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Money talks

A systems perspective on funding and financing barriers to nature-based solutions

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DOI
10.1016/j.nbsj.2024.100200

Publication date
2024

Document Version
Final published version

Published in
Nature-Based Solutions

Citation (APA)
Hüsken, L. M., Slinger, J. H., Vreugdenhil, H. S. I., & Altamirano, M. A. (2024). Money talks: A systems perspective on funding and financing barriers to nature-based solutions. *Nature-Based Solutions*, *6*, Article 100200. https://doi.org/10.1016/j.nbsj.2024.100200

Important note
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Nature-Based Solutions 6 (2024) 100200

Contents lists available at ScienceDirect

Nature-Based Solutions

journal homepage: www.elsevier.com/locate/nbsj

Money talks. A systems perspective on funding and financing barriers to nature-based solutions

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ARTICLE INFO

Keywords:
Integrative literature review
Nature-based solutions
Funding and financing barriers
Opportunity costs
Lifecycle costs and benefits
Institutions

ABSTRACT

A financing gap is seen as a crucial barrier, hampering the further uptake and upscaling of Nature-based Solutions (NbS). However, it is not always clear what is meant by this, nor is it clear why this barrier exists and persists. The aim of this paper is to generate an enhanced understanding of financial barriers to NbS. This is accomplished through first conceptually and theoretically clarifying the difference between funding and financing and then exploring these through an integrative literature review. We expose three different dimensions of financial barriers in NbS projects, namely the occurrence of multiple types of funding gaps, the occurrence of multiple types of financing gaps, and the particular and complex cost structures of NbS. NbS funding gaps can be broken down into public funding gaps, private funding gaps, and funding gaps specific for lifecycle phases, activities, and cost types. Bridging the funding gap is a necessary (although not sufficient) condition for bridging the finance gap and financing alone cannot solve a funding problem. We further find that these different dimensions of financial barriers can be explained by the misalignment between the characteristics of NbS and the characteristics of our existing institutions. These misalignments occur through different institutional mechanism, including (i) Funders' preferences, (ii) Revenue generation enablers, (iii) Justification requirements, (iv) Funders' regimes, (v) Financiers' preferences and (vi) Finance application processes. All mechanisms influence the occurrence of public and private funding and financing gaps and they influence the cost structure of NbS, in particular transaction costs. The results of this analysis suggest that overcoming NbS funding and financing challenges requires a systemic, multi-level approach as the barriers to project implementation are not all located within a project's sphere of influence or control.

1. Introduction

The United Nations has declared the current decade, 2021–2030, the *Decade of Ecosystem Restoration*. This represents an urgent call to action to speed and scale up the restoration and protection of ecosystems throughout the world. At the same time, Nature-based Solutions (NbS) have been gaining traction. The NbS concept emerged towards the end of the 2000s as a result of a paradigm shift from conserving nature for nature to conserving nature for humans [1]. NbS are defined by IUCN as "*actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefitting people and nature*" [2]. NbS, an umbrella term, encompasses a variety of other commonly used concepts such as Green Infrastructure (GI), Building with Nature, or Natural Floodrisk Management [3,4]. Cohen-Shacham et al. et al. [5] distinguish five generic types of NbS approaches, namely i) Ecosystem restoration approaches, ii) Issue-specific ecosystem-related approaches, iii) Infrastructure-related approaches, iv) Ecosystem-based management approaches and v) Ecosystem protection approaches, and in doing so offer conceptual clarity on the span of the NbS concept. A few examples of NbS are mangrove reforestation, wetland (re-)construction, green roofs, rain gardens, coral reef protection, and seagrass restoration [6,7]. The latest IPPC report demonstrates the effectiveness of NbS for mitigation and adaptation [8] and as such, NbS are regarded as an essential component of the necessary global response to climate change.

Despite the potential and growing urgency, investment in NbS

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https://doi.org/10.1016/j.nbsj.2024.100200
Received 10 May 2024; Received in revised form 21 November 2024; Accepted 22 November 2024
Available online 25 November 2024
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remains limited. The global level of investments in 2020 in NbS is estimated to be around USD 133 billion annually [9]. However, if the world is to meet its biodiversity targets, investments have to triple by 2030 and have to increase four-fold by 2050 [9]. Most NbS projects are funded through public and philanthropic funds whilst only 14 % comes from private actors. Increasing public funding alone – a challenge in itself as public budgets are increasingly under pressure - will not be sufficient to bridge the gap and as such, scaling up the flow of private finance for NbS is seen as an essential avenue for the years to come [9]. Although NbS are seemingly more cost-effective than gray infrastructure alternatives, adoption of NbS remains low [10], and is often limited to small scale or experimental pilot projects, and not yet part of mainstream application [11]. Implementing and upscaling NbS faces a multitude of barriers that have been identified and discussed in prior studies [12–15]. Amongst this array of barriers the lack of finance has been recognized as critical in limiting the implementation and upscaling of NbS.

In response, significant scholarly efforts have been directed at improving the NbS investment case (justifying that it is a good investment, and that it achieves the highest value for money). This includes, but is not limited to, research on the values of ecosystems via the ecosystem services approach [16–20], valuation studies of specific ecosystem services or specific species [21], improvements and applications of valuation methodologies [22], exploring the 'demand side' for ecosystem services [23], and studying NbS from a business model perspective [24–26]. Furthermore, studies on the financial mechanisms and instruments that are (potentially) applicable in the context of NbS and as such facilitate payments for the values generated by NbS or specific ecosystem services are emerging in the academic literature [21,27,28]. In this context the implications and trade-offs of such arrangements are being highlighted, particularly their effects on environmental and social equity [29], and their influence on democratic processes [30,31]. This illustrates that the development of novel approaches and instruments may offer relief on the financial side, but at the same time new and different challenges become apparent.

Despite the increased attention and research efforts on this topic, the research remains fragmented and is often approached from different yet single disciplinary perspectives. This makes it difficult to keep track of the state of the art and to apply the collective knowledge base in practice, challenges that are often present in inter- and transdisciplinary research fields [32]. Studies concerned with NbS implementation barriers utilize demarcated categories - typically technical, political, social, and economic - yet, researchers acknowledge the interconnectedness of all these barriers [6,12,33–37]. For instance, a lack of funding for NbS can be the result of internal competition over public budgets [38], the short-term orientation in public and private decision-making whereas NbS require a longer term perspective [39] or the situation discussed by Young [40] in which trees are not considered an asset and as such are subject to funding fluctuations depending on the political winds. Such examples illustrate that financial barriers may have their origins in diverse, interconnected domains, and that showcasing the cost-effectiveness of solutions – a challenge in itself - is not always sufficient for implementation. To the extent of our knowledge, no academic article currently offers a holistic view of the matter.

The existence of a financing gap for NbS is articulated by both scholars and practitioners. However, it is not always clear from the outset what is meant by this, nor is it clear why this situation exists. "*Successful problem solving requires finding the right solution to the right problem. We fail more often because we solve the wrong problem than because we get the wrong solution to the right problem*" [41]. In this paper we therefore take a step back, aiming to analyze and synthesize the existing collective body of knowledge concerning NbS (financial) implementation barriers **to develop a deeper understanding of what financial barriers for NbS entail and why they exist and persist.** To achieve this the phenomenon is delineated in two ways. First, a clear conceptual distinction between funding and financing is made and explored. Although these terms are often used interchangeably and are interconnected, in this problem analysis-oriented study, financing and funding are considered as distinct barriers. Secondly, by taking a more holistic perspective we investigate the systemic nature of funding and financing barriers to NbS and their rooted existence in our social (institutional), environmental, and technological systems. Accordingly, following the paths of Schuitmaker (2012), Eisenack et al., (2014) and Dorst et al.. (2022), we adopt the definition for barriers *as project-level problems that arise from the misalignment between NBS characteristics (e.g., they are growing, living interventions; they present multi-functional solutions) and existing conditions in our institutional systems* [12,42,43].

This paper explores the systemic reasons for the existence and persistence of financial barriers for NbS, identifying key institutional mechanisms and their misalignment with specific NbS characteristics. Such an analysis can provide an effective starting point for both academics and practitioners in general, and institutional economists in particular, to study and develop financial arrangements and broader strategies to scale up NbS. Indeed, in their recent publication Favero and Hinkel [44] highlight the need to look beyond trying to overcome financial barriers solely with financial solutions. Similarly, Op de Beeck et al. (2024) identify that the interplay between policy and financing serves as a catalyst for investments in NbS [45], underscoring the need for a systemic perspective in addressing the funding and financing gap for NbS.

2. Defining funding and financing

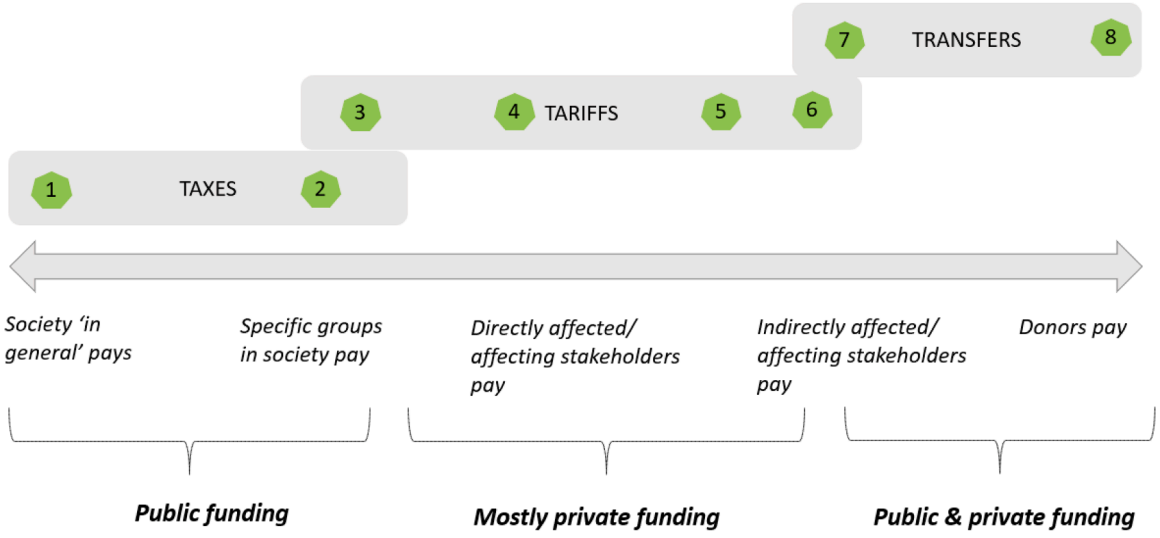
The distinction between funding and financing is often not made explicit. For example, it is common practice to refer to non-return seeking money as finance (e.g. public finance) or to utilize the term 'finance' to encompass both funding and finance. Further, mechanisms such as the Green Climate Fund, often make use of combined funding and financing instruments, further clouding the distinction between these two fundamental concepts. As such, the terms funding and financing are often used interchangeably. However, they are profoundly different concepts in economics. Funding is concerned with the question of **who will ultimately pay** for the project, whilst financing addresses the question of **who will provide the up-front resources** needed to construct or implement it (and under what conditions) [27,46–48].

Consider for example the construction of a new bridge. The asset owner or initiator can turn to the capital market and borrow the up-front money required for the construction – *financing* – whereas once the bridge is utilized, the users of the bridge may pay a user fee every time they cross the bridge, ultimately *funding* the investment. In this example, in the end, the users of the bridge actually pay for the bridge, not the asset owner nor the financier. Revenues generated by projects typically accumulate over time and tend to be backloaded, meaning that little revenue is available during the initial construction phase when the capital needs are high. As it takes time for the revenue streams to initiate, the required up-front money often needs to be sourced elsewhere. The type and stability of project funding primarily determines the availability and conditions of financing, especially in privately financed projects. Reliable funding sources are fundamental to make a debt issuance affordable or an investment attractive, and to ensure the long-term financial viability of the project. A further consideration for policy makers is that the choice in funding can influence the eventual impact of a project; "*Tariffs will provide incentives for more efficient use of water, whereas subsidies generally will not*" [49].

Building upon previous academic and practitioners work, we consider **three generic categories of funding**, namely **T**axes, **T**ariffs, and **T**ransfers, also referred to as the "3T's framework" [46,49–51]. *Taxes* encompasses government revenues which can be generated in different ways but mostly originates from levying (a wide range of) taxes, income from government-owned corporations and the sales of assets. A distinction can be made between generic national government revenues and revenues from earmarked taxes (collected and used for a

designated purpose), and taxes levied at different government levels. Funding from this category means that public money is used to ultimately pay for the NbS, or alternatively framed, "society pays". Although we stick to the framework's original term *Tariff*, in this context this category includes a broad range of potential funders. It reflects the principles of the "user pays" and "polluter pays" [52] as well as regular market mechanisms for selling and buying products. Fees or payments can be either obligatory or voluntary. Funding from this category means that money from the beneficiaries, consumers, or polluters – directly or indirectly affected - is used to ultimately pay for the NbS. The third category, *Transfers*, reflects contributions from (foreign) donors, i.e. donors that are not directly related to the project in question or responsible for the outcomes. This typically includes EU subsidies, philanthropic donations, corporate donations, and Official Development Aid (ODA). Funding from this category means that "donors pay" for the NbS. The first category (taxes) consists of public funding, the second category (Tariffs) consists of mostly private funding although public funding is also possible, and the third category (transfers) typically captures both public and private funding. The above described categories are broad, especially Tariffs, and boundaries between the 3T's are not strictly demarcated, but can rather be seen as a continuum (Fig. 1).

Regarding finance, one can distinguish between commercial finance (finance provided above or at market rates usually provided by the private or financial sectors), concessional finance (finance provided below market rate or under different conditions than commercial finance, can originate from public and private sectors) and public finance (finance provided by the public sector under conditions aligned with policy objectives). Typically, a commercial financiers' objective is to generate revenue through charging interests. Concessional and public finance tend to come at lower interest rates and under different conditions (i.e. pay-back period, size of loan) with a broader range of objectives, including social and environmental objectives being pursued by the financier. As such, commercial finance usually comes at a higher cost than concessional or public finance and arguments such as efficiency gains or risk sharing are needed for why that type of finance is preferred. Academic work in this field typically falls under the public private partnership discourse [53,54]. Further, finance typically comes in the



1	National (ministerial) infrastructure budgets	*Allocation of national government revenues to responsible ministry for infrastucture maintenance and renovation*
2	Water authority tax	*Tax charged (by a water authority), which pays for the maintenance of dikes and waterways, water management, and water purification*
3	Differentiated and earmarked tourist tax	*Environmental footprint based differentiated tax charged to visiting tourists where revenues are dedicated to mitigating associated environmental impacts.*
4	Drinking water utility fee	*Fees charged to utility users to compensate for the use and maintenance of utilities, including NBS measures*
5	Insurance-based funding	*Payments made for NbS by insurance companies who benefit from the risk-reducing effects of the measure*
6	Carbon credits	*Companies buy carbon credits - representing a fixed amount of carbon emission reduction achieved by the NbS - to voluntary compensate their carbon emissions*
7	(Corporate) Philantrophy	*(Initiators of the) NbS projects recieve donations from philantropic organisations or corporations.*
8	Climate finance grants	*Grants provided from multilateral funds (such as Green Climate Fund) to support action on climate change*

Fig. 1. The Funding Continuum, illustrating the generic categories of Taxes, Tariffs and Transfers (the 3T's [49]), with examples, through which stakeholders ultimately pay for (NbS) projects. Source: Authors' own conceptualization.

form of debt (borrowing money that needs to be repaid) and/or equity (selling a portion of the equity in a concern) or a hybrid form.

Thus, both funding and financing can be obtained from public as well as private sources, or combinations thereof. Following Heijer & Coppens [27], who categorize financial models based on combinations of public or private funding and public or private finance, we define public actors as governments and government-affiliated entities and we consider private actors as any actor that does not fall into the category of public actors. In our review, we examine the barriers to funding and financing for NbS, whether from public or private sources.

Now that we have established that funding and financing are conceptually different yet interconnected, that there is a range of options available for both funding and financing, and that both public and private actors can be the source for funding and financing we move on to describe the approach adopted to scrutinize the occurrence of funding and financing barriers in NbS and why securing funding and financing for NbS is such a persistent challenge.

3. Approach

A systems perspective is adopted in this study. Such a perspective draws upon the financial and economic, environmental science, infrastructure development, policy analysis and (multi-level) governance fields of knowledge to provide a deeper and wider understanding of the (non-) occurrence of financial barriers to NbS implementation. In doing so, we go beyond the conventional (bounded, single disciplinary) manner with which the problem has thus far been studied. Furthermore, the authors adopt interpretivist–constructivism as the epistemological basis of the research. The interpretivist–constructivism epistemological basis of this study regards human interpretation as the starting point for developing knowledge about the social world [55–57]. This aligns with the explorative nature of this study and the objective to develop a deeper understanding of the funding and financing challenges for NbS as a problem embedded within (a) bigger system(s) [55,56].

A well-conducted literature review can be seen as a research methodology in its own right [32,58]. By inventorizing and synthesizing efforts, review studies are seen as valuable contributors to evidence-based practice and can address research questions that single studies cannot. This is also applicable to a review of review articles, sometimes referred to as an "umbrella review" or "meta-review". In such procedure evidence is compiled from multiple existing reviews. This type of procedure is especially common in medical science research (see [59,60] but is also applied in social science research (see [61]) and engineering research (see [62]). More specifically, in this study, an integrative literature review (ILR) – "*a form of research that reviews, critiques, and synthesizes representative literature on a topic in an integrated way such that new frameworks and perspectives on the topic are generated*" [63] – is conducted to shed light on our phenomenon of interest. Integrative reviews are typically applied on mature topics that have experienced rapid growth and on new and emerging topics, such as the one in question here, with the purpose of creating initial conceptualizations and theoretical models or to combine perspectives and insights from different research fields [32,63].

There is no general format or strict procedure for an ILR, however, the researcher is required to take systematic approaches that are consistent and can be reproduced [64]. We make use of the generic steps presented in Lubbe et al. [65], which in turn have been derived from the comparison and synthesis of different IRL studies and methodologies, and are aligned with the generic steps that are taken during primary research. Within the IRL, we adopt the established method of thematic analysis through which we enable the process of inductive reasoning [65,66]. The resulting research design underpinning this study is presented in Fig. 2.

Thematic analysis is known to be quite flexible and some common criticisms of this approach include the lack of consistency, or the susceptibility to biases and "cherry picking" [67]. Nowell et al. [66] provide means to enhance consistency and cohesion throughout the different steps of a thematic analysis. Such recommendations have been integrated into the steps taken in this study and are summarized in Table 1. Furthermore, accepted conventions for reporting on how the

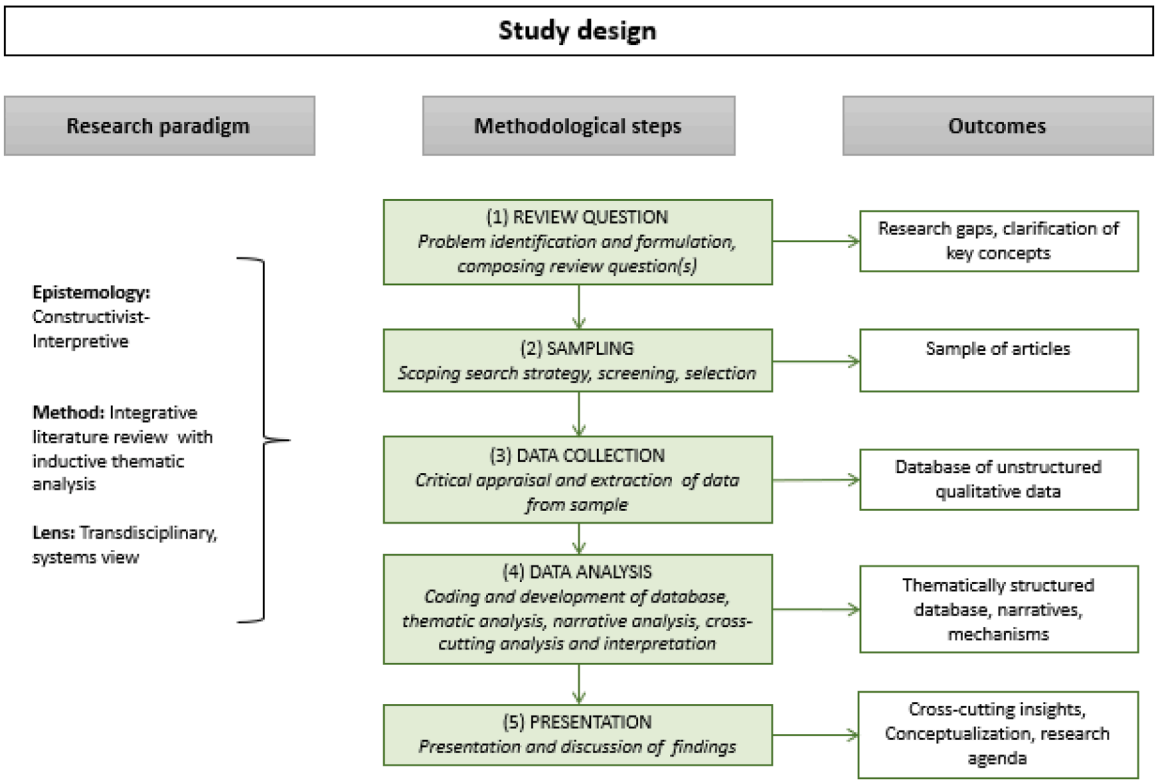


Fig. 2. Study design of Integrative Literature Research (IRL), following the methodological steps for IRL [65,66].

Table 1
Means of enhancing trustworthiness in the thematic analysis, integrated in Integrative Literature Review (IRL) study design. R1 = principal researcher, R2 is senior researcher, R3 is senior researcher, *X*=Entire step conducted, ~ = partly involved for (sample) verification.

Means of establishing trustworthiness (after Nowell et al. (2017)	Researchers involved			Integrated in IRL methodological steps
	R1	R2	R3	
Prolonged engagement with data and triangulation (with experts and algorithm), experimentation with various search terms and exploration of key terms, documentation of reflective thoughts, soring search history and data in will-organized archive	X			(2) SAMPLING
Documenting reflective thoughts, text fragments selected from sample reviewed by second researcher for validation	X		~	(3) DATA COLLECTION
Team consensus, documenting reflective thoughts and alterations, testing referential adequacy by returning to raw data, researcher triangulation and team consensus	X	X	~	(4) DATA ANALYSIS
Summarizing and reporting on process, theoretical and methodological choices made throughout the study	X	~	~	(5) PRESENTATION

study was conducted are followed, specifically addressing conceptual structuring of the topic, offering transparency in the search and analysis process and making the epistemological position that underpins the study explicit [32,63]. Further details on the steps are provided in the following sections.

3.1. Review question

This paper aims **to develop a deeper understanding of what financial barriers for NbS entail and why they exist and persist.** To achieve this a clear conceptual distinction between funding and financing is made and explored, which in turn are studied from a holistic, transdisciplinary perspective.

3.2. Sampling

We draw from the existing literature through a structured search. An extensive body of literature is concerned with the identification and discussion of barriers to implementing NbS – amongst which financial ones. Our approach is to utilize and build on other scholars' valuable review efforts – either as part of primary research articles where the literature review serves as a component of theory building that is matched to another epistemological approach – or standalone review articles. This strategy allows us to study a large collection of barriers identified by different researchers in different contexts. Similar to other author's we do not claim to be exhaustive.

The literature search followed a search protocol (Fig. 3). The electronic databases Scopus and Web of Science - known for their coverage of interdisciplinary research fields – were used for the search. The search query can be found in Table 2. The search was not bound to a specific time period. It was conducted on the 30th of October 2023, and as such this study only contains publications from before that date. A total of 61

Table 2
Search terms for structured literature search.

Search field	Search theme	Search Query
Article title - abstract – keywords	Funding and financing	*financ* OR fund* OR pay* OR invest**
Article title - abstract – keywords	Barriers and enabling conditions	*AND barrier OR enabler OR "enabling condition"*
Article title - abstract – keywords	Nature-based solutions	*AND "nature based solution" OR "nature-based solution" OR "ecological restoration" OR "Ecological engineering" OR "Natural infrastructure" OR "Ecosystem restoration" OR "Building with nature" OR "green infrastructure"*
Article title - abstract – keywords	Review as part of primary research articles or stand-alone reviews	*AND Review*

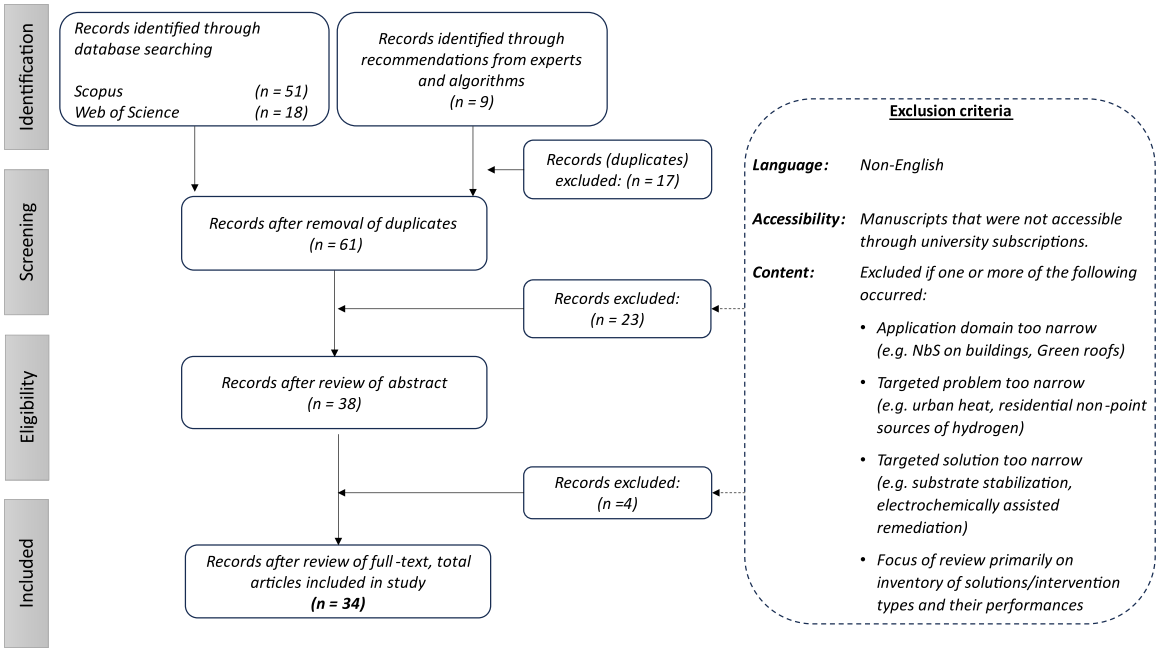


Fig. 3. Literature search decision flow chart.

articles were identified. A further 9 articles were added to relevant literature, based on the recommendations from two experts in the fields of NbS and environmental economics, and from algorithms in Mendeley/ScienceDirect. After both removing duplicates from the search and from two rounds of screening on the exclusion criteria, 34 articles were included in the study. The full list of the articles and a sample description can be found in the supplementary materials (Supplementary 1). Further, an overview of the sample characteristics can also be found in the supplementary material (Supplementary 2).

3.3. Data collection

The thematic analysis comprised identifying, analyzing, and reporting on patterns or themes within the data and the steps are derived from the established method of thematic analysis [66,68]. The selected literature is treated as unstructured qualitative data and as such analyzed through the coding and analysis of text fragments. The literature is considered to be unstructured for two reasons. Firstly, although each of the articles has an internal structure, yet, as a collective data set their structures are not consistent as they vary in terminology, domain of application, and the theoretical or disciplinary perspective taken. Secondly, the review of financial barriers from a transdisciplinary perspective whilst accounting for the differences between funding and financing is novel and does not follow the internal structure found in the reviewed articles.

From the sample of articles, text fragments which describe either a barrier or an enabling condition (a condition that was identified to facilitate the implementation) are highlighted line by line and extracted. Next each text fragment received an individual code that captured the essence of the text fragment in a few words or a sentence. Some text fragments were very generic whilst others were more specific and contained more detail and nuance. As such, some codes are relatively longer than others. Some text fragments captured multiple barriers, and thus received more than one code. This coding approach facilitated the process of inductive reasoning rather than employing a range of initial pre-defined codes. Text extraction and the coding process were supported by the Atlas.ti software.

3.4. Data analysis

The coded text fragments were then printed and cut to individual cards, creating a 'pile' of cards. Using inductive reasoning, each card was read and then categorized into broader themes. The themes emerged, and were named, during the process of categorizing the pile of cards. After all the cards had been categorized into initial themes, the cards in each theme were re-examined. Where appropriate this led to the identification of sub-themes, while within them recurring topics were distinguished. Given the transdisciplinary and interpretive nature of the approach, the positioning and naming of the topics within the different (sub) themes is debatable. Arguments can be found for the positioning of a specific topic within more than one (sub-) theme or an alternative naming of overarching themes. However, the themes remained stable throughout the process; it was the sub-themes and topics that became subject to discussion and iterative revision.

The database which captures the outcomes of the data collection, coding and thematic analysis is available (see 10.4121/178f73b2–37bd-46f6-b6fe-58e3212ea2cb). An example extract is presented in Table 3.

The next step in the analysis process involved the development of coherent accounts (narratives) of the interplay and connections between the topics per (sub-)theme. This step involved frequently returning to the original texts to verify the interpretation of the selected fragments and codes. The narratives then formed the starting point for the subsequent interpretive step where we focused on the misalignment between NBS characteristics and existing conditions in our institutional systems (see [12]). We refer to these mechanisms as institutional mechanisms.

Table 3
Extract from database. Example of text fragments, codes, and their categorization within topics and (sub-)themes.

ID		Quotation content / Text fragment	Code	Theme	Sub-Theme	Topic
7	1	City development for residential, commercial and transportation purposes contributes to the disappearance of green areas.	Other uses of space prevail over use as green areas	F	F.5	F.5.2
7	2	In many European cities, urban areas do not provide adequate space for green infrastructure	Limited space to accommodate GI	F	F.5	F.5.2
7	3	Current state of knowledge confirms that measurable effects of the green roofs application in urban areas may be achieved first of all when large green areas located near one another are constructed. Due to that, the construction of green roofs in cities should not be limited to single investments scattered all over the town.	Larger green areas located near one another are more effective than single scattered projects	F	F.5	F.5.2
22	1	Biodiversity and its erosion are not in the foreground of our societies. For example, in the United States, most people prioritize other issues such as terrorism, health or the economy	People prioritize other issues over biodiversity	D	D.0	D.0.1
22	2	Fear of nature may relate to the fear of the unknown	Fear of nature related to unknown	B	B.0	B.0.1
22	3	discussed by Kabisch et al. in the face of uncertainties and risks of implementing NBS in cities, as well as the changes these may induce in urban planning. This fear of nature can also relate to real problems called ecosystem disservices, such as the mosquito bites mentioned hereabove. Indeed, ecosystem disservices are inconveniences caused by nature and they can be diverse in cities. We can also have	Fear of nature-related ecosystem disservices	B	B.0	B.0.1

(continued on next page)

Table 3 (*continued*)

ID	Quotation content / Text fragment	Code	Theme	Sub-Theme	Topic
	complaints because of pollen and its associated allergies				

Following North [102], institutions are defined as "*The humanly devised constraints that structure political, economic and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct), and formal rules (constitutions, laws, property rights)*". Further, pursuant to Vermeule [69] and Joseph [70] we define institutional mechanisms as "*small-scale rules and institutional arrangements, within existing institutions, which aim to advance certain normative goals*" [70]. As such, we explain the existence and persistence of NbS financial barriers in terms of key institutional mechanisms. In Papari et al. [71] mechanisms are used to explore how the recently implemented EU Green taxonomy might lead to changes in the financing landscape. Rather, in our study we use the term mechanisms to capture how the misalignment between NbS characteristics and institutional conditions plays out and leads to financial barriers for NbS.

3.5. Presentation

The findings are presented in three parts. The first part concerns the results from the inductive thematic analysis (Section 4.1). In the second part (Section 4.2) we further detail in narrative form the funding, financing and costs topics, which came out of the inductive thematic analysis. Other sub-themes and topics can be found in the supplementary material (Supplementary 3). Third, we outline key mechanisms through which financial barriers for NbS manifest.

4. Results

4.1. Overview of themes

In total, 6 overarching themes and 12 sub-themes were identified inductively (Table 4). Within these themes and sub-themes 65 different topics were distinguished. The full list of topics can be found in the supplementary material (Supplementary 3). The main themes are (A) Financial challenges; (B) (E)valuation difficulties; (C) (Implementation) Knowledge and capacity gaps; (D) Awareness and sense of urgency; (E) The political system; and (F) Institutional conditions. Fig. 4 presents an overview of the relative size of each theme (i.e. how many of the 650 barriers extracted from the sample are contained in the different themes), with a more detailed specification of sub-themes (A.1) Funding, (A.2) Financing, (A.3) Costs, and (A.4) Climate Finance.

The most represented themes are A, C, and F comprising 81 % of the occurrences. For theme A: Financial challenges, funding was the predominant sub-theme, representing 61 % of the occurrences. This signals that the problem lies more in securing funding over the lifetime of the project rather than in financing NbS. Although funding and costs concern two sides of the same coin, we find that the significant cost and related uncertainties constitute a barrier in its own right, regardless of cost effectiveness or cost-benefit performances. Theme C comprises 24 % of the occurrences. This is not surprising given the novelty of NbS and the focus on small-scale applications. The knowledge gaps exposed in theme C make a clear mark on Theme A: Financial challenges, specifically in relation to uncertainties and on the processes of (e)valuating NbS interventions, captured in Theme B. Furthermore, within theme F: the Institutional conditions, 41 % of the occurrences relate to the structure of public administration. A major reason is the single-issue focus of governmental authorities, rather than the integrative approach necessary for NbS implementation. This may lead to situations of conflicting interests, limited decision-making and funding mandates, and fragmented budgets and responsibilities over the lifecycle of NbS. Themes D, and E, although much smaller in size, both capture the dimension of long-term and broad societal support for the interventions (at scale), forming a fundamental boundary condition for commitment and financial support.

Table 4
Themes, sub-themes, and number of topics derived from the inductive thematic analysis and the number of occurrences in each (sub-)theme. Bold sub-themes are presented in narrative form in Section 4.2. The narratives of the other (sub)themes can be found in Supplementary 3.

Theme	Sub- Themes	Number of topics within each (sub)-theme	Number of occurrences
A. Financial challenges	**A.1 Funding**	11	113
	A.2 Financing	7	31
	A.3 Costs	4	33
	A.4 Climate finance	3	7
B. (E) Valuation difficulties	*No sub-theme*	5	67
C. (Implementation) Knowledge and evidence gaps	C.1 Performance	3	59
	C.2 Design (process)	4	52
	C.3 Capacity limitations	2	43
D. Recognition, awareness, and prioritization	*No sub-theme*	5	39
E. The political system	*No sub-theme*	5	22
F. Institutional conditions	F.1 Public sector structure	2	50
	F.2 Public sector policies	5	65
	F.3 Market failures and provisioning modes	3	21
	F.4 Informal preferences	3	6
	F.5 Opportunity costs	3	38

4.2. The narratives of theme A: financial challenges

Funding, Financing, and Costs are detailed below in narrative form. The narrative descriptions of the other themes, sub-themes and topics can be found in the supplementary material (Supplementary 3). The topic codes are presented in Table 5 and are referenced in the narrative descriptions.

4.2.1. Funding (Sub-theme A.1)

The existence of a funding gap **(A.1.1)** for NbS is a recurrent issue discussed amongst almost all of the articles. The lack of public funding is identified to be a key barrier to implementation [27,34,35,72–74]. This often coincides with a lack of dedicated (municipal) capacity [12]. Similarly, a lack of funding (both commercial and non-commercial) from the private sector has also been identified [34,35]. In general, access to sufficient resources is identified as an important enabler in sustainability transitions [12]. There are significant implementation costs for NbS, for example, tree planting is seen as expensive, and such costs need to be covered by sufficient funding [75]. The lack of funding extends beyond the initial implementation costs and is also identified for monitoring and maintenance of the projects [73] **(A.1.1)**. More specifically, sources of private funding for start-up capital, certification and capacity building are limited [76] and project evaluation is often seen as low priority and can face resource limitations, particularly on smaller projects [77] **(A.1.1)**. In some types of NbS, such as the integration of a more natural environment into the farmed landscape, the lack of appropriate financial compensation for restoration was identified [34].

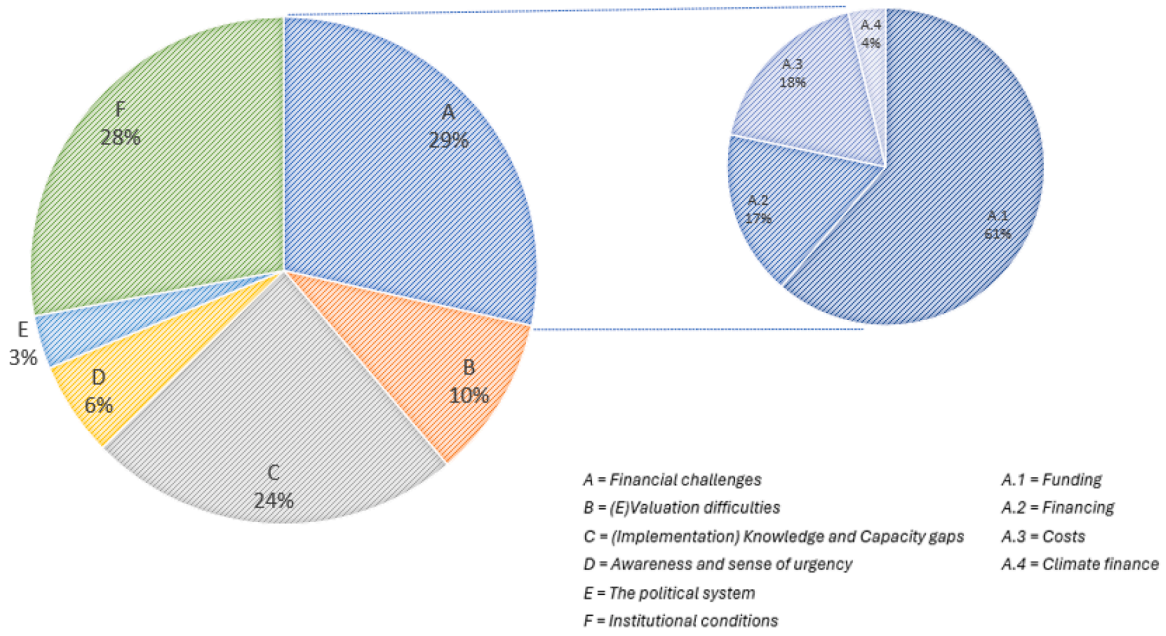


Fig. 4. Relative size of each theme with specification of sub-themes A.1, A.2, and A.3, based on number of codes in each theme.

Table 5
Overview of the topics identified within Theme A: Financial challenges.

Sub-theme	Topic	
A.1 Funding	A.1.1	Different types of funding gaps for NbS: public / private / project phases /activities / cost types
	A.1.2	Long(er) term nature of benefits not aligned with political cycles, budgets, and capacities
	A.1.3	Distribution of responsibilities vis-à-vis budget availability between local, regional, national, transnational authorities
	A.1.4	Natural assets not embedded in financial accounting systems
	A.1.5	Legal/political priorities typically do not include NbS
	A.1.6	Risk associated to innovations
	A.1.7	Lack of knowledge about solution space
	A.1.8	Difficulty to generate revenue/capture values from NbS benefits
	A.1.9	Reputational value as emerging driver for willingness to pay /investing in NbS
	A.1.10	Impact of funding types
	A.1.11	Market conditions for value capture
A.2 Financing	A.2.1	Financing gap for NbS projects for upfront costs and long-term maintenance costs
	A.2.2	(Relatively) Low demand for NbS finance
	A.2.3	Financing gap for NbS / green entrepreneurs
	A.2.4	Un-attractive risk-return profiles: ratio / funding type / timescale / asset value / multiple benefits /performance data
	A.2.5	Lack of confidence and awareness
	A.2.6	Financial sector processes and policies
	A.2.7	Financing applications
A.3 Costs	A.3.1	High (relative) costs of NbS at scale
	A.3.2	The role of costs in decision making
	A.3.3	Key NbS cost items: transaction costs, preparation costs, maintenance costs, monitoring costs
	A.3.4	Complex cost-estimation process

If private lands are needed for restoration activities, accounting and compensating for loss of land or loss of income will rely heavily on publicly funded grant schemes [75]. Developing and implementing such schemes requires extensive consultation, demonstration activities and policymaking, making it difficult to implement specifically such funding mechanisms [76] **(A.1.1).**

Several reasons are discussed why public and private budgets to pay for NbS, or the services it provides, are limited. NbS outcomes, or returns, typically occur after a period of time. This timeframe does not align well with short-term political cycles [77]. This longer time frame also requires longer-term commitments for which funding and capacity is restricted [27,78] **(A.1.2).** Furthermore, responsibilities, and corresponding budgets, have been subject to shifting from national governments, toward transnational actors – a phenomenon referred to as "hollowing-out" - leading to a reduction in national public budgets [79]. Similarly, a lack of spending autonomy and lack of fiscal transfers to a local level has also been identified as a reason for municipal budget constraints [79] **(A.1.3).** In general, cities with less financial capacity also allocate less money to NbS operations and maintenance [29].

Another explanation for the lack of funding arises from the fact that natural assets are not considered infrastructure in the financial, asset management systems. This results in natural assets being subject to politicking, leading to fluctuations in funding, which is not the case for traditional infrastructure [29]. Since NbS are not registered and accounted for as an asset, these structures are not systematically included within maintenance plans [80] **(A.1.4)**. Further, a relatively small portion of the national budget is currently assigned by governments to ecosystem restoration, especially compared to the investments made in other areas, like energy and defense [81]. Governments restrict their budget allocation to investments related to legal obligations and political priorities, neither of which traditionally account for NbS [27] **(A.1.5)**. Also, innovations or novel approaches such as NbS are more risky, a characteristic that is accompanied by a lack of both public and private funding **(A.1.6)**. Further, lack of knowledge about NbS is also seen to play a role, as it was reported that increased awareness of the range of NbS intervention types could leverage more funding [27,82] **(A.1.7)**.

Generating revenue streams or capturing the values **(A.1.8)** from the multiple benefits delivered by NbS projects is reported as difficult. Five explanations for this are given; i) many of the benefits, or values, are difficult to convert into cashflows due to the public good nature of NbS, ii) the benefits are distributed across several beneficiaries, iii) the stochastic nature of several benefits, and iv) the uncertainty and fluctuations associated to ecosystem service-related revenue streams, v) the benefits may not always be reflected in markets (for example land or real estate) [35,36,76,79]. Poor economic returns or lack of financial benefits are often cited barriers [34,77]. On the other side, the reputational value gained through engagement in NbS has been identified as a driver

of investments [76] **(A.1.9)**.

Specific types of funding, or funding mechanisms come with advantages and disadvantages **(E.1.10).** It was reported by sectors that rely on donations that they lack, long-term steady funding as the payments made by their donors are unpredictable and incremental [29]. Funding based on subsidies was also identified as unsustainable to cover longer-term funding requirements [72]. Relying on volunteers introduces – sometimes too much - uncertainty to fully replace public sector commitment [29], a challenge discussed in the context of public-private partnerships. Furthermore, particularly grant schemes come with a lot of bureaucracy [77]. The type of funding mechanisms used can influence the type of project or restoration activities carried out [12] **(E.1.10).**

When it comes to private, commercial funding opportunities, market fluctuations play an important role (e.g. in timber production and value) and can significantly influence the decisions made based on competitiveness of land-use options [77]. For private sector participation in NbS, for example entrepreneurs with green business models or engineering firms being contracted for implementation, the availability of public funding through instruments such as grants and subsidies have been identified as an enabler. Yet, other enterprises see public funding as a source of revenue generation as being risky [76]. Lastly within the context of funding mechanisms, the novelty of markets for ecosystem services or NbS is challenging. Industry networks and social enterprise networks are identified as important enablers for the development of functioning NbS or ecosystem service-related markets and business (Mcquaid et al. [76]) **(A.1.11)**.

4.2.2. Financing (Sub-theme A.2)

There is **a lack of finance** (usually credit) available for the potentially high upfront costs and long-term maintenance costs **(A.2.1)** [74]**.** However, the demand for NBS-specific finance is quite low relative to the overall demand for sustainable investment – which also includes sustainable energy [27]. This suggests competition between sustainable investment opportunities **(A.2.2)**. Further, a distinction can be made between the demand for finance for NbS restoration activities and demand for finance for enterprises (or green businesses) operating in or looking to enter in the NbS environment. A lack of financing for NbS rather than a lack of financing for nature-based enterprises has been identified [76] **(A.2.3)**. Nature based enterprises do also report difficulties in gaining access to finance, but this is mostly the result of their small size or the lack of market awareness from financiers [76]. Furthermore, such entrepreneurs express a preference to rely on 'cheaper' sources of financing, such as impact investors or concessional financing rather than commercial finance. They are more hesitant to rely on commercial finance due to the dynamic performance of their sector [76].

The availability of (specific) finance for the implementation of NbS depends on the project's risk-return profile **(A.2.4)**. For NbS, typically, the risks are (relatively) high, and the returns are (relatively) low and as such, these projects are not attractive for financiers [72]. The type of returns (type of funding) are also reported to be unattractive because of a high dependency on sufficient social awareness [83] and an over reliance on public sector funding with the associated difficulties of maintaining sufficiently stable policies [27,34,76,84,85]. Further, the time scales associated to NbS (returns on investments only occur after 20 to 30 years) are not attractive to many investors, especially non-institutional ones [33,73,77,85] and it is difficult to clarify the value of the underlying (natural) assets [36]. Finally, the multiple benefits that are generated by NBS make it less attractive to finance, as all need to be considered to show the 'superiority' of the NBS as an intervention as opposed to other (grey) infrastructure investments**)** [76] whilst there is a lack of credible performance data and uncertainty or low predictability of profitability in comparison with 'grey alternatives [27,86].

Aside from the projections based on modelling, forecasting and financial calculations (which typically find their way into the risk-return profiles) there seems to be a certain level of scepticism about the costs, performance, and profitability of NbS [12,74], as well as high risk perceptions or low confidence levels amongst financiers [81] which in turn lead to a lower willing to engage or invest **(A.2.5)**. Further, a lack of awareness or (technical) understanding of the range of NbS options and the multiple benefits they deliver is reported as a barrier to investment or engagement [85] **(A.2.5)**.

On another note, the financial sector has its own set of practices, including selection processes and routines. These are typically not accommodating for innovations such as NbS [12]**.** One of these rules relates to the (minimum) investment sizes that financiers require, which most NbS projects or enterprises do not come close to [76] **(E.2.6).** Further, a resistance to alternative investment strategies by the traditional financial players has been reported [36]. Finally, restoration projects may not have the expertise required to put together a business plans for finance applications, and there is a need for preparation support in this query [35,87] **(A.2.7)**.

4.2.3. Costs (Sub-theme A.3)

Overall, there is a low willingness to implement NbS due to their costs **(A.3.1)** [37]. Specifically, implementation at catchment scale requires a substantial investment [72]. Some argue that implementation and maintenance costs of NbS are higher than compared to grey alternatives [88] especially when financial mechanisms, such as flood recovery schemes or insurances, do not support taking adaptive measures [37]. Ex-ante cost estimations play a role in determining the potential outcome of restoration efforts: a negative correlation was detected between restoration outcomes and expenditures [89], which was explained by the restoration of poorer quality lands being more costly, which in turn led to a situation where lower cost – and often lower benefit- projects being favored [77] **(A.3.2)**.

Several cost items **(A.3.3)** have been addressed in the literature that are said to be typical for NbS projects. Firstly, transaction costs need to be considered and are said to be high [27]. Different reasons are given for this, such as the due diligence process being costly as it is more difficult to measure impact [76], the project complexities and multiple stakeholders, both at the outset and for the duration of the payment period [77], and dealing with the complex regulatory environment [87]. Secondly, project preparation costs are high, especially in larger scale adaptation projects. This could lead to public criticism if large sums of public money are spent on a project that is not eventually implemented [79]. Such high preparation costs might lead to pre-financing needs, also impacting the risk-return balance of the project [27]. Thirdly, maintenance costs concern a long period of time, and thus require long-term commitment, which is often seen as not desirable [73]. There is uncertainty regarding the long term maintenance costs and a lack of understanding of the cost structure of NbS has been reported [73,76]. Fourth, monitoring costs in NbS can also be significant. For example, monitoring air pollution levels required costly equipment [74]. For funding mechanisms that rely on conditional payments, cost-effective monitoring methods are essential to verify cash flows and limit transaction costs [27].

Several factors influence restoration costs, complicating the cost estimation process **(A.3.4)**. Restoration costs vary for different ecosystems, where coral reefs and seagrass have been identified as the most expensive [86]. Costs also vary per country: restoration costs were significantly cheaper in countries with developing economies. Furthermore, restoration projects based on community or volunteer efforts usually have lower costs. Economies of scale had not occurred in the projects studied [86].

4.3. Key mechanisms through which financial barriers manifest

Based on the results from the inductive thematic analysis, we distinguish six mechanisms through which financial barriers to NbS

(including funding gaps, financing gaps, and cost structure) manifest.

For funding, these mechanisms include:

- **Mechanism 1: Funders' preferences.** *This mechanism entails the mismatch between multiple NbS characteristics and the preferences that funders have, resulting in funding gaps for NbS.*
- **Mechanism 2: Revenue generation enablers**. *This mechanism entails the conditions through which revenue generation is typically enabled and how these are misaligned with the characteristics of NbS benefits, resulting in funding gaps for NbS.*
- **Mechanism 3: Justification Requirements.** *This mechanism entails the range of justification requirements that funders have and the characteristics of NbS characteristics give rise to challenges in this matter, resulting in funding gaps for NbS.*
- **Mechanism 4: Funders' regimes.** *This mechanism entails the different regimes, or processes, apart from justification requirements, that funders have, which do not accommodate for NbS with their particular characteristics, resulting in funding gaps for NbS.*

For financing these mechanisms include:

- **Mechanism 5: Financiers' preferences.** *This mechanism entails the mismatch between multiple NbS characteristics and the preferences that financiers or investors have, resulting in financing gaps for NbS.*
- **Mechanism 6: Finance application process**. *This mechanism entails the mismatch between the financial application processes and multiple NbS characteristics, resulting in financing gaps for NbS.*

The cost structure of NbS (in particular the transaction costs) is influenced directly by the characteristics of the NbS as well as the six mechanisms leading to funding and financing gaps. These six mechanisms are elaborated the following sections.

4.3.1. Mechanism 1: Funders' preferences

Table 6 summarizes NbS characteristics and how these are misalligned with funders' preferences. Both public and private funders have a preferences for short(er) term results (fast solutions), and short term responsibilities [73,77,78]. For the case of public funding, such preferences are rooted in the political system. Electoral cycles and government planning cycles are short and showcasing results is important for increasing politicians' popularity [73,76]. As long as the awareness and sense of urgency to invest in NbS, and the importance of the long-term benefits they deliver remains limited (or absent) amongst the general public (voters), politicians are incentivized to prioritize other objectives [79]. Recognition of NbS and a sense of urgency for investing in them is required to be present amongst a broad spectrum of stakeholders. For example, even if politicians were to have a high perception of risk and as such be motivated to take action for enhanced coastal protection, such projects would receive less priority if the public perception of risk is low, since such investment decisions influence the politician's popularity [71]. Further, the dynamics in the political arena (changing administrations) can lead to the rapid replacement of officials in favor (or not) of NbS [73,76], whilst for long-term, structural funding and commitment, political stability is required. Also, NbS often deliver services with local public good characteristics. As such, they benefit some citizen groups more than others. Investing in local public goods may therefore not be favorable for politicians' popularity and reduces the incentive for (national and regional) politicians to support NbS [34,73].

Table 6
The mismatch between multiple NbS characteristics and the preferences that funders have resulting in funding gaps for NbS (Mechanism 1).

Funders' preferences	NbS Characteristics	Funding affected	
		Public	Private
Short-term results & responsibilities	Outcomes typically occur after long time period and long project duration (lifecycle)	●	●
Investments that benefit the majority	Benefits are typically (local) public goods	●	
Certainty in costs, funding and outcomes	Novel approaches (uncertainty, dynamic)	●	●
Low (initial) costs	High (initial) costs	●	
Well established and known solutions	Diversity of solutions, with limited track-record	●	●
Small scale	Large scale	●	
Proven, existing, simple financial arrangements,	Novel arrangements, multiple funders and funding types	●	●

Further, political attitudes tend to be risk averse, leading to a preference for quick results rather than for (more uncertain) long-term outcomes. Novel approaches, which NbS mostly are, come with more uncertainty and are thus perceived as riskier. Risk-aversion impedes commitments from public and private funders. Private actors are more incentivized to provide standard solutions at reliable profits than to go for innovative, uncertain, solutions [27,36] and, a strong evidence base is needed to enable payments, such as utility fees and developer obligations [27]. Additionally, lack of knowledge about NbS is also seen to play a role. Often only a single type of intervention, such as tree planting, is known. Increased awareness of the range of NbS intervention types could leverage more funding [27,82]. Also, since project preparation costs are high, large sums of public money are needed early on in the project implementation cycle. If these projects are not eventually implemented this could lead to public criticism [79]. Further, risk aversion in the public sector leads to reluctance to commit to innovative solutions and to commit to large-scale, longer-term investments. A larger scale is often needed from the outset to achieve impact, but the public sector tends to favor rolling out smaller (pilots) projects and gradually scale up [76].

Risk-averse political attitudes tend to favor existing financial arrangements and proven technologies over innovative financing models [27] whilst alternative financing models tend to be more accepted when attitudes/ideology are accommodating to privately financing NBS [27]. Also, different funding types have their particular characteristics and come with conditions. For example, payments from donors are typically unpredictable and incremental [29] and reliance on volunteer contributions may reduce the funding requirements but introduces capacity uncertainties [27]. As such, not all funding types are suitable to bridge all types of funding gaps. Further, the availability of public funding through instruments such as grants and subsidies is seen to work as both a barrier (risky source for revenues) and an enabler (secure source for revenues) for private actors to engage in NbS [76]. As such, not all funding types seem suitable to combine. Further, tapping into multiple funding sources requires different organizational forms. For example, private actor involvement can unlock the possibility to deploy different payment mechanisms such as levying user charges [27,36] and NGO's have the potential to tap into other sources of financial support [80]. Decision-makers may favor the least complex provisioning modes, rather than most suitable or impactful [77,87].

4.3.2. Mechanism 2: Revenue generation enablers

Table 7 summarizes NbS characteristics and how these are misalligned with the typical conditions for revenue generation. NbS hold the potential to be funded by different revenue streams derived from combinations of taxes – tariffs – transfers. In general, the more public the nature of the economic good is, the higher the share of NbS revenues that is expected to come via taxes and transfers; and the more private the nature of the economic good is the higher the share of NbS revenues that is expected to come via tariffs, sales, and user fees. Revenues that are generated by the NbS can be used to pay for (fund) the implementation and management of the NbS, often referred to as cost-recovery. As such the difficulty to generate revenues for and from NbS is one of the explanations for the occurrence of funding gaps. If the revenues generated exceed the costs of implementation, one can speak of profits or financial

Table 7
The conditions through which revenue generation is typically enabled and how these are misaligned with the characteristics of NbS benefits, leading to funding gaps for NbS (Mechanism 2).

Revenue generation enablers	NbS Characteristics	Funding affected	
		Public	Private
Excludability and /or Rivalrousness	Mostly (local) public good benefits	●	●
Internalized negative environmental impacts	Externalized positive environmental impacts	●	●
Few, concentrated beneficiaries	Multiple, dispersed beneficiaries	●	●
Unambiguous and certain benefits	Stochastic and uncertain benefits	●	●
Availability of stable markets (in which values are reflected)	Absence of (stable) markets for many benefits, and values not reflected in market prices	●	●

returns.

Revenue generation is commonly associated to commercial activities, and in that context it refers to the strategies and activities that businesses undertake to generate income and maximize their profits. Revenue generation also refers to the public sector, where governments collect revenues from tax and non-tax sources for two main purposes, namely, to fund the goods and services they provide to society and to fulfil their redistributive role [92]. The responsible authority, or initiator for an NbS can be public and/or private (either commercial or non-commercial). All income generated by the NbS to fund it and to make profits are considered as revenues.

The potential to generate revenue streams from the ecosystem services that are provided by NbS is limited. Many of the benefits generated by NbS, such as a beautiful scenery, air purification, or a nursery habitat for juvenile fish, cannot easily be converted into money, or payments. NbS characteristics, more specifically the characteristics of the benefits of NbS, are not aligned with the conditions through which revenue generation is typically enabled.

Firstly, many of the benefits have a public goods character [35,79] which means that these benefits are non-excludable (people cannot be prevented from consuming them) and non-rival (individuals can consume them without affecting their availability to other individuals). As such, if one actor decides to invest in improving or delivering a public good, others who pay nothing will also enjoy the benefit of that investment. This behavior is referred to as "free-riding" which inhibits funding for NbS [27,79]. Additionally, many of the goods and services NbS provides are local, meaning the NbS mainly benefits those people in proximity to where the NbS is located [36] limiting the potential pool of stakeholders willing to pay. Further, negative environmental effects from societal (economic) activities are often considered externalities. As such, there is no market (or demand) for several of the environmental services delivered by NbS which can offset those externalities giving rise to a market failure (a situation in which goods and services are not allocated (pareto) efficiently by the free market), resulting from individuals' pursuit of self-interest and leading to a suboptimal situation from a societal perspective [27,79,90]. Market failures (generally associated with monopolies, asymmetric information, externalities and public goods) often justify governments to intervene. Once public investments are made, they incentivize private actors to engage in rent-seeking behavior to influence such investment decisions [79]. Rent-seeking, another economic concept, occurs when an entity seeks to gain wealth without any reciprocal contribution of productivity (e.g. a company lobbying the government for tariff protection). Diverse lobby groups were cited as a barrier to restoring degraded lands, and increasing transparency regarding the public dialogue with lobbyist was a recommended action to overcome this [87].

Other explanations given for why revenue generation is challenging are that NbS deliver benefits to multiple beneficiaries (the dispersed benefits are said to make revenue generation more difficult [35]), some NbS benefits are stochastic in nature (for example, the full benefits of flood protection only occur during extreme high-water level events) [35] and come with uncertainty (mostly related to climate change and declining natural resources) [76]. Regarding the former, in fact, one could think that the characteristic of multiple benefits for multiple stakeholders could also lead to ample opportunities for revenue generation from diverse sources. However, there are a number of possible explanations for why it is difficult to tap into these multiple benefits. For one, multiple benefits and stakeholders, require joint action, cooperation, and consensus building amongst multiple stakeholders which requires continuous effort and is seen as a logistical challenge and the capacity – both in time and in knowledge - to do so is not always available [12,27]. Moreover, multiple benefits and beneficiaries often comes with dealing with trade-offs between ecosystem services provided and, as such, alignment is needed [84,91]. Those benefits that do have the potential to generate revenues are prioritized, and as such influence the decisions regarding what type of restoration activities are carried out [12,84]. Further, several funding models are criticized and opposed, especially those where public responsibilities are transferred to private parties (raising concerns for democratic legitimacy), where NbS services are commodified, and where private sector participation and revenue generation results in social inequity [27,29]. Finally, tapping in to multiple sources of funding, requires multiple types of (payment) infrastructure to be present, such as monitoring methods for conditional payments [27], (eco-)certification [76], or the placement of offices or counters in natural parks where visitors are charged an entrance fee. As such, the overall project costs – including transaction costs – may also be higher when multiple funders are involved.

Finally, revenue generation is typically enabled through (well) functioning markets. However there are many NbS benefits for which there is no existing market [77,92]. In those cases where there are existing markets, benefits may not be reflected in them. For example, the values of land or real estate do not always / entirely reflect the benefits of flood risk reduction especially when the awareness of risks posed by sea-level rise is low [93]. Moreover, when it comes to private (commercial) funding opportunities, market fluctuations play an important role (e.g. in timber production and value) and can significantly influence the decisions made based on competitiveness of land-use options [77]. Lastly, the novelty of markets for both ecosystem services and for NbS in general is challenging. Industry networks are identified as important enablers for the development of functioning NbS or ecosystem service-related markets and business, including aspects such the access to transportation infrastucture and labelling or certification systems [76,87].

4.3.3. *Mechanism 3: Funding justification*

Table 8 summarizes NbS characteristics and how these are misalligned with the requirements funders have to justify expenditures. When it comes to public funding, the justification of expenses is often anchored in procedures. The ability to prove the positive effects of NbS is

Table 8
Mismatches between the requirements funders have to justify expenditures and the characteristics of NbS (Mechanism 3).

Funding Justification	NbS Characteristics	Funding affected	
		Public	Private
(Comparable) costs and benefits	(Uncertain, dynamic, non-linear) Natural values at varying scales	●	●
Short-term mandates	Long project duration	●	
Legal obligations and responsibilities	Responsibilities over natural assets vague/undefined.	●	
Jurisdictional and administrative boundaries	Ecological spatial and time scales	●	
Singular objectives	Multiple benefits	●	

identified as a legal requirement and in some cases a cost-benefit ratio and quantitative impact estimation (i.e. number of properties that will have a lower floodrisk) is a policy requirement [35,73]. Yet, determining outcomes, costs, and effectiveness of NbS over its lifecycle is a difficult task [37,77,88,94]. Moreover, there are significant knowledge and evidence gaps that complicate this process [12,34,80,95]. NbS typically come with a wide range of social, cultural, economic and environmental effects which can vary over spatial scales, time scales, and (groups of) stakeholders. Accounting for NbS outcomes either quantitatively (sometimes including monetization) or qualitatively requires substantial capacity and is further hampered by the lack of comparable data on the lifecycle costs and benefits of NbS [72,96] and by the lack of a single accepted valuation method [94]. Further, NbS are part of a complex non-linear system and are dynamic. An example of such system complexities is the situation where the public perception of floodrisk changes as a result of the intervention, leading to overreliance on the protection measures with increased exposure and vulnerability as a result (instead of the desired reduction) [80]. There are many (uncertain and dynamic) variables to consider related to the performance of NbS and the resulting costs and benefits. Further, lifecycle costs are often unknown [75] and models are often informed by average cost calculations rather than actual costs incurred, rendering cost–benefit forecasts inaccurate [27]. Private actors mostly depend on profitability [77], and as such, face similar challenges as those described above.

Mandates for long-term commitments from public actors are restricted, and as such, so is funding and capacity [27,78]. Governments are seen to restrict their budget allocation to investments related to legal obligations and political priorities, especially under continuous austerity policies, neither of which traditionally account for NbS [27,79]. A lack of spending autonomy and lack of fiscal transfers to a local level has also been identified as a reason for municipal budget constraints [79]. Further, the lack of clarity in responsibilities is also seen in the specific context of climate finance, which has fallen short of what is needed and what was promised in the Paris Agreement [89]. The specific conditions under which funding and finance is provided and the tracking methodology for the financial flows are not clear. As such it is difficult to hold developed countries accountable to meet their funding obligations [89].

Different public organisations, and within them different departments, often have singular societal objectives and are said to operate in silos. Expenditures on multiple benefits are unauthorized or legally restricted as mandates are often limited to specific services or objectives. Contributions to domains outside of their primary objective need to be justified [94]. Further, if private lands are needed for restoration activities, compensating for loss of land or loss of income – often relying on public funding – is particularly difficult to justify and implement and requires extensive consultation, demonstration and policymaking [77]. Also, different departments have different responsibilities, leading to situations where capital expenditures and operating expenditures are typically separated into distinct budgets [29]. NbS implementation and management as well as the multiple benefits delivered by NbS often requires coordination over geographically and ecologically determined scales, exceeding jurisdictional and administrative boundaries [12,80]. As it is the wide range of benefits delivered by NbS that creates an interesting business case, organizations' orientations towards single objectives render NbS less attractive or they are not even considered [36,73]. Conflicting interests may arise between public actors operating at different levels (national vs local) within the institutional system because of the localized nature of the public goods provided [79] and public actors with different restoration goals, where biodiversity, climate change mitigation, and nutrient retention were cited as examples in which optimization towards singular objectives led to lower overall outcomes [34].

4.3.4. Mechanism 4: Funders' regimes

Table 9 summarizes NbS characteristics and how these are misalligned with funders' regimes (processes). Several of the regimes that have been identified in the literature have their impact on the availability of funding for NbS, either directly or indirectly via the associated complexities and the increased transaction costs. Furthermore, such processes lead to a preference, or bias, towards more standard, grey infrastructure solutions and correspondingly budget allocations towards them.

Table 9
Regimes (processes) that funders have, which do not accommodate for NbS with their particular characteristics, resulting in funding gaps for NbS.

Funders' regimes	NbS Characteristics	Funding affected	
		Public	Private
Traditional forms of administration	Trans/multi-disciplinary collaboration and partnerships needed for delivering, capturing and sharing multiple values	●	
Grey- infrastructure asset management systems	Natural asset	●	
Epistemically locked-in to engineering practices	Systemic, integrated approaches and guidelines	●	●
Predefine problems and targets	Dynamic, requiring reflexivity and adaptivity	●	
Procurement "delivery" oriented	Pre-delivery and post-delivery activities	●	●

The 'business as usual' way of working, or traditional forms of administration, within the public sector are not always accommodating for NbS, which require inter- and transdisciplinary collaboration [34,76,84,87]. Scaling up restoration efforts also requires a shift in partnerships, which should also include owners, engineers, social scientists, modelers, economists, infrastructure development experts, and project managers [91]. To enhance collaboration there are emerging roles for knowledge brokers or intermediaries in establishing appropriate legal frameworks or agency bodies that can ensure the sharing of benefits between sectors and agencies [76]. Further, leadership and monitoring of NbS projects may be hindered by internal governance structures or staff turnover and it is challenging to integrate knowledge systems (procedures) within and between different institutions [74,94]. Responsibilities to design, incentivize, implement and monitor NbS need to be redistributed [37], which has been done in the case of the Sponge City program. Here responsibilities were shared between central government and local government [72].

Matsler (2019), describes an "Epistemological mismatch between ecological and accounting systems" rendering ecological values unaccounted for (Matsler, 2019, pg. 167). It is conceptually difficult to include, as an asset, the value of nature on accounting ledgers. Due to financial accounting rules and standards, natural components, such as trees, are not considered as assets and nature as a service provider - similar to grey infrastructural assets - are not yet embraced. Such financial asset management standards prohibit the mainstreaming of natural infrastructure [94]. Since the economic value of natural assets remain unaccounted for these systems also lead to public divestment [27].Since natural assets are not typically considered infrastructure in asset management systems they are not systematically included in maintenance plans and corresponding funding allocations. This results in the situation where maintenance and management of natural assets is subject to fluctuations in funding and politicking, which is not the case for traditional infrastructure [29,80].

Difficulties arise when transitioning from the existing (knowledge) capacity to what is needed for NbS, a phenomenon referred to as epistemic lock-in [37]. Persistent historical practices undermine trust in new approaches and dominant engineering backgrounds lead to reluctance to change to other approaches [37,80]. For example, the term "floodplain" has become synonymous with flood safety regulations and objectives and not with the important contribution of intact floodplains in supporting thriving ecosystems [97]. Similarly, a preference for the

known, more convenient and standard hydrological and hydraulic modelling approaches for flood risk calculations was reported, which are more accommodating for grey measures and cause biases towards grey alternatives [80]. Moreover, legacies from the past and trust in 'engineering' practices have played a role in the development of codes, standards, and knowledge paradigms. This legacy leads to the situation in which engineering-heavy technologies are favoured 'soft' NBS benefits and performance [12]. Guidelines and standards for NbS are difficult to develop because the system is alive [74]. Guidance should cover the development, monitoring and maintenance of interventions [74]. A lack of such guidance leads to lack of institutional and financial mechanisms to be tapped into [37]. Further, there seem to be few decision support models that can be qualified as systemic, integrated approaches, that account for NbS complexities. Current evaluation approaches are strongly focused on small scale effects of interventions whilst there is a need for larger scale impact assessments for NbS [85,92,98]. NbS further challenges the tendency of both urban planning professionals and decision-makers to predefine problems and solutions. These interventions require a more reflexive and adaptive approach, allowing for open-ended and iterative process of learning-by-doing and doing-by-learning [84].

Lastly, challenges were identified within the domain of (public) procurement. the process by which public authorities purchase work, goods, or services from companies. NbS are typically characterized by pre-delivery activities such as stakeholder engagement and post-delivery activities such as monitoring and stewardship for which public procurement procedures are not designed [76]. Furthermore, procurement processes tend to prioritize financial criteria over other benefits, specifically environmental criteria. Procurement affects the market potential for NbS. However, public procurement is associated with high levels of bureaucracy and long decision-making timeframes making it difficult, or unattractive for small and medium enterprises to participate. A lack of competition for public tenders was identified and discussed [76].

4.3.5. *Mechanism 5: Financiers' preferences*

Table 10 summarizes NbS characteristics and how these are misalligned with financiers' preferences. Firstly, it has been well documented that NbS have an unattractive risk return profile and that NbS generate insufficient return on investment [12,33,85]. The high costs (or additional costs) of NbS are not being matched by high(er) revenues [27,72]. This had been, for example, the reason why the private sector would not invest in the Sponge City project in China [99]. One aspect of the risk-return profile is related to the revenue generation potential of NbS, discussed under Mechanism 2: Revenue generation enablers. The limited potential to generate revenue from NbS and their ecosystem services leads to restricted financial returns and as such, NbS funding models that rely predominantly on income from taxes and transfers [100]. In turn, this leaves commercial sources of repayable finance at bay since such financiers prefer investments where higher profit margins secure repayments for the costs of finance.

Others explain that the risk-return profile is un-attractive due to the relatively high initial construction costs, the need to maintain them, and the dependency on sufficient social awareness for generating returns [85]. Moreover the type of funding that generates the returns (fees and tax cuts) and the duration before the initial costs are covered (after 20–30 years) make NbS an unattractive offer for investors [85]. An overreliance on public sector funding, meaning that revenues are based mainly on income from (periodical) subsidies or grants, makes NbS less attractive for private financiers [76]. Further, financing (a pipeline of) NbS projects that rely on public sector funding requires a stable policy environment [27].

Private actors, or entrepreneurs are wary to approach commercial investors as they are expected to not understand the (dynamic) performance of their business. They would rather rely on 'cheaper' sources of financing -such as impact investors or concessional financing [76]. The longer time scales make it difficult to obtain a (quick) return on investment and discourage, in particular, non-institutional investors such as pension funds and insurance companies [73,77]. Further, performance data is less credible than for grey alternatives leading to relatively higher risk-profiles [76,86] and there seems to be a degree of skepticism about the costs, performance, and profitability of NbS [12,74]. Sceptical attitudes of investors may result from a lack of technical (construction) knowledge as well as lack of understanding of multiple benefits [85], resulting in higher perceived risks of the activities involved [81].

It is difficult to clarify the underlying value of the (natural) assets [36]. Urban regeneration projects are often perceived by private investors as high risk due to a lack of information about the underlying value of assets [36]. Finally, the multiple benefits that are generated by NBS make it difficult, or less attractive, to finance as it gives rise to complexities. All benefits need to be considered to show the superiority of the NBS as an intervention as opposed to other (grey) infrastructure investments [76]. Measurable benefits are important to trigger financiers' interests [99], yet this is a difficult and costly task.

4.3.6. *Mechanism 6: Finance application process*

Table 11 summarizes NbS characteristics and how these are misalligned with finance application processes. Applying for and gaining access to credit can be complex, and the required expertise is not always present amongst NbS initiators and implementors. Indeed, initiators of restoration projects often lack the expertise to put together business plans that are aligned with investor requirements [35] and to develop such plans for a pipeline of projects [27]. A need for preparation support in this query has been identified [35,77,87]. Even if such expertise is

Table 10
The mismatch between multiple NbS characteristics and the preferences that financiers or investors have, resulting in financing gaps for NbS (Mechanism 5).

Financiers' preferences	NbS Characteristics	Financing affected		
		Public	Concessional	Commercial
Low risk – high return, established track-record, short term-costs	High risk – low (monetary) return, limited track-record, long-term costs	●	●	●
Stable revenue generation	Mostly (local) public good benefits and therefor public funding, dynamic performance			●
Quick return	Long time-scales		●	●
Clear value of underlying asset	Natural asset with natural values		●	●
Simple calculations	Multiple benefits		●	●

Tabel 11
The mismatch between the financial application processes and multiple NbS characteristics resulting in financing gaps for NbS (Mechanism 5).

Finance application process	NbS Characteristics	Financing affected		
		Public	Concessional	Commercial
Requires financial expertise and capacity	Initiators are typically non-financial experts	●	●	●
Large investment size	Small investment size			●
Selection criteria not accommodating for innovations	Innovative, uncertain			●
Resistance to change the status quo	New, innovative			●

available, stable policy environments are paramount Further, the investment size that is offered by NbS projects is not adequate for all financiers [79].

Green entrepreneurs also reported difficulties in financing due to their small size, or due to the lack of market awareness amongst financiers [76]. Also, mainstream selection processes in the financial sector, such as risk assessment methodologies, can prevent the break-through of innovations such as NbS. Practices, rules, and routines in the financial sector are reported be more accommodating for gray, traditional infrastructure projects rather than for NbS [12]. Finally, resistance from traditional financial players, such as pension funds, to alternative investment strategies has been documented as well as the lack of entry of these players in the NbS market [36].

5. Discussion

5.1. Explaining NbS financial barriers through institutional mechanisms

This study set out to develop a deeper understanding of (i) what financial barriers for NbS entail and (ii) why they exist and persist. We summarize and visualize our findings in Fig. 5. Regarding the first part of the research question, our results expose three related but different dimensions of financial barriers in NbS projects, namely the occurrence of multiple types of funding gaps, the occurrence of multiple types of financing gaps, and the particular and complex cost structures of NbS. Funding gaps entail both public and private funding, (inconsistent) funding for different implementation phases, and funding for specific activities related to NbS, such as certification and stakeholder engagement. Moreover, some cost items or activities (such as the need to compensate landowners for the loss of land or income) are particularly challenging to fund since extensive consultation and policy making is required for this. Financing gaps are reported particularly in relation to commercial finance and concessional finance, whilst public finance gaps are only discussed within the context of climate finance. Financing gaps manifest particularly in relation to the preparation and long-term maintenance of NbS, and in relation to specific activities, such as capacity building. Although these different aspects of financing gaps are documented, the demand for NBS-specific finance is quite low relative to the overall demand for sustainable investment. This suggests competition between sustainable investment opportunities and a lack of NbS that are capable of revenue generation beyond cost-recovery. Although funding and costs concern two sides of the same coin, we find that the significant costs, the uncertain costs, the complex cost structures, and specific cost items of NbS constitute a barrier in its own right, regardless of cost-effectiveness, cost-benefit or risk-return performances of NbS, which in turn are often anchored in institutional procedures and preferences. As such, one could say that the (high) implementation costs for NbS are in itself a reason for decision-makers to not engage (financially) in NbS, especially under strict austerity conditions or absence of financial resources in the first place.

Within these three dimensions of financial barriers, funding was the predominant sub-theme, representing 61 % of the occurrences. This signals that the problem lies not so much in financing NbS as in securing funding over the lifetime of the project, which concerns the question who will ultimately pay for (the goods and services provided by) the NbS? These findings suggest that a more subtle problem framing is appropriate, rather than the generic framing of "a financing gap for NbS". This aligns with the recent call of an eminent professor of economic policy [102] to add more nuance to the ongoing discussions on Green Finance by explicitly including the issue of funding. Bridging the funding gap is a necessary (although not sufficient) condition for bridging the finance gap and financing alone cannot solve a funding problem.

Regarding the second part of the research question (why do these financial barriers to NbS exist and persist), we find six institutional mechanisms that surface the misalignment between the particular

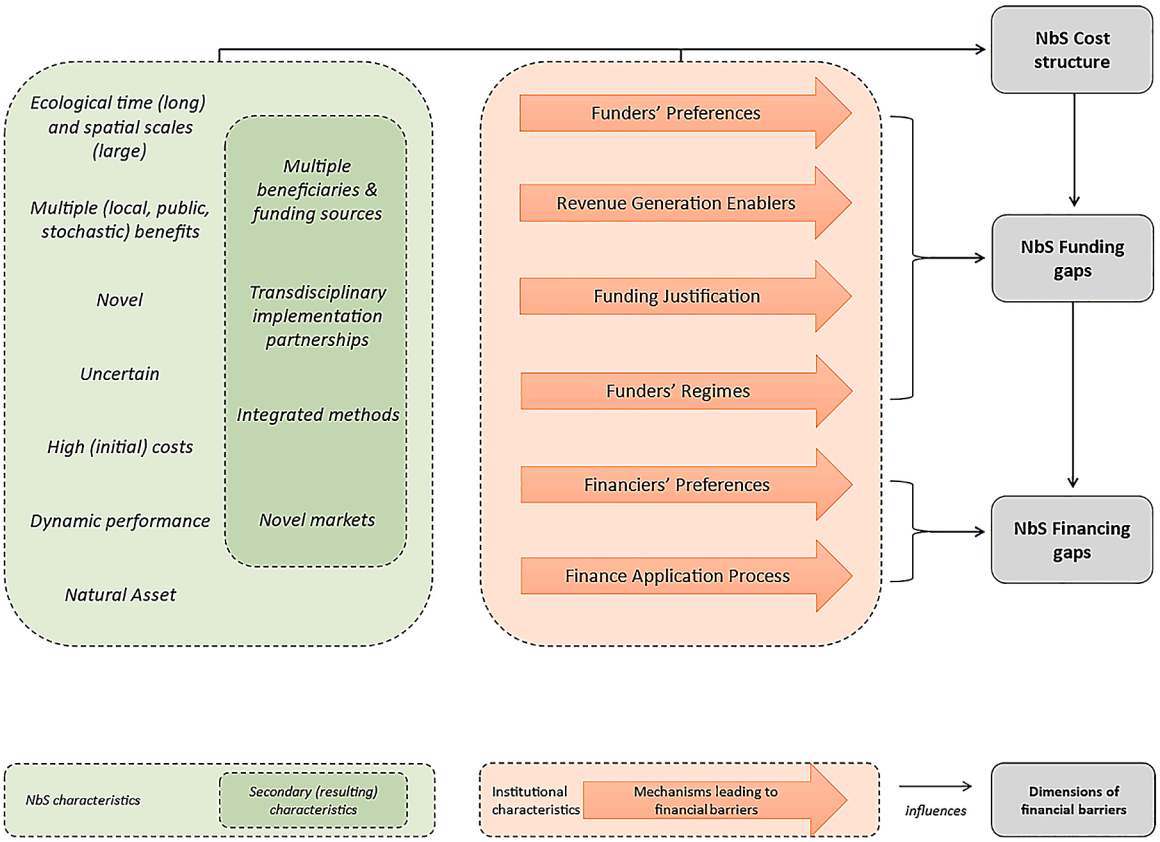


Fig. 5. The occurence of financial barriers for NbS, explained in terms of six institutional mechanisms that are misaligned with the characteristics of NbS.

characteristics of NbS and our existing public and private sector institutions. Such conditions are congruent with the findings from Slinger and Vreugdenhil [3] in their study on the shift from traditional hydraulic and coastal engineering towards more nature-based approaches. Ecosystems around the world have been deteriorating, leading to the ecological crisis we are currently facing and as such the urgent call to action for ecosystem restoration to redress this declining trend. The under investment in nature and the undervaluing of ecosystem services, is indeed said to be the direct result of the economic and institutional systems in place [18,103]. Our results confirm this and illustrate that many of the funding, financing and generic implementation barriers arise from institutional conditions such as standards, procedures, and organizational structures that are not accommodating to NbS. Further, novel financial models and provisioning arrangements, such as those discussed in Heijer and Coppens [27] are not necessarily suitable to overcome these systemic misalignments. As such, the authors infer that although financial barriers for NbS can be overcome for small-scale, pilot, NbS projects in the current playing field (the playing field that led to the underinvestment in nature in the first place), unlocking funding and finance to achieve the desired large scale interventions and restoration outcomes requires a more rigorous and systemic approach to addressing financial barriers by changing the institutional playing field (see [100]).

Opportunity costs - the potential benefits or value of the "next best" alternative, which is foregone when a choice is made - reflect a scarcity of resources and illustrate the trade-off between competing options. High opportunity costs are an often-cited barrier, meaning that the "next best" alternative has a higher (perceived) value than the NbS option on the table. High opportunity costs play a crucial role in both funding gaps and financing gaps for NbS and they are embedded in the mechanisms. These result primarily from competing demands for public budgets, less attractive risk-return profiles of other investment opportunities (aggravated by perverse or mis-aligned subsidies) and competition between land-use functions. As such, even if positive benefit-to-cost ratios can be delivered with confidence, financing and funding NbS are conditioned by the presence and magnitude of opportunity costs, suggesting that upscaling restoration efforts or mainstreaming NbS requires tackling the issue of opportunity costs.

The costs of NbS implementation, especially at catchment scale, are reported to be substantial and higher than compared to grey alternatives [88]. This can be explained by the multiple stakeholders that need to be engaged throughout the long lifecycle, the need to understand and design for system complexities and embrace adaptive management, and the costs associated with monitoring, capacity building and knowledge development [101]. As long as NbS are novel, and not accommodated within existing procedures, accounting systems, and other institutional conditions, the implementation costs will remain relatively high and persist as a barrier for large-scale implementation. Burszta-Adamiak & Fialkiewicz [85] refer to "secondary motivational tools" which support NbS implementation by alleviating the initiators from having to cover the costs of specific activities but are rather funded through another process. "*Such form of support not only allows the investor to save time, but, first of all, to minimise the risk of an erroneous project and to expedite formal procedures*" [87, p664]. The results of our study suggest there is an important role to be played for funding mechanisms that facilitate the transition needed for NbS to move from innovation to mainstream, similar to transition funds for the energy sector, often referred to as transition finance. However, even if transaction costs resulting from the novelty of NbS were to be removed from the equation, high implementation costs will remain a persistent barrier as long as they are not considered in the light of the multiple benefits generated over the lifetime of the NbS.

5.2. Avenues for further research

The results of this analysis suggest that overcoming funding and financing challenges requires a systemic approach as the barriers to project implementation are not all located within a project's sphere of influence or control. Instead, they may be located within the governing institutions and market conditions, which determine the playing field within which a project must operate. Our inventory of barriers, and specifically their structuring into the three dimensions of financial barriers and the six institutional mechanisms leading to funding and financing gaps can serve as a useful framework and diagnostic tool. These elements may serve as a starting point for the development of solution strategies to address one or several barriers or, alternatively, to collect further empirical evidence, by analyzing existing (large-scale) NbS projects in an effort to understand their cost structures, and not only what financing and funding has been secured, but also how and why financing and funding was secured. As such, it may guide future research on the processes deployed that unlocked the possibility for transactions and payments and whether these extend over the project lifecycle. Lastly, the results of this study can also be of use in analyzing the extent and effectiveness of new and emerging policies or guidelines, such as the implementation of the EU Taxonomy, to adress funding and financing gaps for NbS (see [71]).

Further research into whether some barriers are more or less associated with particular regions, specific types of ecosystems or specific NbS could shed light on the enabling conditions for NbS projects with specific characteristics in a particular institutional playing field. The articles included in this review were not selected for their ecosystem or regional representation and so are not suited to answering these questions. Research on the relation between specific financial barriers and their occurrence regionally and/or in particular ecosystems or NbS could prove fruitful.

Studies to formulate and test financial strategies aiming to address the systemic nature of financing and funding issues will be required to advance NbS implementation. Solving a single financial problem with a single financial solution has not proven to be an effective strategy to overcome (financial) implementation barriers [44,45]. This systems view can be a useful starting point for researchers and practitioners in co-designing multi-level governance and funding and financing strategies for envisaged NbS projects and then evaluating their efficacy in practice. We further emphasize the need to address the challenges in mainstreaming NbS through interdisciplinary approaches covering the themes identified in this research. In relation to mainstreaming NbS, theoretical fields such as transition finance, innovation finance, multi-level governance, environmental policy and institutional economics seem particularly relevant to further articulate the current institutional playing field and explore how alterations can unlock financial flows for NbS.

6. Conclusion

The question of what financial barriers for NbS entail and why they exist and persist is explored in this review study. We do so by first conceptually and theoretically clarifying the difference between funding and financing and then exploring this through an integrative literature review, making use of thematic and narrative analyses. In the inductive thematic analysis we explore 650 coded barriers identified in a sample of literature ($n = 34$) collected through a structured search.

We find that the financial barriers to NbS can be broken down into three dimensions, namely different funding gaps, different financing gaps (although a low demand for finance comes from NbS) and the particular and complex cost structures of NbS. The complex cost structures and specific cost items of NbS constitute a barrier in its own right, regardless of cost-effectiveness, cost-benefit or risk-return performances of NbS. We further find, by adopting a systems perspective, that these dimensions of financial challenges can be explained by the misalignment between the characteristics of NbS and our existing institutions – in the broadest sense of the word, including political, economic, and social as well as formal and informal institutions [102]. Four mechanisms for

funding, and two mechanisms for financing through which these misalignments occur were surfaced from the studied literature. These are: Funders' preferences (Mechanism 1), Revenue generation enablers (Mechanism 2), Justification requirements (Mechanism 3), Funders' regimes (Mechanism 4), Financiers' preferences (Mechanism 5), and Finance application process (Mechanism 6). All mechanisms influence the occurrence of public and private funding and financing gaps and the cost structure of NbS.

We infer from both the prevalence of barriers and the multiple mechanisms associated with funding that the problems lie more in securing funding over the lifetime of NbS project rather than in financing NbS. Moving towards large scale implementation of NbS therefore requires addressing the systemic nature of financial barriers currently faced, the funding gap in particular. We identify and discuss elements that seem critical in the transformative path towards upscaling NbS, including transitional support and addressing the pernicious problem of high opportunity costs.

CRediT authorship contribution statement

Lieke M. Hüsken: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Jill H. Slinger:** Writing – review & editing, Validation. **Heleen S.I. Vreugdenhil:** Writing – review & editing, Validation, Project administration. **Mónica A. Altamirano:** Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

L.M. Hüsken and H.S.I. Vreugdenhil report financial support was provided by European Research Executive Agency - Innovation Action number 101037097. M. A. Altamirano reports financial support was provided by Horizon Europe Research and Innovation Programme - NetworkNaturePLUS 101082213. L.M. Hüsken, J. H. Slinger, H.S.I. Vreugdenhil and M. A. Altamirano report financial support was provided by Multi-Actor Systems Research Programme of the Delft University of Technology. L.M. Hüsken and H.S.I. Vreugdenhil report financial support was provided by Stichting Deltares.

Acknowledgments

This work is undertaken within REST-COAST, the Large scale RESToration of COASTal ecosystems through rivers to sea connectivity project, financed by Innovation Action number 101037097 of the European Research Executive Agency - Biodiversity, Circular Economy and Environment call.

We thank the reviewers for their time spent on reviewing our manuscript, careful reading and insightful comments and suggestions that lead to improve the quality of this manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nbsj.2024.100200.

Data availability

The underlying database has now been published in the open access 4TU data repository of the Netherlands and can be found here: 10.4121/178f73b2–37bd-46f6-b6fe-58e3212ea2cb.

References

[1] G.M. Mace, Whose conservation? Science 345 (2014) 1558–1560, https://doi.org/10.1126/science.1254704 (80-.).
[2] IUCN: Ensuring effective nature-based solutions. (2020).
[3] J.H. Slinger, H.S.I. Vreugdenhil, Coastal engineers embrace nature: characterizing the metamorphosis in hydraulic engineering in terms of four continua, Water 12 (2020) 1–12, https://doi.org/10.3390/w12092504 (Switzerland).
[4] Seddon N., Smith A., Smith P., Key I., Chausson A., Girardin C., House J., Srivastava S., Turner B.: Getting the message right on nature- - based solutions to climate change. 1518–1546 (2021). 10.1111/gcb.15513.
[5] E. Cohen-Shacham, G.M. Walters, C. Janzen, S. Maginnis, Nature-Based Solutions to Address Global Societal Challenges, IUCN, 2016.
[6] Slinger J.: Building with nature & beyond. principles for designing nature based engineering solutions. (2021).
[7] Nature-based Solutions Initiative: good examples Nature-based solutions, 2024 https://www.naturebasedsolutionsinitiative.org/research/examples-of-nature-based-solutions/?sf_paged=2.
[8] IPCC: Climate change 2022: mitigation of climate change. contribution of working group III to the sixth assessment report for the intergovernmental panel on climate change., Cambridge, UK and New York, NY, USA (2022).
[9] United Nations environment programme: state of finance for nature 2021. (2021).
[10] J. Deely, S. Hynes, J. Barquín, D. Burgess, G. Finney, A. Silió, J.M. Álvarez-Martínez, D. Bailly, J. Ballé-Béganton, Barrier identification framework for the implementation of blue and green infrastructures, Land Use policy 99 (2020), https://doi.org/10.1016/j.landusepol.2020.105108.
[11] S. Janssen, H. Vreugdenhil, L. Hermans, J. Slinger, On the nature based flood defence dilemma and its Resolution : a game theory based analysis, Sci. Total Environ. 705 (2019) 135359, https://doi.org/10.1016/j.scitotenv.2019.135359.
[12] H. Dorst, A. van der Jagt, H. Toxopeus, L. Tozer, R. Raven, H. Runhaar, What's behind the barriers? Uncovering structural conditions working against urban nature-based solutions, Landsc. Urban Plan. 220 (2022) 104335, https://doi.org/10.1016/j.landurbplan.2021.104335.
[13] N. Kabisch, N. Frantzeskaki, S. Pauleit, S. Naumann, M. Davis, M. Artmann, D. Haase, S. Knapp, H. Korn, J. Stadler, K. Zaunberger, A. Bonn, Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action, Ecol. Soc. 21 (2016), https://doi.org/10.5751/ES-08373-210239.
[14] S.E. Sarabi, Q. Han, A.G.L. Romme, B. de Vries, L. Wendling, Key enablers of and barriers to the uptake and implementation of nature-based solutions in urban settings: a review, Resources 8 (2019).
[15] C. Davies, R. Lafortezza, Transitional path to the adoption of nature-based solutions, Land use policy 80 (2019) 406–409, https://doi.org/10.1016/j.landusepol.2018.09.020.
[16] G.C. Daily, Nature's Services: Societal Dependence On Natural Ecosystems, Island Press, Washington, DC, 1997.
[17] Assessment, M.E, Ecosystems and Human Well-being: Synthesis, Island Press, Washington, DC, 2005.
[18] TEEB, The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, Conclusions and Recommendations of TEEB, Progress Press, Malta, 2010.
[19] R.A. Feagin, T.S. Bridges, B. Bledsoe, E. Losos, S. Ferreira, E. Corwin, Q. Lodder, M.W. Beck, B. Reguero, A. Sutton-grier, J. Figlus, R. Palmer, D.R. Nelson, C. Smith, L. Olander, B. Silliman, H. Pietersen, R. Costanza, R.K. Gittman, S. Narayan, Commentary Infrastructure investment must incorporate Nature 's lessons in a rapidly changing world, One Earth 4 (2021) 1361–1364, https://doi.org/10.1016/j.oneear.2021.10.003.
[20] R. Costanza, H.E. Daly, Natural capital and sustainable development, Conserv. Biol. 6 (1992) 37–46.
[21] S.W.K. van den Burg, E.E.W. Termeer, M. Skirtun, M. Poelman, J.A. Veraart, T. Selnes, Exploring mechanisms to pay for ecosystem services provided by mussels, oysters and seaweeds, Ecosyst. Serv. 54 (2022) 101407, https://doi.org/10.1016/j.ecoser.2022.101407.
[22] Y. Peled, S. Zemah Shamir, A. Israel, M. Shechter, E. Ofir, G. Gal, Incorporating insurance value into ecosystem services assessments: mitigation of ecosystem users' welfare uncertainty through biological control, Ecosyst. Serv. 46 (2020) 101192, https://doi.org/10.1016/j.ecoser.2020.101192.
[23] C. Unterberger, R. Olschewski, Determining the insurance value of ecosystems: a discrete choice study on natural hazard protection by forests, Ecol. Econ. 180 (2021) 106866, https://doi.org/10.1016/j.ecolecon.2020.106866.
[24] B. Mayor, H. Toxopeus, S. McQuaid, E. Croci, B. Lucchitta, S.E. Reddy, A. Egusquiza, M.A. Altamirano, T. Trumbic, A. Tuerk, G. García, E. Feliu, C. Malandrino, J. Schante, A. Jensen, E. López Gunn, State of the art and latest advances in exploring business models for nature-based solutions, Sustainability 13 (2021) 1–21, https://doi.org/10.3390/su13137413.
[25] S. Kampelmann, Knock on wood: business models for urban wood could overcome financing and governance challenges faced by nature-based solutions, Urban For. Urban Green 62 (2021) 127108, https://doi.org/10.1016/j.ufug.2021.127108.
[26] Toxopeus H., Polzin F.: Characterizing nature-based solutions from a business model and financing perspective. (2017).
[27] C.D Heijer, T. Coppens, Paying for green : a scoping review of alternative financing models for nature-based solutions, J. Environ. Manag. 337 (2023) 117754, https://doi.org/10.1016/j.jenvman.2023.117754.

[28] F. Berzaghi, R. Chami, T. Cosimano, C. Fullenkamp, Financing conservation by valuing carbon services produced by wild animals, Proc. Natl. Acad. Sci. U. S. A. 119 (2022) 1–10, https://doi.org/10.1073/pnas.2120426119.

[29] Thompson A., Hipp J.A., Bunds K., Larson L., Cutts B.: Paying for nature-based solutions : a review of funding and financing mechanisms for ecosystem services and their impacts on social equity. (2023). 10.1002/sd.2510.

[30] C.M. Beer, Bankrolling biodiversity: the politics of philanthropic conservation finance in Chile, Environ. Plan. E Nat. Sp. (2022), https://doi.org/10.1177/25148486221108171.

[31] S. Grotenbreg, M. Altamirano, Government facilitation of external initiatives: how Dutch water authorities cope with value dilemmas, Int. J. Water Resour. Dev. 35 (2019) 465–490, https://doi.org/10.1080/07900627.2017.1374930.

[32] H. Snyder, Literature review as a research methodology: an overview and guidelines, J. Bus. Res. 104 (2019) 333–339, https://doi.org/10.1016/j.jbusres.2019.07.039.

[33] W. Knifka, R. Karutz, H. Zozmann, Barriers and solutions to green facade implementation—A review of literature and a Case Study of Leipzig, Germany, Buildings. 13 (2023) 1–26, https://doi.org/10.3390/buildings13071621.

[34] J. Cortina-Segarra, I. García-Sánchez, M. Grace, P. Andrés, S. Baker, C. Bullock, K. Decleer, L.V. Dicks, J.L. Fisher, J. Frouz, A. Klimkowska, A.P. Kyriazopoulos, D. Moreno-Mateos, P.M. Rodríguez-González, S. Sarkki, J.L. Ventocilla, Barriers to ecological restoration in Europe: expert perspectives, Restor. Ecol. 29 (2021) 1–18, https://doi.org/10.1111/rec.13346.

[35] A. Sanchez-Arcilla, I. Caceres, X. Le Roux, J. Hinkel, M. Schuerch, R.J. Nicholls, M. Otero, J. Staneva, M.De Vries, U. Pernice, C. Briere, N. Caiola, V. Gracia, C. Ibanez, S. Torresan, Barriers and enablers for upscaling coastal restoration, Nat. Based Solut. 2 (2022), https://doi.org/10.1016/j.nbsj.2022.100032.

[36] H. Toxopeus, F. Polzin, Reviewing financing barriers and strategies for urban nature-based solutions, J. Environ. Manag. 289 (2021) 112371, https://doi.org/10.1016/j.jenvman.2021.112371.

[37] P. Raska, N. Bezak, C.S.S. Ferreira, Z. Kalantari, K. Banasik, P. Davids, M. Madruga, D. Brito, M. Bertola, M. Bourke, A. Cerd, R. Evans, D.C. Finger, R. Halbac-cotoara-zamfir, M. Housh, A. Hysa, M. Pezzagno, K. Poto, E. Keles, S. Kohnov, S. Rufat, S. Seifollahi-aghmiuni, A. Schindelegger, M. Sraj, G. Stankunavicius, J. Stolte, T. Hartmann, L. Slavíkov, Identifying barriers for nature-based solutions in flood risk management : an interdisciplinary overview using expert community approach, J. Environ. Manag. 310 (2022), https://doi.org/10.1016/j.jenvman.2022.114725.

[38] Droste N., Schröter-Schlaack C., Hansjürgens B., Zimmermann H.: Nature-based solutions to climate change adaptation in urban areas. In: Nature-Based Solutions to Climate Change Adaptation in Urban Areas. pp. 51–64 (2017).

[39] N. Seddon, A. Chausson, P. Berry, C.A.J. Girardin, A. Smith, B. Turner, Understanding the value and limits of nature-based solutions to climate change and other global challenges, Philos. Trans. R. Soc. B Biol. Sci. 375 (2020), https://doi.org/10.1098/rstb.2019.0120.

[40] R.F. Young, Planting the living city: best practices in planning green infrastructure - Results from major U.S. cities, J. Am. Plan. Assoc. 77 (2011) 368–381, https://doi.org/10.1080/01944363.2011.616996.

[41] R.L. Ackoff, Redesigning the Future: A Systems Approach to Societal Problems, John Wiley & Sons Inc., New York, 1974.

[42] K. Eisenack, S.C. Moser, E. Hoffmann, R.J.T. Klein, C. Oberlack, A. Pechan, M. Rotter, C.J.A.M. Termeer, Explaining and overcoming barriers to climate change adaptation, Nat. Clim. Change 4 (2014) 867–872, https://doi.org/10.1038/nclimate2350.

[43] T.J. Schuitmaker, Identifying and unravelling persistent problems, Technol. Forecast. Soc. Change 79 (2012) 1021–1031, https://doi.org/10.1016/j.techfore.2011.11.008.

[44] F. Favero, J. Hinkel, Key innovations in financing nature-based solutions for Climate (2024).

[45] T. Op de Beeck, C. den Heijer, T. Coppens, Financing climate adaptation in Flemish cities: unpacking financial strategies and policy dynamics for nature-based solutions, Landsc. Urban Plan. 248 (2024) 105094, https://doi.org/10.1016/j.landurbplan.2024.105094.

[46] Altamirano M.A., de Rijke H., Basco Carrera L., Arellano Jaimerena B.: Handbook for the implementation of nature-based solutions for water security: guidelines for designing an implementation and financing arrangement. (2021).

[47] M. Fay, D. Martimort, S. Straub, Funding and financing infrastructure: the joint-use of public and private finance, J. Dev. Econ. 150 (2021) 102629, https://doi.org/10.1016/j.jdeveco.2021.102629.

[48] D. Pulido, G. Darido, R. Munoz-Raskin, J. Moody, The Urban Rail Development Handbook, World Bank Group, 2018.

[49] OECD: Managing water for all: an OECD perspective on pricing and financing. (2013).

[50] Antal I., Burrows B.: A short guide to developing green business models. (2018).

[51] EUREAU: '3Ts': tariffs, taxes and transfers in the European water sector A short guide. (2012).

[52] J. Rode, H. Wittmer, L. Emerton, C. Schröter-Schlaack, Ecosystem service opportunities': a practice-oriented framework for identifying economic instruments to enhance biodiversity and human livelihoods, J. Nat. Conserv. 33 (2016) 35–47, https://doi.org/10.1016/j.jnc.2016.07.001.

[53] J.F.M. Koppenjan, Private Partnerships for green infrastructures. Tensions and challenges, Curr. Opin. Environ. Sustain. 12 (2015) 30–34, https://doi.org/10.1016/j.cosust.2014.08.010.

[54] J.F.M. Koppenjan, B. Enserink, Public-private partnerships in urban infrastructures: reconciling private sector participation and sustainability, Public Adm. Rev. 69 (2009) 284–296, https://doi.org/10.1111/j.1540-6210.2008.01974.x.

[55] F. Tuli, The basis of distinction between qualitative and quantitative research in social science: *reflection on ontological, epistemological and methodological perspectives*, Ethiop. J. Educ. Sci. 6 (2011), https://doi.org/10.4314/ejesc.v6i1.65384.

[56] P.R. Ulin, E.T. Robinson, E.E. Tolley, Qualitative methods in public health: a field guide for applied research, Med. Sci. Sport. Exerc. 37 (2005) 1249, https://doi.org/10.1249/01.mss.0000172593.20181.14.

[57] D.J. MacInnis, A framework for conceptual contributions in marketing, J. Mark. (2011) 136–154, https://doi.org/10.2139/ssrn.1845968.

[58] J. Webster, R.T. Watson, Analyzing the past to prepare for the future: writing a literature review, MIS Q. 26 (2002) xiii–xxiii, https://doi.org/10.1110/4.6570.

[59] N. Stiglic, R.M. Viner, Effects of screentime on the health and well-being of children and adolescents: a systematic review of reviews, BMJ Open 9 (2019) 1–15, https://doi.org/10.1136/bmjopen-2018-023191.

[60] S. Van Dulmen, E. Sluijs, L. Van Dijk, D. De Ridder, R. Heerdink, J. Bensing, Patient adherence to medical treatment: a review of reviews, BMC Health Serv. Res. 7 (2007) 1–13, https://doi.org/10.1186/1472-6963-7-55.

[61] A. Spasiano, S. Grimaldi, A.M. Braccini, F. Nardi, Towards a transdisciplinary theoretical framework of citizen science: results from a meta-review analysis, Sustainability 13 (2021) 1–22, https://doi.org/10.3390/su13147904.

[62] J. Reis, P.A. Marques, P.C. Marques, Where Are smart cities heading? A meta-review and guidelines for future research, Appl. Sci. 12 (2022), https://doi.org/10.3390/app12168328.

[63] R.J. Torraco, Writing integrative literature reviews: guidelines and examples, Hum. Resour. Dev. Rev. 4 (2005) 356–367, https://doi.org/10.1177/1534484305278283.

[64] C.B. Soares, L.A.K. Hoga, M. Peduzzi, C. Sangaleti, T. Yonekura, D.R.A.D. Silva, Integrative review: concepts and methods used in nursing, Rev. da Esc. Enferm. 48 (2014) 335–345, https://doi.org/10.1590/S0080-623420140000020000020.

[65] W. Lubbe, W. Ham-Baloyi, K. Smit, The integrative literature review as a research method: a demonstration review of research on neurodevelopmental supportive care in preterm infants, J. Neonatal Nurs. 26 (2020) 308–315, https://doi.org/10.1016/j.jnn.2020.04.006.

[66] Nowell L.S., Norris J.M., White D.E., Moules N.J.: Thematic analysis : striving to meet the trustworthiness criteria. 16, 1–13 (2017). 10.1177/1609406917733847.

[67] I. Holloway, L. Todres, The status of method: flexibility, consistency and coherence, Qual. Res. 3 (2003) 345–357, https://doi.org/10.1177/1468794103033004.

[68] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2006) 77–101, https://doi.org/10.1191/1478088706qp063oa.

[69] A. Vermeule, Mechanisms of democracy. Institutional Design Writ Small, Oxford University Press, 2007.

[70] Joseph R.: Institutional mechanisms. In: The War Prerogative: History, Reform, and Constitutional Design. Oxford (2014).

[71] C.A. Papari, H. Toxopeus, F. Polzin, H. Bulkeley, E.V. Menguzzo, Can the EU taxonomy for sustainable activities help upscale investments into urban nature-based solutions? Environ. Sci. Policy 151 (2024) https://doi.org/10.1016/j.envsci.2023.103598.

[72] T.T. Nguyen, H.H. Ngo, W. Guo, X.C. Wang, N. Ren, G. Li, J. Ding, H. Liang, Implementation of a specific urban water management - Sponge City, Sci. Total Environ. 652 (2019) 147–162, https://doi.org/10.1016/j.scitotenv.2018.10.168.

[73] C. Duffaut, N. Frascaria-Lacoste, P.A. Versini, Barriers and levers for the implantation of sustainable nature-based solutions in cities: insights from France, Sustainability 14 (2022) 1–19, https://doi.org/10.3390/su14169975.

[74] Redondo C., Kanai J.M., Astbury J., Jorgensen A.: Green fences for buenos aires : implementing green infrastructure for (More than) air quality. 1–23 (2022).

[75] Shoo L.P., Catterall C.P.: Stimulating natural regeneration of tropical forest on degraded land : approaches, outcomes, and information gaps. 1–8 (2009). 10.1111/rec.12048.

[76] Mcquaid S., Kooijman E.D., Rhodes M., Cannon S.M.: Innovating with nature : factors influencing the success of nature-based enterprises. (2021).

[77] H.J.D. Thomas, J.S. Paterson, M.J. Metzger, L. Sing, Towards a research agenda for woodland expansion in Scotland, For. Ecol. Manag. 349 (2015) 149–161, https://doi.org/10.1016/j.foreco.2015.04.003.

[78] P. Kumar, S.E. Debele, J. Sahani, L. Aragão, F. Barisani, B. Basu, E. Bucchignani, N. Charizopoulos, S. Di Sabatino, A. Domeneghetti, A.S. Edo, L. Finér, G. Gallotti, S. Juch, L.S. Leo, M. Loupis, S.B. Mickovski, D. Panga, I. Pavlova, F. Pilla, A. L. Prats, F.G. Renaud, M. Rutzinger, A.S. Basu, M.A.R. Shah, K. Soini, M. Stefanopoulou, E. Toth, L. Ukonmaanaho, S. Vranic, T. Zieher, Towards an operationalisation of nature-based solutions for natural hazards, Sci. Total Environ. 731 (2020) 138855, https://doi.org/10.1016/j.scitotenv.2020.138855.

[79] A. Bisaro, J. Hinkel, Mobilizing private finance for coastal adaptation: a literature review, Wiley Interdiscip. Rev. Clim. Change 9 (2018) 1–15, https://doi.org/10.1002/wcc.514.

[80] J. Wells, J.C. Labadz, A. Smith, M.M. Islam, Barriers to the uptake and implementation of natural flood management: a social-ecological analysis, J. Flood Risk Manag. 13 (2020) 1–12, https://doi.org/10.1111/jfr3.12561.

[81] Meli P., Schweizer D., Winowiecki L.A., Chomba S., Aynekulu E., Guariguata M. R.: Mapping the information landscape of the United Nations decade on ecosystem restoration strategy. 31, 1–14 (2023). 10.1111/rec.13810.

[82] Bosshard E., Jansen M., Löfqvist S., Kettle C.J.: Rooting forest landscape restoration in consumer markets — a review of existing marketing-based funding initiatives. 3, 1–7 (2021). 10.3389/ffgc.2020.589982.

[83] S. Pan, M. Gao, H. Kim, K.J. Shah, S. Pei, P. Chiang, Advances and challenges in sustainable tourism toward a green economy, Sci. Total Environ. 635 (2018) 452–469, https://doi.org/10.1016/j.scitotenv.2018.04.134.
[84] M.J. Collier, N. Frantzeskaki, S. Connop, G. Dick, A. Dumitru, A. Dziuba, I. Fletcher, P. Georgiou, H. Katharina, E. Kooijman, M. Lodder, N. Madajczyk, S. Mcquaid, C. Nash, A. Osipiuk, M. Quartier, A. Reil, M. Rhodes, D. Rizzi, P. Vandergert, K.VDe Sijpe, P. Vos, D. Xidous, An integrated process for planning, delivery, and stewardship of urban nature-based solutions : the connecting nature framework, Nat. Based Solut. (2023) 3.
[85] E. Burszta-adamiak, W. Fialkiewicz, A review of green roof incentives as motivators for the expansion of green infrastructure in European cities, Eng. Environ. Sci. 28 (2019) 641–652, https://doi.org/10.22630/PNIKS.2019.28.4.58.
[86] E. Bayraktarov, M.I. Saunders, S. Abdullah, M. Mills, J. Beher, H.P. Possingham, P.J. Mumby, C.E. Lovelock, The cost and feasibility of marine coastal restoration, Ecol. Appl. 26 (2016) 1055–1074.
[87] A. Arneth, L. Olsson, A. Cowie, K. Erb, M. Hurlbert, W.A. Kurz, A. Mirzabaev, M. D.A. Rounsevell, Restoring degraded lands, Annu. Rev. Environ. Resour. (2021).
[88] A.I. Haruna, R.A. Oppong, A.B. Marful, A. Ida, R.A. Oppong, A. Boakye, Exploring eco-aesthetics for urban green infrastructure development and building resilient cities : a theoretical overview exploring eco-aesthetics for urban green infrastructure development and building resilient cities : a theoretical overview, Cogent Soc. Sci. 4 (2018) 1–18, https://doi.org/10.1080/23311886.2018.1478492.
[89] D.C. Macmillan, E.I. Duff, Estimating the non-market costs and benefits of native woodland restoration using the contingent valuation method, Forestry 71 (1998) 247–259, https://doi.org/10.1093/forestry/71.3.247.
[90] P.R. Krugman, Robin Wells, Economics. Worth Publishers, 2006.
[91] I.M. McLeod, M.Y. Hein, R. Babcock, L. Bay, D.G. Bourne, N. Cook, C. Doropoulos, M. Gibbs, P. Harrison, S. Lockie, M.J.H. van Oppen, N. Mattocks, C.A. Page, C. J. Randall, A. Smith, H.A. Smith, D.J. Suggett, B. Taylor, K.J. Vella, D. Wachenfeld, L. Boström-Einarsson, Coral restoration and adaptation in Australia: the first five years, PLoS One. 17 (2022) 1–22, https://doi.org/10.1371/journal.pone.0273325.
[92] P. Ovando, R. Brouwer, A review of economic approaches modeling the complex interactions between forest management and watershed services, For. Policy Econ. 100 (2019) 164–176, https://doi.org/10.1016/j.forpol.2018.12.007.
[93] A. Bisaro, J. Hinkel, G. Le Cozannet, T. van der Pol, A. Haas, Global Climate Services: a Typology of Global Decisions Influenced by Climate Risk, Front. Mar. Sci. 8 (2021) 1–15, https://doi.org/10.3389/fmars.2021.728687.
[94] A.M. Matsler, Making ‘ green ’ fit in a ‘ grey ’ accounting system : the institutional knowledge system challenges of valuing urban nature as infrastructural assets, Environ. Sci. Policy 99 (2019) 160–168, https://doi.org/10.1016/j.envsci.2019.05.023.
[95] T. Christmann, I.O. Menor, A synthesis and future research directions for tropical mountain ecosystem restoration, Sci. Rep. 11 (2021) 1–17, https://doi.org/10.1038/s41598-021-03205-y.
[96] S.E. Debele, P. Kumar, J. Sahani, B. Marti-Cardona, S.B. Mickovski, L.S. Leo, F. Porcù, F. Bertini, D. Montesi, Z. Vojinovic, S. Di Sabatino, Nature-based solutions for hydro-meteorological hazards: revised concepts, classification schemes and databases, Environ. Res. 179 (2019) 108799, https://doi.org/10.1016/j.envres.2019.108799.
[97] A. Pawley, D. Moldoff, J. Brown, S. Freed, Reducing flood risk and improving system resiliency in Sacramento, California: overcoming obstacles and emerging solutions, Front. Water 5 (2023), https://doi.org/10.3389/frwa.2023.1188321.
[98] S. Arya, A. Kumar, Evaluation of stormwater management approaches and challenges in urban flood control, Urban Clim. 51 (2023) 101643, https://doi.org/10.1016/j.uclim.2023.101643.
[99] L. Liu, M.B. Jensen, Green infrastructure for sustainable urban water management: practices of five forerunner cities, Cities 74 (2018) 126–133, https://doi.org/10.1016/j.cities.2017.11.013.
[100] A. Van Buuren, H. Vreugdenhil, J. Van Popering-Verkerk, G.J. Ellen, C. van Leeuwen, B. Breman, The pilot paradox: exploring tensions between internal and external success factors in Dutch climate adaptation projects, in: B. Turnheim, P. Kivimaa, F. Berkhout (Eds.), Innovating Climate Governance: Moving Beyond Experiments, Cambridge University Press, 2018, p. 145.
[101] S.O.S.E. Ermgassen, S. Löfqvist, Financing ecosystem restoration, Curr. Biol. 34 (2024) R412–R417, https://doi.org/10.1016/j.cub.2024.02.031.
[102] North D.C.: Institutions. AThe J. Econ. Perspect. 5, 97–112 (1991). 10.1017/S0570608400000867.
[103] P. Dasgupta, The Economics of Biodiversity: The Dasgupta Review, Headline Messages (2021).