Nations Environment Programme) have highlighted the need for rapid adaptation to the impacts of climate change. The scale of the challenge - with UNEP (2023) estimating the costs for low and middle-income countries alone at US$215-387 billion per year - means that decisions made on what adaptation options to pursue will have a widespread and long-lasting impact on human and planetary wellbeing. The IPCC highlights the risks of maladaptation which 'can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities' (IPCC, 2022, p. 27), identifying a reduction of biodiversity and ecosystem resilience as one channel through which maladaptation can occur. Therefore, decisions on climate adaptation have to be made with nature and long-term effectiveness in mind.

Nature-based solutions (NBS) are one approach that has emerged to address such concerns. NBS are actions that involve people working with nature, as part of nature, to address societal challenges, providing benefits for both human well-being and biodiversity (Cohen-Shacham et al., 2019; Seddon et al., 2020b, 2021). The European Commission defines NBS as interventions that rely on nature and the services it generates to address environmental problems while simultaneously generating additional benefits to ecosystems and societies (EC, 2015; Cohen and Shacham, 2016; EC, 2016a). Adapting to climate change is one such societal challenge. Commonly proposed applications include the protection from both inland and coastal flooding and related hazards (Geukes et al., 2024; Seddon et al., 2020b; Vermaat et al., 2016); protection from soil erosion (Brown et al., 2011; Jia et al., 2017), and the moderation of urban heatwaves and heat island effects (Bowler et al., 2010; Seddon et al., 2020b).

The main difference between technical climate adaptation solutions and NBS is that, while technical solutions mainly fulfill the specific purpose for which they were created, NBS provide a wider range of so-called ecosystems services. Ecosystem services are defined as 'the benefits human populations derive, directly or indirectly, from ecosystem functions' (Costanza et al., 1997, p. 253). They are typically grouped into three categories: provisioning, regulating and cultural/intangible services (Babí Almenar et al., 2021; EEA, 2021).[1] Provisioning services are the most tangible type of ecosystem service and relate to the material products obtained from nature, such as agricultural products or fresh water. Regulating services stem from ecosystems' ability to regulate themselves and their environment. These include benefits such as climate regulation and pollination. Finally, cultural services are the intangible services provided by nature, such as recreation or spiritual value (Millennium Ecosystem Assessment, 2005). Because of the complexity of natural systems, the ecosystem services NBS provide will be varied, providing environmental, social and economic co-benefits such as habitat creation, increases in biodiversity or opportunities for recreation, in addition to the desired climate adaptation benefits (see e.g., Singhvi et al., 2022).

However, these co-benefits are often under-appreciated in formal planning and decision-making processes, resulting in NBS receiving less attention than technical adaptation solutions (Nelson et al.,

[1] Some authors include supporting services as a fourth category (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005) while in other cases these are grouped under regulating services (EEA, n. d.)

2020; Toxopeus and Polzin, 2021; Blackwood and Renaud, 2022). Therefore, to support climate adaptation decisions, this paper provides a comprehensive review of the factors that lead to under-utilisation of NBS as well as methods to overcome these barriers and 'internalise' co-benefits into decision-making processes. This will support planners and decision-makers in integrating NBS as a natural element of the climate adaptation choice set.

Previous authors have developed frameworks which aim to compare NBS and technical solutions on equal footing. There are two recent articles by Calliari et al. (2019) and Wickenberg et al. (2021) which review these adapted decision-making frameworks. In their review, Wickenberg et al. (2021) analyse frameworks proposed by other authors with a focus on the governance process and the pre-conditions required to successfully implement NBS. They find that multi-stakeholder collaboration and the co-creation of knowledge are the most important pre-conditions for NBS implementation. The seven frameworks which Wickenberg et al. (2021) review are largely conceptual and the authors identify a need to focus on a practical understanding of what is needed to implement NBS.

This call for more practical guidance is partly being met when it comes to including NBS in the evaluation step of the decision-making cycle, as outlined by Calliari et al. (2019) who review seven NBS assessment frameworks. The reviewed assessment frameworks focus mainly on quantifying the benefits NBS provide for policy targets (climate adaptation and disaster response) and the co-benefits provided by NBS outside of these targets. Calliari et al. (2019) themselves contribute an assessment framework which accounts for the dynamic element of NBS, namely the changes to NBS over time resulting from changing climatic conditions. However, with the exception of a framework developed by the World Bank, the frameworks they review, as well as the one Calliari et al. (2019) contribute themselves, largely do not provide guidance on how to consider broader governance issues surrounding NBS planning, implementation, and monitoring/maintenance (see Calliari et al., 2019). Even the World Bank framework, which does present guidance covering a full project cycle, is limited to flood protection in its recommendations and assumes that the decision to use an NBS over a technical solution has already been made (World Bank, 2017).

There is, therefore, a need for holistic and practical guidance for the full decision-making cycle to supplement the existing conceptual and assessment-focused frameworks. This is the gap we aim to fill with this article. We collate existing research which highlights knowledge, behavioural, governance and financial barriers as well as policy solutions to overcome them to help better incorporate NBS into all steps of the decision-making process. While the focus of this paper is climate adaptation, most barriers and recommendations identified likewise apply to other environmental problems that NBS can play a role in addressing.

This paper proceeds as follows. Section 2 outlines the barriers to the adoption of NBS in policy decision-making, whilst Section 3 considers the possible policy solutions for the barriers identified at each step of the decision-making process. In so doing, we both complement and update existing frameworks, providing guidance for policymakers to implement the proposed assessment steps and summarizing past research. Section 4 concludes, providing a brief overview of the key insights alongside suggestions for policymakers and future research.

2 Barriers to the adoption of nature-based solutions

This section identifies the factors leading to externalities and the under-provision of nature-based solutions both for climate adaptation purposes and more generally. Externalities occur when there are costs or benefits external to a transaction. These are costs or benefits imposed on others that are not factored into the price of a good or service (Pigou, 1920; Kolstad, 2011), as can be the case with the co-benefits, but also costs, of NBS. This creates a gap between the private and social impacts of an activity which results in under or over-provision of a good or service.

These barriers are structured according to their occurrence within the decision-making cycle, in order to facilitate the transfer of this knowledge to practical application. Four general decision-making steps have been identified here which align with the structure of NBS-focused decision-making and assessment frameworks proposed by other authors (see e.g., Seddon et al., 2020a; Raymond et al., 2017b; Calliari et al., 2019). These steps are (1) Identify objectives and possible intervention options; (3) Evaluate the possible interventions; (4) Implement the chosen intervention; (5) Monitoring, maintaining, and scaling up interventions. It should be pointed out, however, that these steps, while presenting a general sequential order, should be viewed as part of a cyclical and iterative process, through which decision-makers, planners, stakeholders and other experts go back to the problem, revise the desired objectives, refine the set alternatives and evaluate them in light of new evidence and external factors.

2.1 Identifying objectives and possible intervention options

Clear objectives are essential to project design: they indicate the results that are expected *ex ante* and inform on the intervention's performance *ex post*. Once these objectives are clear, possible solution options can be identified which can fulfill the objectives. In the context of NBS for climate adaptation, there are several difficulties encountered at this stage which can stand in the way of fully incorporating NBS as possible adaptation interventions. Each will now be outlined in turn.

2.1.1 Uncertainty

Uncertainty may manifest in a number of ways. At the pre-implementation stage, there may be uncertainty surrounding future climatic conditions and climate change impacts, leading to uncertainty on the magnitude of required climate adaptation. Climate change presents a unique combination of global causes and long-term, uncertain and widespread consequences (Stern, 2008). Our knowledge about future climatic conditions comes from simulation models — e.g., the global climate models presented in the IPCC AR6 WG1 report (IPCC, 2023). However, we do not know which (if any) of these projections will come to fruition as future climatic conditions depend largely on the implementation of climate mitigation measures as well as on if, or when, environmental tipping points are reached (McPherson et al., 2023). This introduces ambiguity when defining the objective and brings with it the risk of NBS interventions not being adequately sized to effectively respond to climate impacts. Indeed, research has found that policymakers tend to underestimate the dangers posed by climate risks (Seddon et al., 2020a, p. 9). Consequently, the implementation of

NBS as an adaptation solution is perceived as less pressing than the actual risks call for (Sarabi et al., 2020, p. 2).

Additionally, socio-ecological systems, and therefore NBS, are highly complex, so the uncertainty about how they will develop is higher than for technological solutions, although this difference becomes less pronounced when considering future climate change (Iacob et al., 2014). This is compounded by the fact that the scholarly debate on NBS has only been developed in recent years, meaning there has not been enough time to evaluate and monitor their performance over the long run (Sarabi et al., 2020), especially across spatial scales and socio-ecological contexts (Castelo et al., 2023, p. 9). Engineered solutions, on the other hand, have a very clear timeline and outcome (Seddon et al., 2020a, p. 7), although, as mentioned, their effectiveness under changing climatic conditions is subject to uncertainty as well (Iacob et al., 2014). Thus, risk averse decision-makers may hesitate to consider NBS to achieve their climate adaptation goals.

2.1.2 Path dependence

Limited knowledge on, and experience with, NBS may create path dependencies that favour established technical solutions (Davies and Lafortezza, 2019; Frantzeskaki et al., 2019; Sarabi et al., 2020; Castelo et al., 2023). This lack of experience and knowledge, in particular regarding the co-benefits of NBS (Solheim et al., 2021), is coupled with behavioural barriers such as resistance to change and risk aversion, making it difficult for NBS to establish themselves (Davies and Lafortezza, 2019). As a result, decision-makers may not even think of NBS as possible interventions to meet their climate adaptation objectives, or they will quickly disregard them even if they do.

2.1.3 Compartmentalised problem-solving

The literature has found that both planners and scholars tend towards a so-called 'silo mentality', focusing only on their main goal and area of responsibility, e.g., climate change adaptation or mitigation (Ershad Sarabi et al., 2019; Calliari et al., 2019; Sarabi et al., 2020; Seddon et al., 2020a). This can lead to problems and objectives being defined narrowly and specific to the main goal at hand, without consideration of the interconnections between it and other (policy) aims, which is then reflected in planning and communication where ownership of cross-cutting problems is not clearly assigned (Ershad Sarabi et al., 2019; Sarabi et al., 2020; Seddon et al., 2020a). As a result, the multifunctionality of NBS can remain external to public decision-making, with NBS not being valued for the full benefits they provide when evaluating the benefits and costs of various interventions (Calliari et al., 2019).

Additionally, conflicts or inaction may emerge in the implementation phase, resulting from the lack of ownership (Sarabi et al., 2020; Seddon et al., 2020a). For example, the responsibility for coastal erosion protection may be shared between the risk-management, the planning, and the environment units in the public sector organization with each of the units seeing the responsibility with the other two and therefore none of them taking the initiative (Storbjörk and Hedrén, 2011).

Due to their interconnected nature and the larger area covered than with technical solutions, NBS often require the collaboration of actors across jurisdictions (Seddon et al., 2020a) for which there

are frequently only less established channels of communication (Ernstson et al., 2010; Storbjörk and Hedrén, 2011; Braunschweiger, 2022). This exacerbates existing cross-sectoral coordination and ownership challenges.

2.1.4 Myopic decision-making

The disconnect between the long-term benefits provided by these interventions and the short-term benefits frequently pursued by policymakers and private investors can represent a strong governance barrier (Kabisch et al., 2016; Sarabi et al., 2020). For policymakers, this disconnect is created because electoral and associated decision-making cycles only span a few years whereas the benefits of NBS are often only felt with a significant time lag after their implementation (Iacob et al., 2014; Kabisch et al., 2016; Sarabi et al., 2020). For private investors, the time lag until revenue is generated represents a risk that many are not willing to take (European Investment Bank, 2023). As a result, grey infrastructure - i.e., technological solutions -, which can often be implemented more quickly than NBS, may be favoured by policymakers and private investors, even when NBS provide greater benefits in the long term. Additionally, the time lag can create difficulties in public funding for NBS projects as some funding is tied to project completion within a specific timeline and does not reimburse costs after the formal project deadline (Solheim et al., 2021).

A second element of myopic decision-making is not temporal but spatial. Climate change is a global phenomenon, but NBS are implemented at a local level. This dichotomy creates a source of friction that can prevent the "optimal' amount of NBS from being be provided. NBS present public good characteristics (Samuelson, 1954) and can generate positive externalities, i.e., measures introduced locally produce uncompensated benefits at other scales, thus reducing the incentives for any given agent to implement them (Pigou, 1920). Like the time lag associated with NBS, myopic decision-makers may overlook these additional benefits or undervalue them as they do not provide a direct personal pay-off to the decision-makers themselves. This, in turn, can lead to NBS being disregarded as adaptation intervention options.

2.1.5 Context dependence

An additional complication is that site-specific natural and cultural contexts need to be considered for NBS (Cohen-Shacham et al., 2016), since they have to be integrated with the existing ecosystem and social fabric. Such site-specific characteristics can be institutional or be linked to biophysical and ecological conditions (Seddon et al., 2020a; Dorst et al., 2022). This means that the same climate change impact can be addressed with different NBS in different areas (Eggermont et al., 2015), not only across countries, but even across regions within the same country. The consequence is that, when considering the adoption of NBS, planners can rarely draw entirely from pre-existing interventions, but have to conduct independent examinations to identify the solutions that are suitable to their specific context (Frantzeskaki et al., 2019). This is compounded by a 'lack of site-specific design criteria' (Castelo et al., 2023, p. 1). These factors make identifying and implementing the viable NBS options a more challenging task than with conventional engineering interventions.

Additionally, once NBS have been implemented, this context dependence means it can be difficult to

measure effectiveness and compare the results across projects due to the responsiveness of ecosystems to site-specific characteristics and changes over time (Seddon et al., 2020a, p. 7). For the same reason, monitoring cannot be done using one-size-fits-all indicators, which increases the complexity of the monitoring process (Seddon et al., 2020a, p. 7), especially in the absence of standards or guidelines (Sarabi et al., 2020). This, in turn, may lead to a lack of generalisable evidence, as a result of which NBS may not be considered as a possible intervention option.

2.2 Evaluating the possible interventions

Once the issues and objectives have been outlined, it is necessary to utilize evaluation tools to find the alternative that provides the best outcome according to a pre-determined set of criteria. To address climate change impacts, options include technical/engineered/grey infrastructures, green solutions, i.e., NBS, or hybrid approaches (see e.g., Singhvi et al., 2022). Grey infrastructure regroups the conventional built and engineering approaches; examples include pipes, water filtration plants and concrete flood banks. Hybrid approaches combine the ecosystem services provided by NBS with technological interventions, for example integrating bioswales and rain gardens with conventional drainage systems to manage urban waters and flooding. The main difficulty at the evaluation stage is that the benefits provided by NBS can be undervalued and grey solutions chosen due to lower costs, even where NBS or hybrid solutions would have been preferable if their co-benefits had been included in the evaluation (Calliari et al., 2019). The reasons for the undervaluation of NBS are outlined in this section.

2.2.1 Multifunctionality

The multifunctionality of NBS, i.e., their ability to simultaneously provide an array of economic, social, and environmental benefits that are external to the target of the intervention, is easily underrepresented in decision-making processes (Calliari et al., 2019). These co-benefits may be local, regional, or even global (e.g., climate mitigation as a co-benefit to a climate adaptation project) (Raymond et al., 2017a) and can therefore fall outside of the assessment criteria. This is linked to the tendency towards compartmentalised problem-solving mentioned in the previous step. As discussed above, compartmentalised problem-solving leads to a narrow focus which in turn means that benefits are categorised as external in the first place. For example, one agency may have a climate adaptation goal and therefore overlook the 'external' climate mitigation benefits of a project. If this agency worked together with the agency focusing on climate mitigation, they would automatically internalise both adaptation and mitigation benefits, so that neither of these benefits would be overlooked.

However, if benefits remain external and are overlooked for that reason, the set of evaluation criteria will be incomplete as it will not include criteria which go beyond the specific target of the project (e.g., climate adaptation). This will consequently undervalue NBS and result in them not being selected, even when they would have been the optimal choice.

2.2.2 Difficulties with quantification and evaluation methods

Another reason why some ecosystem services are often excluded from decision-making processes is that they are difficult to quantify (Castelo et al., 2023). This makes choosing and measuring relevant indicators more complex. This is especially true where ecosystem services provide non-material or less tangible benefits as is the case for many cultural and regulating ecosystem services.

Monetary quantification of ecosystem services can be particularly complicated or controversial. In some cases, markets for certain ecosystem services and biodiversity exist, as in the UK which has regulated markets for biodiversity credits and pollution load abatement to waterways (European Investment Bank, 2023, p. 23), or carbon markets which exist in many countries across the globe.

However, in many contexts such markets do not exist and even where they do they are unlikely to cover all ecosystem services, leaving the benefits derived from the others to remain 'public goods' with no attached revenue streams. Other methods exist which provide a monetary quantification of non-use values, or attach a monetary value to activities that do not have a direct economic valuation, such as contingent valuation.

However, these typically rely on surveys that are complex to design and expensive to carry out; and, like other stated preference methods, they suffer from hypothetical bias (Murphy et al., 2005). In addition, these methodologies tend to assign a unique value for the entire society (Kenter et al., 2015), whereas, in reality, valuation can vary considerably between different social groups (Rauschmayer et al., 2009; Small et al., 2017).

Beyond these methodological difficulties, monetary valuation techniques inherently imply substitutability between ecosystem services and the associated natural capital and other forms of capital, which has been widely criticized (see e.g., Wilson and Wu, 2017; Randall, 2022, as recent examples).

As a result of these shortcomings, monetary values often fail to present an accurate representation of the true value of ecosystems and their services (Baveye et al., 2013; Melathopoulos et al., 2015; Saarikoski et al., 2016). These complexities can result in relevant criteria being excluded to make the evaluation easier or because they do not provide revenue (European Investment Bank, 2023).

This, in turn, can lead to traditional evaluation methods undervaluing NBS. For example, to compare different intervention options, cost-benefit analysis (CBA) has typically been adopted in the past, but it faces limitations when applied to NBS (Saarikoski et al., 2016). These limitations arise primarily from the difficulties in quantifying many of the ecosystem services associated with NBS, as mentioned above. CBA compares the (net present value of) costs and benefits of the available options, and selects the one offering the highest benefit-to-cost ratio. This requires monetary quantification of all criteria. Since this is often not available for NBS, the assessment cannot always be condensed down to one (monetary) criterion, which is where CBA excels. Instead, the comparison of different alternatives may require consideration of multiple criteria with varying units, for which CBA is less suited (Hagedoorn et al., 2021).

Moreover, CBA considers the total stream of costs and benefits over the lifetime of the projects, expressed in present value terms based on a selected discount rate. This computation is significantly hindered by the uncertainty surrounding the time at which the effects of NBS interventions are going to manifest and their duration. Because of these challenges in applying CBA to NBS, CBA may exclude or undervalue relevant benefits.

In addition to difficulties with (monetary) quantification, some ecosystem services or their interactions may simply be overlooked, if the necessary knowledge is lacking (Sutherland et al., 2018). Furthermore, the large number of ecosystem service types (see e.g., the Common International Classification of Ecosystem Services) to consider can seem daunting to evaluate without prior experience.

2.2.3 Disregard of trade-offs and synergies

Ecosystem services, and with them NBS, are inherently complex and interconnected, displaying synergies and trade-offs between certain benefit groups, or between the stakeholder groups affected by the intervention (Ring et al., 2010; Howe et al., 2014; Dumitru et al., 2020; Seddon et al., 2020a). For example, maximising climate mitigation through tree monocultures can significantly harm other regulatory ecosystem services and biodiversity (Seddon et al., 2019, 2020a). Similarly, managing an area for the climate adaptation benefits provided by regulating services can negatively affect the amount of land available to grow crops (Iacob et al., 2014). On the other hand, restoring coral reefs to address sea level rise also provides habitat for wildlife (Morris et al., 2018), thus synergies are closely linked with the multifunctionality of NBS. However, such effects are widely excluded from the evaluation process (Dumitru et al., 2020). This can present a barrier to the implementation of NBS either through an undervaluation of the benefits associated with an NBS or by leading to negative experiences with NBS if trade-offs were not considered in the selection process. Overall, lack of consideration of synergies and trade-offs can lead to decision-making which overlooks a preferable option because the full impact of the different options is not taken into account.

2.3 Implementing the chosen intervention

Once the most suitable adaptation option has been identified, the next step is its implementation. Even when an NBS has been chosen as the climate adaptation intervention, it can face difficulties in the implementation stage which are not faced to the same extent by grey infrastructure. In the worst case, these difficulties can lead to NBS having unintended negative consequences or the project being abandoned altogether (Solheim et al., 2021). If NBS are to be successfully integrated into climate adaptation, then these issues have to be identified and overcome. The problems faced at the implementation stage are outlined in this section.

2.3.1 Lack of public support

A lack of public awareness of and support for NBS can form a barrier to implementation (Kabisch et al., 2016; Ershad Sarabi et al., 2019; Sarabi et al., 2020; Solheim et al., 2021). Knowledge of NBS is, so far, not widespread outside of academia (Ershad Sarabi et al., 2019, p. 9) and policymakers and residents sometimes even view green infrastructure as 'dirty' and 'harmful' (Kabisch et al., 2016, p. 6). Furthermore, economic gains resulting from the negative impacts that NBS are designed to prevent can be another reason for some individuals to mount opposition to a proposed project (Solheim et al., 2021). For example, Solheim et al. (2021) outline a case where landowners were supplementing their income by digging gravel out of a river after it floods, leading them to oppose actions to mitigate the

flooding (p. 16). Such public opposition can lead to delays and even contribute to the cancellation of projects (Solheim et al., 2021, pp. 14-15).

2.3.2 Social (in)justice

The social justice dimension of NBS is often overlooked, although research on it is has been emerging over the past years (Cousins, 2021; Zuniga-Teran et al., 2021; Snep et al., 2023). While the question of climate adaptation itself is fundamentally intertwined with justice concerns (UNEP, 2023), the implementation of NBS adds another dimension. Where the analysis of social and health impacts is concerned, for example, there is often little consideration of the differential effects across social groups (Dumitru et al., 2020) who may be affected differently, depending on their relationship with natural resources (Seddon et al., 2020a, p. 7).

Without such consideration of justice issues, planners, policymakers, and private investors may even exacerbate existing inequalities through the implementation of NBS. This can occur through their choice of location, with NBS more frequently located in already privileged areas (Escobedo et al., 2015; Zuniga-Teran et al., 2021). Higher income neighbourhoods and cities are more likely to have access to financing (both public and private), therefore choosing areas where financing is readily available, or where funds can be collected through measures such as crowdfunding in the local area, may lead to increasing inequalities both within and between cities (Thompson et al., 2023). However, even if NBS are placed in areas that are most in need of them, implementing green spaces, or similarly attractive NBS, in cities may lead to gentrification of neighbourhoods, resulting in community members losing access to their homes if no appropriate measures are taken to prevent this (Haase et al., 2017; den Heijer and Coppens, 2023; Thompson et al., 2023). While such social justice implications are linked to the implementation of NBS, their roots lie in a history of unjust treatment that must often be addressed alongside the direct implications of an NBS project, in order to mitigate negative consequences (Zuniga-Teran et al., 2021).

2.3.3 High land and time requirements

NBS typically have higher space and time requirements than grey infrastructure which can represent a significant barrier to their implementation (Ershad Sarabi et al., 2019). In urban areas, which are often the target of NBS, space is particularly constrained (Ershad Sarabi et al., 2019; Singh et al., 2020). As a result, NBS can only be implemented at limited scale in such circumstances (Singh et al., 2020). The time-lag from the implementation of NBS to them becoming operational and providing the associated ecosystem services represents the main time constraint in the implementation phase. As mentioned previously, such time lags make NBS less attractive for policymakers hoping to see quick results and can even lead to the cancellation of projects if the political will changes during the period of implementation (Solheim et al., 2021). This time constraint can be especially sensitive in rural and mountainous areas and is tied to the time required for public procurement. In such areas, environmental circumstances for the implementation of NBS may only be right within a short window each year, so that any delay in the procurement process can lead to a year-long delay in implementation (Solheim et al., 2021), exacerbating existing time constraints.

2.3.4 Difficulty procuring funding

The difficulties faced in procuring funding for NBS are widely documented (Ershad Sarabi et al., 2019; Sarabi et al., 2020; Seddon et al., 2020a; Castelo et al., 2023; European Investment Bank, 2023). As Dumitru et al. (2020) report, "most medium-sized cities in Europe often struggle to convince investors that nature-based solutions can deliver on the multiple objectives and interests their stakeholders have'. Given the nature of these frictions, there is no *a priori* reason for this phenomenon to be restricted to the European context and, in fact, a lack of funding for NBS has been found to be a particular problem in low and middle-income countries (Castelo et al., 2023).

The hesitancy from private investors is linked to the externalities and public goods issues connected with NBS which undermine individual incentives to act (Seddon et al., 2020a, p. 8), as investors are not able to capture the full benefits provided by NBS. This generates missing or insufficiently sized markets. Moreover, the uncertainty regarding the timing and magnitude of impacts leads to imperfect capital markets, which can result in credit rationing or interest rate rationing (Kempa and Moslener, 2017). The former affects primarily long-term contracts, where risks for the lender are larger, and can give rise to a lack of a market for long-term debt (Stiglitz, 1993). The latter, despite not preventing financial resources from being obtained, worsens the conditions for the borrower (Jaffee and Stiglitz, 1990). The inability to obtain sufficient financial resources risks generating systematic under-financing problems due to externalities of monitoring, selection and lending (Stiglitz, 1993). If a project cannot gather enough capital, this sends a negative signal to other potential investors, thus making it harder to raise additional financing. Notably, this can spill over to similar projects. This is exacerbated by the impression that NBS projects are inherently expensive, which prevails despite evidence to the contrary (Sarabi et al., 2020).

Finally, actors often do not know which financing opportunities are available, with limited funding dedicated specifically to NBS projects (Ershad Sarabi et al., 2019; Sarabi et al., 2020). The difficulty in accessing funding is partly driven by a tendency in recent years to move away from decentralised 'Pigouvian' solutions, toward a more project-specific approach (Kempa and Moslener, 2017), making the funding landscape more difficult to navigate. This limits access to funding and increases the resources required to identify funding sources.

2.4 Monitoring, maintaining, and scaling up interventions

Even when NBS are (successfully) implemented, the monitoring process, or rather lack thereof, limits the ability to gather robust information to remodel, optimize or scale-up NBS interventions and to provide richer knowledge for future projects (Dumitru et al., 2020). Additionally, if NBS are not maintained appropriately, then they cannot unfold their full potential, which may in turn lead to them being considered as less beneficial intervention options fur future projects. This section outlines the barriers faced when monitoring, maintaining, and scaling up NBS.

2.4.1 Absence of long-term commitment structures

Monitoring and maintenance is hampered by the time lag with which NBS develop their benefits (Iacob et al., 2014; Kabisch et al., 2016; Sarabi et al., 2020). Existing governance structures often only

support projects for the duration of the official project implementation phase, disregarding long-term needs (Kabisch et al., 2016). However, climate adaptation interventions are inherently long-term interventions which are supposed to guard against future climate change impacts. Consequently, past monitoring and maintenance efforts have often not taken place over the time period required to assess the full benefits from NBS and learn from them for future projects.

2.4.2 Lack of supportive regulation

Existing legislative structures are tailored to fit grey infrastructure projects (Ershad Sarabi et al., 2019), and have largely not been adapted to NBS (Sarabi et al., 2020). For example, NBS typically require more land than grey infrastructure but access to this land is often restricted due to private ownership (Bogdzevič, 2023). Finding a solution which provides legal certainty and protection to private land owners while also allowing for more flexibility in access to land for the implementation of NBS would greatly facilitate the scaling up of NBS in the future. In some instances, there are even conflicts in existing regulation either between sectors or between governance levels which undermines trust in the legal and policy basis for such a scaling up process and can lead to different government bodies working towards contradictory goals (Sarabi et al., 2020; Seddon et al., 2020a). For example, in an extensive study of legislation on flood risk in 33 countries Mehryar and Surminski (2021) find that disaster-risk management legislation and climate change-related legislation often function in isolation to each other, leading to reduced ownership and separate financing mechanisms. These shortcomings present a significant barrier to systematically scaling up climate adaptation NBS.

2.4.3 Economic growth paradigm

More ingrained even than existing regulation is what has been termed the 'economic growth paradigm' which is anchored in socio-cultural norms in many countries and has been identified as an underlying barrier to the widespread implementation of NBS (Kabisch et al., 2016; Ershad Sarabi et al., 2019; Castelo et al., 2023). The use of the term 'economic growth paradigm' is not always consistent but in general it refers to a focus on economic growth as the primary policy concern which may crowd out other values, such as those that are important to NBS (Schmelzer, 2015).[2] One example of this are the policy and funding decisions made in cities. Kabisch et al. (2016) highlight that in circumstances of population decreases in cities, funding for economic growth-inducing activities always remains a priority, while funding for NBS or other green infrastructure is quickly neglected. The low value attributed to nature and the high value attributed to extractive land uses under this paradigm may hold back the development of NBS as they lead to criteria favouring technical solutions being given more weight in decision-making processes (Seddon et al., 2020a; Castelo et al., 2023).

2.5 Summary of barriers

Table 1 gives an overview of the barriers presented in this section divided by the different steps in the decision-making cycle. The consequence of these barriers is a distorted picture of the effectiveness of

[2] Schmelzer (2015) gives an overview of the history of the term as well as its core tenants.

NBS, as well as an unsupportive regulatory and socio-cultural landscape, hampering implementation, and scale up of NBS.

Table 1: Barriers to the implementation of NBS at each step of the decision-making process

Step 1: Identifying objectives and possible intervention options

- Uncertainty about climate impacts and resulting adaptation needs (Stern, 2008; IPCC, 2023; McPherson et al., 2023) as well long-run effectiveness of NBS (Kabisch et al., 2016; Sarabi et al., 2020; Castelo et al., 2023)
- Path dependence favouring established intervention options (Davies and Lafortezza, 2019; Frantzeskaki et al., 2019; Sarabi et al., 2020; Castelo et al., 2023)
- Compartmentalised problem-solving leading to a narrow view of problems and objectives (Ershad Sarabi et al., 2019; Calliari et al., 2019; Sarabi et al., 2020; Seddon et al., 2020a)
- Myopic decision-making resulting from a disconnect between short-term decision-making cycles and the long-term benefits provided by NBS (Iacob et al., 2014; Kabisch et al., 2016; Sarabi et al., 2020; Solheim et al., 2021; European Investment Bank, 2023)
- Context dependence of NBS (Eggermont et al., 2015; Cohen-Shacham et al., 2016; Frantzeskaki et al., 2019; Sarabi et al., 2020; Seddon et al., 2020a; Dorst et al., 2022)

Step 2: Evaluating the possible interventions

- Undervaluation of multifunctionality (Raymond et al., 2017a; Calliari et al., 2019)
- Difficulties with quantification and evaluation methods (Baveye et al., 2013; Melathopoulos et al., 2015; Saarikoski et al., 2016; Hagedoorn et al., 2021; Castelo et al., 2023; European Investment Bank, 2023)
- Disregard of trade-offs and synergies (Ring et al., 2010; Dumitru et al., 2020; Seddon et al., 2020a)

Step 3: Implementing the chosen intervention

- Lack of public awareness and support (Kabisch et al., 2016; Ershad Sarabi et al., 2019; Sarabi et al., 2020; Solheim et al., 2021)
- Social justice issues not considered, leading to exacerbation of existing inequalities (Escobedo et al., 2015; Haase et al., 2017; Cousins, 2021; Zuniga-Teran et al., 2021; den Heijer and Coppens, 2023; Snep et al., 2023; Thompson et al., 2023)
- Higher land and time requirements (Ershad Sarabi et al., 2019; Singh et al., 2020; Solheim et al., 2021)
- Difficulty procuring funding (Ershad Sarabi et al., 2019; Dumitru et al., 2020; Sarabi et al., 2020; Seddon et al., 2020a; Castelo et al., 2023)
  - Positive externalities, multifunctionality, and uncertainty make it difficult to convince investors
  - Credit rationing due to uncertainty of climate impacts
  - NBS projects seen as high cost
  - Few funding opportunities specifically targeting NBS

Step 4: Monitoring, maintaining, and scaling up interventions

- Implementation, maintenance, and monitoring needs are not secured for the long term after the official end of the project (Iacob et al., 2014; Kabisch et al., 2016; Sarabi et al., 2020)
- Lack of supportive regulation presenting a structural barrier to the scaling up of NBS (Ershad Sarabi et al., 2019; Sarabi et al., 2020; Seddon et al., 2020a; Mehryar and Surminski, 2021; Bogdzevič, 2023; Castelo et al., 2023)
- Economic growth paradigm favouring extractive land uses and undervaluing nature (Kabisch et al., 2016; Ershad Sarabi et al., 2019; Seddon et al., 2020a; Castelo et al., 2023)

3 Policy solutions to integrate nature-based solutions into decision-making

This section collects good practices and policy solutions proposed in the literature to address the previously-identified barriers. This provides tools to facilitate a sound evaluation and implementation of NBS projects alongside technical climate adaptation measures.

3.1 Across all steps

3.1.1 Implement a participatory decision-making process

Participation has long been advocated for in environmental decision-making, although so far the practical implementation has often fallen short in achieving the anticipated benefits (Irvin and Stansbury, 2004; Wamsler et al., 2020; Young and Tanner, 2023). It can take many forms, from round tables to citizens fora, but the basis is a two-way flow of information between those with the power to make a decision - typically policymakers and planners - and those who will be affected by it - citizens and other stakeholders (Rowe and Frewer, 2005).

Where participation is implemented successfully, it offers many advantages (Eckersley, 2006; Blackstock and Richards, 2007; Biggs et al., 2010; Collier et al., 2013). Involving multiple stakeholders (i) informs and improves project design and planning (van den Hove, 2000); (ii) facilitates knowledge generation (Krasny et al., 2014) and transfer (Andersson and Barthel, 2016); (iii) allows for multiple sources of financing, thus creating economic insurance to guarantee functionality over time and potential scaling up (Andersson et al., 2017); (iv) increases the legitimacy of the project (Schultz et al., 2011) and ultimately its support as it becomes more acceptable and better understood (Parkins and Mitchell, 2005).

For NBS specifically, these benefits can address many of the barriers their implementation currently faces at all stages of the decision-making process. For example, increasing the legitimacy of and support for NBS projects can mitigate otherwise low levels of public acceptance. Similarly, when defining the objectives at the start of a project, different stakeholders are likely to present different (and possibly conflicting) priorities (Rauschmayer et al., 2009; Small et al., 2017) which may help address silo mentality among policymakers and embed NBS into the local context.

However, participation in decision-making processes is often not well implemented, in which case not only do the desired benefits not emerge but the outcome can even be worse than if participation had not been attempted in the first place (Wamsler et al., 2020; Van Dijk and Lefevere, 2023). This frequently occurs if participation is tokenistic rather than delegating true decision-making power to the participating actors, leading to backlash from the participants (Carrick et al., 2023; Cutts et al., 2023; Van Dijk and Lefevere, 2023). Wamsler et al. (2020) examine participation within the context of NBS for climate adaptation in Sweden and find that, in the projects they accompanied, citizen participation negatively impacted sustainability outcomes by generating conflict between citizen groups as well as active contestation of planned adaptation measures. They identify two main barriers to successful citizen engagement. One on the side of the municipalities which lack the capacity and institutional framework for participatory decision-making. The other on the side of the citizens who have conflicting personal interests and a limited focus on environmental concerns.

To address such barriers, several good practice recommendations have been developed over time,

including (1) truly delegating decision-making power to the participants and avoiding tokenistic citizen engagement; (2) implementing participation through all stages of the decision-making process, beginning with the setting of objectives; (3) ensuring that all relevant stakeholders are involved on an equal basis, thereby preventing capture through powerful or conflicting interests; (4) communicating transparently on how the input from participation will be included in the overall decision-making process; (5) providing citizens/stakeholders with access to expertise to inform their own position; and (6) institutionalising stakeholder participation in decision-making processes (Hampton, 1999; Reed et al., 2018; Wamsler et al., 2020). If these recommendations are followed, then participation has the potential to become a powerful tool in the implementation of NBS.

3.1.2 Involve a wide range of experts and policymakers

Not only external stakeholders should be brought together in the decision-making process, policymakers themselves should talk to each other across policy boundaries as well to overcome the often prevailing silo mentality (Scott et al., 2022). This will likewise enable experts from a range of relevant disciplines to be involved who can lend their expertise to ensure that interconnections between issues such as biodiversity loss and climate adaptation are recognized. In particular, interdisciplinary expertise on socio-ecological systems will be relevant to understand the interlinkage of social and ecological impacts (Jellinek et al., 2014; Mofrad and Ignatieva, 2023). This forms the basis for benefits and costs outside of the climate adaptation target to be included throughout the decision-making process. Additionally, bringing together policymakers from across policy boundaries and governance levels will allow procedural experience to be shared as well.

3.1.3 Explicitly include social justice considerations

Social justice considerations may also guide the choice and location of NBS. To do so, it is essential to not only look at measures of aggregate well-being in decision-making processes, but to include distributional considerations as well, including long-term impacts like (eco-)gentrification (Thompson et al., 2023). This can be operationalised by including justice and inequality indices in the evaluation and in decisions on the implementation process (den Heijer and Coppens, 2023, p. 9). For example, data on the socio-economic profile of different neighbourhoods alongside data on the position of existing green spaces can help identify areas of greater need instead of favouring middle and high-income neighbourhoods as has often been the case in the past (Escobedo et al., 2015; Haase et al., 2017). Additionally, NBS should be tailored in such a way as to fit the existing community by catering to diverse social as well as environmental needs, rather than aiming to provide the greatest increase in market value (Haase et al., 2017).[3] Similarly, funding should be procured in a way that does not systematically reinforce existing inequalities, such as by selecting only areas where funding is readily available.

[3] Haase et al. (2017) outline prerequisites for such an inclusive approach, namely 1) explicitly including socio-spatial inequalities at each step of the decision-making and planning process, 2) including local stakeholders in the planning and implementation process, 3) considering trade-offs between social and environmental benefits, 4) ensuring accessibility and functionality for a diverse range of people, 5) implementing 'multi-actor governance' which ensures all members of the affected population are represented, and 6) researching existing market pressures and power structures which may disadvantage certain stakeholders (pp. 45-46).

If NBS are implemented with a focus on social justice, then they can provide valuable services to underserved and vulnerable communities thanks to their ability to improve health and well-being, thereby reducing rather than exacerbating existing inequalities (Faivre et al., 2017).[4] In addition to this mainstreaming of social justice considerations in these decision-making processes, the underlying causes of existing inequalities must be addressed as well (Zuniga-Teran et al., 2021). Examples of measures to be taken are anti-displacement policies as well as incentives, e.g., time off from work, for the participation in governance processes, thereby facilitating equal participation of all groups (Zuniga-Teran et al., 2021).

3.1.4 Create a legal and regulatory framework that can accommodate NBS

Putting in place a legal and regulatory framework that can accommodate NBS will facilitate the integration of NBS throughout the entire decision-making process. This includes addressing the space requirement of NBS by finding a solution for access to private land through measures other than expropriation (Nikolić Popadić, 2021; Bogdzevič, 2023), tackling financing barriers (Sarabi et al., 2020), and specifically recognising and integrating nature-based solutions in national climate legislation (Mehryar and Surminski, 2021). For example, in their analysis of flood risk management laws from 33 countries, Mehryar and Surminski (2021) identify several pieces of legislation regarding the preservation of existing natural capital, but no legal guidance on the implementation of nature-based solutions for flood risk management. Implementing such a regulatory framework could help overcome silo mentality and ensure that monitoring and maintenance needs are met in the long term. To tackle financing barriers, the budget of local authorities could be increased, local authorities given more autonomy to make spending decisions and bureaucratic hurdles faced by private actors reduced (Toxopeus and Polzin, 2021), to name just a few options. These measures will allow a more systematic mainstreaming of nature-based solutions to overcome the institutionalisation of practices built around grey infrastructure, as has been shown to be the case where such legislation already exists (Ershad Sarabi et al., 2019, p. 11).

3.2 Identifying objectives and possible intervention options

3.2.1 Consider a variety of future scenarios

A variety of future scenarios should be considered to identify the range of potential adaptation needs and how NBS might respond to a changing climate (Calliari et al., 2019). This can help in addressing the uncertainty surrounding future climatic conditions. These scenarios should be based on various climate change projections — such as the IPCC's global climate models (IPCC, 2023) — and environmental, economic and social targets to be achieved. As an example, one of the case studies presented by the International Union for the Conservation of Nature details the restoration of a river and the associated flood plain to reduce flood risks. This project faced significant uncertainty about future hydrological conditions, and lessons learned to address this uncertainty include considering multiple different scenarios as well as planning for the need to maintain or adapt

[4] For example, it has been shown that access to green spaces can help prevent socio-economic inequalities (de Vries et al., 2013) and reduce morbidity and mortality (Hartig et al., 2014; Mitchell et al., 2015).

the measures taken (Cohen-Shacham et al., 2016, pp. 37-39). This flexibility both in the assessment process and in the later implementation allows for uncertainty to be addressed and decisions on risk to be made from an informed point of view.

3.2.2 Explicitly consider nature-based solutions as intervention options

When identifying possible interventions, NBS should be deliberately considered alongside more established options to overcome any existing bias or path-dependence favouring technical solutions. The set of potential alternative interventions can include, where appropriate, (multiple) NBS, (multiple) grey infrastructures, and (multiple) hybrid solutions (Calliari et al., 2019). Additionally, 'doing nothing' should always be included as an option to compare the effects of intervening with those of inaction (Calliari et al., 2019, p. 697). This should also contribute to an understanding of the benefits currently provided by any natural environment which may be replaced or altered by the intervention. The different intervention options can be inspired by previous examples of successful implementation in other contexts, where these exist (Nesshöver et al., 2017). For instance, Bona et al. (2023) map nature-based solutions implemented throughout Europe in an urban context with a focus on climate adaptation. They provide an overview of the different types of intervention, their benefits, and case studies which can provide inspiration and guidance to policymakers.

3.2.3 Disincentivise myopic decision-making and internalise ecosystem service externalities

Furthermore, actions to disincentivise myopic, i.e., short-term and narrow, decision-making should be taken, as it may lead to NBS not being included among the possible intervention options. There is the risk that stakeholders are not able to realise or enjoy all the benefits that NBS generate, especially where benefits are external to the stated policy goal of climate adaptation. In these cases, the economic literature on externalities and public goods can offer solutions to incentivise uptake (like subsidies, tax exemptions, facilitate access to capital and labour, and so on; see, among others, Randall, 1972; Varian, 1993, 1994; Ostrom, 2012). For example, tax credits have proven to be successful in incentivising research and development investment which can provide similarly long-term benefits to society that are not necessarily fully internalised by the business choosing to invest (Bloom et al., 2002). Furthermore, funding through payments for ecosystem services, i.e., 'programmes that exchange value for land management practices intended to provide or ensure ecosystem services' (Salzman et al., 2018, p. 136), may help internalise the ecosystem services provided by NBS which do not provide a direct economic return to investors through other means. Such state support can encourage non-state actors to look beyond the narrow, short-term frame which might otherwise be used when setting up a business or making investment decisions.

However, there could also be a lack of political incentive on the part of state actors to undertake NBS. Voters have been shown to reward(punish) politicians for good(bad) performance, a phenomenon known as retrospective voting (see Healy and Malhotra, 2013, for a review of the literature). Given that the effects of NBS mostly appear in the long-run, they might not be enjoyed by the administrations that implement them. And since administrations do not want other administrations to reap the (political) benefits of their work, they might be inclined to prioritize short-term solutions instead.

Hence, legal and regulatory frameworks are needed that favour the adoption of forward-looking projects.

3.3 Evaluating the possible interventions

The evaluation step draws on the elements already put in place in the two previous sub-sections to holistically evaluate both NBS and technical interventions. Potential interventions should be evaluated under multiple environmental scenarios and scales of intervention. The evaluation process should consider the main objective, all relevant sub-objectives highlighted by stakeholders, as well as any wider ecosystem services which will be affected by the intervention. This includes assessing any changes to the existing natural systems and the subsequent losses and benefits by including a 'doing nothing' option as one of the scenarios. Also, it should consider all affected stakeholder groups and include appropriate baselines to measure impacts across different social groups.

3.3.1 Expand valuation techniques beyond monetary valuation

To represent the co-benefits of NBS as well as the plurality of values attached to different ecosystem services and other environmental and social outcomes, monetary and non-monetary valuation methods should be combined, unless all relevant criteria can be represented in monetary terms (Sijtsma et al., 2013; Saarikoski et al., 2016; Adem Esmail and Geneletti, 2018). This also accounts for the fact that many of the benefits and costs generated by NBS are non-material. Where clear monetary values exist for all components, cost-benefit analysis is still a good option, but in the many situations where this is not the case, options which can combine different types of values, such as multi-criteria analysis are to be preferred (Saarikoski et al., 2016). As a first step, an expansion of valuation techniques can be operationalised for decision-making by including them in the public expenditure guidelines. For example, the Irish Public Spending Code (now 'Infrastructure Guidelines') includes multi-criteria analysis among its recommended economic appraisal techniques (Department of Public Expenditure and Reform, 2012).

Multi-criteria (decision) analysis (MCA/MCDA) is particularly suited to making decisions in the face of complex environmental problems. For this reason, it generally outperforms CBA when valuing ecosystem services (Saarikoski et al., 2016). This is because it allows for multi-dimensional criteria to be included and weighted according to the preferences and values of the affected actors, thereby also enabling a transparent participatory valuation approach (Saarikoski et al., 2016). The inclusion of stakeholders in the process, along with other best practice approaches, is necessary to ensure that MCA/MCDA does not end up being a black box. Some of these best practices are outlined by Adem Esmail and Geneletti (2018) and include an 'adequate justification and communication of the methods for criteria assessment and weighting', a 'reasoned choice of the criteria aggregation method', and a 'comprehensive sensitivity analysis' (p. 42). To follow these often complicated steps appropriately, the authors recommend involving an expert on participatory MCA/MCDA techniques (p. 49). The sensitivity analysis is of heightened importance in a climate adaptation context as it can account for the uncertainty regarding future developments and present the decision consequences of different scenarios. Overall, MCA/MCDA presents many tools to address the

complexities inherent in so-called wicked problems, i.e., problems 'characterized by high levels of complexity and ambiguity and involv[ing] multiple stakeholder groups with strongly divergent values and perspectives' (Hanson, 2018), for example, climate change.

3.3.2 Apply a multi-scalar valuation approach

Ecosystems and governance often function at different scales, both spatial and temporal (Folke et al., 1996; Cash et al., 2006; Galaz et al., 2008; Tzanopoulos et al., 2013). Hence, evaluations should be carried out adopting a multi-scalar approach (Small et al., 2017) considering socio-ecological systems and their interlinkages and incorporating network-based tools to assess the interactions between multiple stakeholders, including natural systems (Rathwell and Peterson, 2012). This should be facilitated through the collection of data with a high level of spatial disaggregation and the use of Geographical Information Systems (GIS; Small et al., 2017; Dumitru et al., 2020). The structure and impetus for such data collection may, for instance, be provided by the UN System for Environmental Economic Accounting (SEEA), in particular the Ecosystem Accounting framework (SEEA-EA), an international accounting standard which integrates economic accounts with environmental and ecosystem ones (United Nations, 2021).

Such a multi-scalar approach allows for costs and benefits to be assessed at local, regional, and even global level, as appropriate to the different intervention options, and across different time scales, thereby accounting for the multifunctionality and the time-lag associated with NBS. In particular, the evaluation process should extend beyond the climate adaptation target itself to include co-benefits and costs as well as trade-offs and synergies between ecosystem services (Raymond et al., 2017c). This will allow the full set of benefits and costs associated with NBS to be considered when making the decision which intervention option to implement.

3.3.3 Draw on pilot projects and past examples to assess effectiveness

Wherever possible, it is useful to learn from previous successful projects (Nesshöver et al., 2017). While the concept of NBS may be new, the idea of natural solutions to societal problems is not. Collier (2021) investigates the example of hedgerows which have existed for centuries and can be directly compared to technical counterparts, such as barbed-wire fences, in the benefits they provide. This example demonstrates that, if managed properly, the value of NBS can appreciate over time instead of depreciating, as is usually the case for technical infrastructure (Collier, 2021). Additionally, they may even address problems whose existence we are not yet aware of by strengthening ecological resilience (Collier, 2021). Searching for other examples like this one may well provide insights into how NBS may evolve over time, albeit without the accelerated climate change impacts that affect the natural world today. Drawing on these insights can then help inform the evaluation of NBS and overcome uncertainty regarding their long-term effectiveness.

Where such past examples are lacking, concerns related to time lags and the effectiveness of NBS can also be overcome through pilot projects which provide new insights on NBS and create positive experiences (Wolf et al., 2021). These can reduce uncertainty regarding the effectiveness of NBS at lower space and time requirements, making it easier to include them in the evaluation. Such pilot

projects can likewise provide the blueprint for the implementation of larger-scale NBS.

3.4 Implementing the chosen intervention

3.4.1 Strengthen awareness of benefits from NBS

Communicating the benefits provided by NBS is essential to improve public acceptance of such interventions (Anderson and Renaud, 2021). Awareness of benefits can be increased by ensuring that they, including 'hidden' benefits such as regulatory services, are clearly linked to the NBS intervention in question and are framed within the value systems of the local population (Anderson and Renaud, 2021). To additionally increase support for NBS, interventions should be multifunctional, aesthetically appealing, and serve clear purposes in periods between extreme events (Andersson et al., 2017; Frantzeskaki, 2019; Anderson and Renaud, 2021). A valuable strategy to achieve this is the co-creation and co-design with various (local) actors (like designers, artists, architects; Frantzeskaki, 2019).[5] The aesthetic benefits of NBS in particular have been shown to be very important for public acceptance (Anderson and Renaud, 2021). Additionally, they reinforce some of the other co-benefits that NBS generate, like spiritual enrichment or improved mental health, especially if communities are involved in their co-creation (Frantzeskaki et al., 2018). Such a process could be embedded in the overall participatory process accompanying the decision-making process.

3.4.2 Support financing through an array of approaches

Financing is a major element throughout the entire process but in particular in the implementation phase. This is an ongoing research area in and of itself and many authors have presented and reviewed a variety of recommendations (see e.g., Toxopeus and Polzin, 2021; den Heijer and Coppens, 2023; Thompson et al., 2023; Frantzeskaki et al., 2019; Kedward et al., 2023; Hagedoorn et al., 2021), a comprehensive account of which is beyond the scope of this paper. However, a brief overview of some of the key insights will be presented here.

Many of the recommendations align with other guidelines for the general decision-making process, such as communicating co-benefits, including participatory valuation to align different values, increasing the time scale, in this case the investment horizon, and many more. In particular, valuation that accounts for co-benefits and the appropriate scale to fully assess the value of NBS is a necessity to attract funding (Toxopeus and Polzin, 2021). Here, a central tension lies between the reliance of (traditional) financing mechanisms on monetary valuation to make investment decisions and the difficulty and ethical controversy associated with such monetary valuation. Public finance may be favoured in such instances because it can more easily take into account the less tangible public good character of such projects, as is often the case with spending on education and healthcare. In fact, up until this point, public funding appears to dominate for NBS projects. In the European Union, for example, 97 percent of projects received at least 50 percent of their funding from the public sector (European Investment Bank, 2023, p. 3).

[5] See Hofmann et al. (2012), Prestamburgo et al. (2016) and Vanstockem et al. (2018) for a discussion of the role of design characteristics in supporting acceptability.

Nevertheless, many authors highlight the role of private financing, although this is not seen as a replacement for public financing (den Heijer and Coppens, 2023; Thompson et al., 2023). However, the role of private investment is not clear-cut and even seen very critically by some authors (see e.g., Kedward et al., 2023). Public finance, on the other hand, also faces issues such as short-termism and a focus on projects that will provide (quick) economic growth above all else, for example by focusing on real estate development to the detriment of projects which provide wider ecological and social benefits (Toxopeus and Polzin, 2021; Thompson et al., 2023). The interplay of public and private financing of NBS projects is therefore complex and will likely depend on the local circumstances.

Many innovative alternative funding mechanisms for public, private, and joint funding have been developed, such as crowdfunding, tax increment financing, co-financing across government departments, green bonds, impact investing, and many more (see e.g., Toxopeus and Polzin, 2021; den Heijer and Coppens, 2023; Thompson et al., 2023). As mentioned above, a detailed description of all of them is beyond the scope of this paper, but collating lists of successful mechanisms to build on is important for the implementation of NBS and requested by policymakers, scientists, and practitioners (Frantzeskaki et al., 2019). Many of the proposed mechanisms focus on high-income countries but there are likewise suggestions such as time contributions which may be more suited to countries or communities where money is a more strongly restrictive factor or of less relevance in everyday interactions (Hagedoorn et al., 2021).

In all settings, general recommendations to contribute to increased investment in NBS include stable policy environments and legal frameworks (den Heijer and Coppens, 2023, p. 9), calls for pilot projects to demonstrate the success and benefits of NBS (Toxopeus and Polzin, 2021; den Heijer and Coppens, 2023), and monitoring with a focus on local specificities to understand the potential for transferability (den Heijer and Coppens, 2023, p. 8).

3.5 Monitoring, maintaining, and scaling up interventions

Monitoring interventions not only ensures that they are carried out as planned, and possibly adapted, but likewise provides insights for future projects. Ultimately, it will inform management practices for restoring, maintaining and optimizing NBS (Campbell et al., 2016).

3.5.1 Ensure early and continued maintenance and monitoring

Monitoring should be prepared early on, ideally already in the design phase, to ensure that the implementation is designed in such a way as to measure its effectiveness, thereby providing information for the implementation of future NBS (World Bank, 2017). Indicators for monitoring should be selected in such a way as to acknowledge the existence of environmental and non-environmental effects (e.g. social, cultural, health) in the design and implementation phase (Raymond et al., 2017c), defining different baselines for their measurement across various social groups (Haase et al., 2017). Potential (causal) pathways through which these effects emerge and techniques to investigate them should be assessed. To ensure the successful completion of each of these steps, appropriate data collection mechanisms and analysis tools have to be put in place as the NBS is being designed (World

Bank, 2017).[6] This ensures that the data collected during the monitoring phase is appropriate to identify whether the (causal) pathways develop as anticipated and lead to the desired outcomes.

Additionally, climate adaptation measures aim to address climate impacts that will likely manifest over decades, if not centuries, to come. To effectively inform on potential corrective measures, and given that certain (most) effects of NBS appear only in the long run, monitoring should be continuous and prolonged (Raymond et al., 2017b; World Bank, 2017).

3.5.2 Map behaviour and experience

To produce insight on NBS perception, utilization and causal pathways, it is advisable to produce behaviour and experience mapping (Dumitru et al., 2020). Such mapping aims to identify how citizens and other stakeholders engage with and experience the NBS once it is in place. For example, just because a new urban forest in a business district has trails on which citizens can take a walk at lunch time, thereby potentially improving their health and well-being, does not necessarily mean that these trails will actually be used. Such uptake by citizens and their subjective experiences are what behaviour and experience mapping aim to assess and will likewise provide the insights that are lacking so far to inform future projects. This requires using tools of geo-localization in surveys, participatory GIS assessments, transdisciplinary mapping of causal chains, for example through feedback loops, and other combined quantitative-qualitative approaches. The need to integrate multiple disciplines and approaches has been recognised in other, more established research strands such as forestry interventions (Miller et al., 2017). However, only few NBS studies have implemented them to date (Larondelle et al., 2016; Panno et al., 2017).

3.6 Summary of policy solutions

As outlined in this chapter, there are some key changes that need to be made to decision-making processes in order to ensure that NBS are not overlooked. These changes are outlined in Table 2 and include broadening the expertise involved in the process, the evaluation tools, and the scope of the benefits and costs that are considered, to move beyond the prevalent silo mentality. They are necessary when planning climate adaptation measures but apply more generally to all projects in which NBS could be a possible solution to the problems faced.

[6] An array of different methods to be used is outlined in Raymond et al. (2017c).

Table 2: Policy solutions for the implementation of NBS at each step of the decision-making process

Across all steps

- Implement a participatory approach which involves a diverse range of stakeholders to ensure all knowledge and value types are represented throughout the entire decision-making process. (Irvin and Stansbury, 2004; Eckersley, 2006; Blackstock and Richards, 2007; Biggs et al., 2010; Collier et al., 2013; Reed et al., 2018; Wamsler et al., 2020; Young and Tanner, 2023)
- Involve a wide range of experts, including policymakers across policy boundaries and governance levels. (Jellinek et al., 2014; Scott et al., 2022; Mofrad and Ignatieva, 2023)
- Explicitly include social justice considerations at each step of the decision-making process (Faivre et al., 2017; Haase et al., 2017; Zuniga-Teran et al., 2021; Thompson et al., 2023)
- Create a legal and regulatory framework that can accommodate NBS. (Sarabi et al., 2020; Mehryar and Surminski, 2021; Nikolić Popadić, 2021; Bogdzevič, 2023)

Step 1: Identifying objectives and possible intervention options

- Consider a variety of future scenarios to identify the range of adaptation needs and how NBS might respond to a changing climate. (Cohen-Shacham et al., 2016; Calliari et al., 2019)
- Explicitly consider NBS as intervention options alongside more established solutions to mitigate path dependence. Include a 'do nothing' option. (Nesshöver et al., 2017; Calliari et al., 2019)
- Disincentivise myopic decision-making both in the private and the public sector, for example through financial incentives or regulatory/legal frameworks. (Randall, 1972; Varian, 1993, 1994; Ostrom, 2012)

Step 2: Evaluating the possible interventions

- Expand valuation techniques beyond monetary valuation if all relevant costs/benefits cannot be captured monetarily. (Sijtsma et al., 2013; Saarikoski et al., 2016; Adem Esmail and Geneletti, 2018)
- Apply a multi-scalar valuation approach, including different spatial and temporal scales as well as co-benefits and costs. (Rathwell and Peterson, 2012; Raymond et al., 2017c; Small et al., 2017)
- Draw on past examples of successful nature-based interventions and pilot projects to inform insights into their long-term benefits and costs. (Nesshöver et al., 2017; Collier, 2021; Wolf et al., 2021)

Step 3: Implementing the chosen intervention

- Strengthen awareness of benefits from NBS to support social acceptance. (Andersson et al., 2017; Frantzeskaki, 2019)
- Support financing by seeking out alternative financing mechanisms, e.g., co-financing across government departments, and by communicating the multiple benefits of NBS, among other measures. (Toxopeus and Polzin, 2021; den Heijer and Coppens, 2023; Thompson et al., 2023)

Step 4: Monitoring, maintaining, and scaling up interventions

- Prepare the monitoring process early on and ensure monitoring and maintenance take place over the long run. (Raymond et al., 2017b; World Bank, 2017)
- Conduct behaviour and experience mapping to assess how the NBS is being experienced and taken up by citizens in practice. (Dumitru et al., 2020)

4 Conclusion

This paper synthesizes previous research on NBS through a comprehensive literature review to identify barriers and policy solutions at each step of the decision-making process. This provides guidance for policymakers who wish to integrate NBS as a tool to address climate adaptation challenges, but can be applied to other policy challenges as well. This analysis complements previous studies, that developed conceptual and assessment-focused frameworks, by providing a holistic and practical overview of the barriers decision-makers face when trying to include NBS in the decision-making process and how these barriers can be overcome.

While this overview aims to be as comprehensive as possible, some limitations remain. The large body of research on NBS that has developed in recent years means that not every barrier or policy recommendation identified could be included in the present review. Instead, an emphasis was put on recurring themes across the literature. Additionally, an entire separate body of studies exists on funding for NBS which could not be fully represented here. Nevertheless, this paper should provide a structured overview of the key insights that have emerged from NBS research over the past years which will be useful both to policymakers and to researchers.

As this paper has shown, NBS still face many barriers at each step of the decision-making process that prevent them from being considered on equal footing with technical climate adaptation interventions. Decision-makers will have to make changes to this process if they want to change the status quo.

Some of these changes go beyond individual decision-making processes, instead requiring an institutional shift. These include fostering an environment for truly participatory public policymaking, addressing drivers of existing inequalities, and creating a legal and regulatory framework that can accommodate NBS.

Other recommendations will have to be implemented at the level of individual projects. For example, it is important to include a diverse range of experts as well as stakeholders in the process to prevent silo mentality and guarantee that different values are represented. Additionally, social justice considerations need to permeate the entire decision-making process to ensure that NBS remedy rather than exacerbate existing inequalities. This affects the choice of where NBS are placed and how they are implemented, for example to avoid (eco-)gentrification resulting from the creation of new green spaces in underserved communities. To address the uncertainty of what climate impacts will come to pass, different possible scenarios need to be considered. Similarly, a wide range of alternative interventions should be considered, explicitly including NBS to mitigate path dependence which favours more established solutions. For the evaluation, it is important to use a multi-scalar valuation approach which includes co-benefits (and costs) that NBS provide but are external to the specific aim of the project. This may require an expansion of existing evaluation techniques to include non-monetary costs and benefits, for instance through a multi-criteria analysis. To overcome risk aversion and lack of public support, pilot projects or previous successful projects can be a way to demonstrate the potential of NBS, as can reinforcing the visible benefits they provide, such as aesthetic value. This can also help to attract funding, for example through alternative mechanisms such as co-financing across government departments or crowdfunding, as can a clear communication of the multiple benefits NBS provide. Finally, preparing the monitoring process early

on and implementing it in a similarly holistic way as the decision-making process itself facilitates scaling up and allows others to learn from successful examples.

These measures are not intended to favour NBS over technical solutions. Rather, they aim to support the inclusion of NBS in the decision-making process, to ensure they are not systematically overlooked, and that all relevant benefits and costs are effectively taken into consideration. This will enable better policy decision-making for climate change adaptation measures, or in any other situations where NBS might improve policy outcomes.

While this paper presents a holistic and practical overview, climate adaptation, in particular through NBS, is always site specific. Further research should assess the effectiveness of the recommendations developed here by accompanying and providing context-specific guidance to individual projects. The research presented here will present a clear and practical starting point for such research efforts. Such place-based, transdisciplinary research can be beneficial to researchers, decision-makers, and stakeholders alike. In the long run, this can help identify what recommendations are relevant under which conditions and how the different decision-making steps are interlinked. This will help expand the understanding policymakers and stakeholders have of the socio-ecological systems in which we interact with nature, and, ultimately, lead to better policy decisions.

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