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Review

The nature-based solution implementation gap: A review of nature-based solution governance barriers and enablers

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ABSTRACT

Nature-based solutions (NbS) represent a critical umbrella concept encompassing measures that employ nature's properties to systemically address societal challenges, potentially providing benefits for biodiversity, climate and people. NbS are accordingly emerging on an ever-expanding number of policy agendas, such as the Kunming-Montreal Global Biodiversity Framework and multiple European Union strategies. However, despite this increasing political traction, NbS implementation (that is, the design, planning, construction, monitoring and maintenance of NbS) remains fragmented and is often too context-specific for their wider upscaling and mainstreaming, creating an 'NbS implementation gap' between ambitions and on-the-ground operationalization. Based on a systematic review of grey- and peer-reviewed literature and workshop results (N = 34), we identify and discuss the institutional, legal, regulatory, social and economic enablers (N = 301) and barriers (N = 307) to NbS implementation. Our results highlight the governance factors that currently facilitate or limit NbS implementation and mainstreaming, which are often homologous. These include inclusive stakeholder engagement processes and true co-design; an evidence base on NbS performance and their co-benefits, including quantitative cost-benefit analyses; the existence of or lack of knowledge products and NbS-specific expertise; and available funds earmarked for NbS. We find that polycentric governance arrangements may act as a critical enabler for NbS implementation, yet path dependencies significantly limit NbS by still favouring grey alternatives. By providing an overview of NbS implementation enablers and barriers across literature and workshop findings, this analysis represents a first step towards understanding key pitfalls and leverage points for enhancing NbS implementation and mainstreaming.

1. Introduction

With biodiversity declining at unprecedented rates both globally (World Wildlife Fund et al., 2022) and in Europe (European Environment Agency, 2020), and the window of opportunity for remaining below a global temperature rise of 1.5 °C rapidly closing (Boehm et al., 2023), urgent action is needed. Nature-based solutions (NbS) have emerged as an umbrella concept which includes all measures to protect, conserve, restore, sustainably use and manage ecosystems to address societal challenges (United Nations Environment Assembly, 2022). NbS are increasingly promoted as promising solutions to simultaneously help manage climate change mitigation and adaptation (Kabisch et al., 2016; Frantzeskaki et al., 2019; Chausson et al., 2020), disaster risk (Ruangpan et al., 2020; Faivre et al., 2018; Debele et al., 2019), and biodiversity loss (Seddon et al., 2019; Gómez Martín et al., 2020; Maes and Jacobs, 2017).

NbS have thus gained recognition in global policy discourses; they have been included for the first time in the decision text of the 27th Conference of the Parties (COP27) of the United Nations Climate Change Conference (United Nations Framework Convention on Climate Change, 2022). NbS are additionally featured in the Global Biodiversity Framework in Targets 8 and 11 (Convention on Biological Diversity, 2022), the

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United Nations Environment Assembly resolution 5/5 (United Nations Environment Assembly, 2022) and an increasing number of nations include NbS in their Nationally Determined Contributions (Seddon et al., 2019).

NbS are embedded in a variety of cross-cutting policy frameworks in Europe, such as the EU Strategy on Adaptation to Climate Change, in which they are considered essential for increasing climate resilience and sustaining healthy water, oceans and soils (European Commission, 2021a). Likewise, the EU Biodiversity Strategy for 2030 (European Commission, 2020) and the EU Forest Strategy (European Commission, 2021b), which are both key pillars of the European Green Deal (EGD) (European Commission, 2019), rely on NbS to preserve and restore ecosystem integrity and resilience. But will these ambitious new strategies comprehensively address the current barriers and support the enablers to NbS implementation? Although the policies have advanced the conceptualization of NbS in Europe, a much wider adoption is needed to reach the ambitious goals of the EGD (Calliari et al., 2019). Indeed, we observe what may be coined an 'NbS implementation gap', where policy ambitions for NbS do not match actual on-the-ground implementation (European Environment Agency, 2021a; Davis et al., 2018; Calliari et al., 2022; Corgo et al., 2024). This is best evidences by the fact that nature-negative investments are still 140 times larger than nature-positive investments, which would need to be tripled by 2030 to reach global climate and biodiversity targets (United Nations Environment Programme, 2023).

Information on successful NbS implementation in different policy settings as well as on governance bottlenecks for their wider uptake is still scarce. In general, governance issues relating to NbS have been less systematically addressed than their technical performance and characteristics. In a recent analysis, the European Environment Agency (EEA) found that socio-economic contexts and cost considerations are still largely missing from NbS monitoring schemes (European Environment Agency, 2023). Likewise, in their global review of urban NbS research, Li et al. (2021) found that governance themes were insufficiently recognized in the literature. A gap analysis performed by the European NetworkNature project showed that governance issues represent one of four key gaps identified across 171 cases (El Harrak and Lemaitre, 2022). We address this gap by identifying barriers and enablers for NbS implementation as well as governance policy innovations. NbS governance goes beyond 'government' and the legal, institutional and policy arrangements it encompasses, to include a network of state and non-state actors (e.g., businesses, civil society, NGOs and expert communities) in the process of deciding on and implementing NbS (Lemos and Agrawal, 2006; Steurer, 2013; Vandergert et al., 2021).

For NbS to meet their promise of addressing global societal challenges, a fuller grasp of the barriers and policy bottlenecks currently hindering their uptake and mainstreaming of into governance regimes is needed. Studies addressing governance enablers of and/or barriers to NbS have mainly focused on specific geographic settings, such as cities and urban areas (Dumitru et al., 2020; Sarabi et al., 2019; Castelo et al., 2023); specific NbS actors, such as nature-based enterprises (McQuaid et al., 2021) or technical experts (Castellar et al., 2024); or a specific NbS purpose, such as climate change adaptation (Calliari et al., 2019; Corgo et al., 2024) or disaster risk reduction (Anderson and Renaud, 2021; European Environment Agency, 2021a). The present review aims to review and summarize current research findings on barriers and enablers of NbS implementation across different governance settings and for different purposes. We identify the political, legal, social, environmental, technical and economic opportunities and barriers to NbS, as well as potential governance innovations that can help promote and enhance their adoption.

2. Methods

Key governance barriers and enablers of NbS implementation were extracted through a systematic literature review (Page et al., 2021) and content analysis (Vaismoradi et al., 2016) from three sources, namely (i) findings from workshop and discussion sessions using workshop discussion transcripts (see Appendix A, table A1); (ii) grey literature (mainly including project reports) and (iii) peer-reviewed literature. We include the design, planning, construction, monitoring and maintenance of NbS as part of implementation. The data search was performed between May 2021 to April 2023 from 462 extracted records. Peer-reviewed literature was identified using a Scopus search (Elsevier) due to its broad scientific literature coverage. Grey literature was identified through Google Scholar and Overton. Only articles published after 2010 were included in the study due to the emergence of NbS as a term (Cohen-Shacham et al., 2016) and the wish to represent the most recent research advances in this study. Out of the 462 identified records (see Table 1 for the keyword list), 379 were excluded as they either did not relate to NbS; did not discuss NbS governance enablers or barriers; were published before 2010; were duplicate papers; or only covered a single barrier and/or enabler as this would have biased the analysis. The remaining 83 records were screened and of these 34 were selected to be analysed in depth using the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher et al., 2009; Page et al., 2021). Emphasis was given to scientific reviews to maximize data entries. Only studies written in English were included. Although no geographic constraints were applied in the literature search, the majority of included records originated from Europe, reflecting the current concentration of research on NbS in this region. The data selection process is detailed in Fig. 1.

Fig. 2 details the different steps of this analysis. First, after the selection of data sources (Fig. 2, step 1), a thematic content analysis of the selected data sources was undertaken using NVivo version 12.4.0. (Swain, 2018; Vaismoradi et al., 2016) (Fig. 2, step 2). Barriers and enablers were thus coded from the source texts. Barriers and enablers were extracted only when they were explicitly described as such in the primary sources (no interpretations or inferences were made). Bearing in mind the diversity of interpretations and definitions of governance (Ruhanen et al., 2010; Fukuyama, 2013; Rhodes, 2007), there is a wide range of governance barriers and enablers. Here, we define governance in its broadest sense encompassing all aspects related to collective and networked decision-making, including the social, ecological, political, and financial conditions through which NbS are implemented (Sekulova and Anguelovski, 2017).

Barriers and enablers were classified into clusters (see Appendix B, table B1 for a full description of the coding definitions and rules applied to these clusters) and subsequently classified into broader governance categories (Fig. 2, step 3). Enabler and barrier clusters were identified applying a grounded theory approach (Walker and Myrick, 2006), meaning that themes were derived from the data rather than from a pre-existing theory. The PESTEL (Political, Economic, Social, Technological/technical, Environmental/ecological, Legal) framework (Aguilar, 1967) was selected to provide an overview of broader governance categories of barriers and enablers. While this framework was originally developed to analyse external factors affecting businesses or organizations, it captures the broad governance definition applied in this review. Moreover, the PESTEL framework has recently been

Table 1
Scopus search terms for peer-reviewed literature search.

Theme	Scopus search terms
Nature-based solutions	("nature-based solution*") OR ("hybrid solution*") OR ("NbS") OR ("eco-DRR") OR ("green infrastructure*") OR ("ecosystem-based adaptation") OR ("natural infrastructure*") OR ("blue-green infrastructure*") OR ("blue green infrastructure*") OR ("natural engineering")
Barriers	(barrier*) OR (obstacle*) OR (challenge*) OR (bottleneck*) OR (limitation*)
Enablers	(enabler*) OR (driver*) OR (catalyser*) OR (opportunity*)
Publication period	PUBYEAR >2010

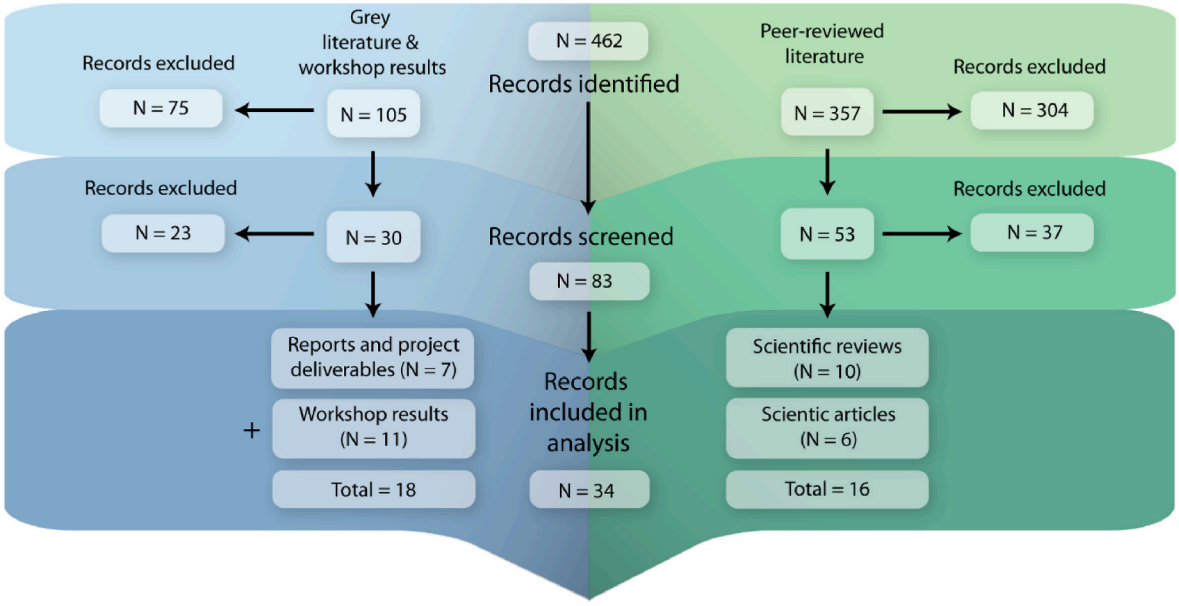

Fig. 1. Data source selection process for the review.

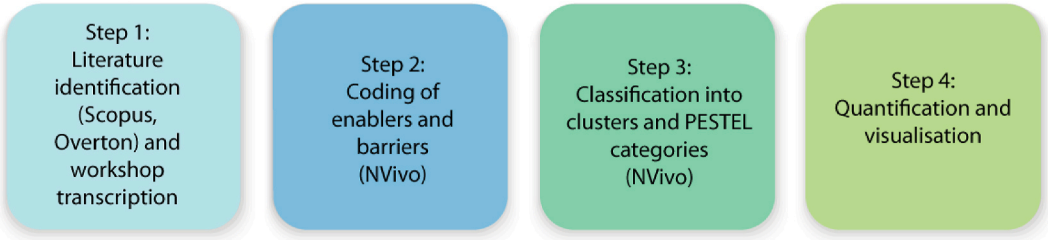

Fig. 2. Detailed steps of the applied content analysis.

employed in the context of NbS governance research (e.g., McQuaid et al., 2021; Fonseca et al., 2022).

Finally, data were quantified to identify trends (Fig. 2, step 4). A total of 301 NbS enablers, as well as 307 barriers, were extracted from the selected sources (N = 34). Several authors were involved in reviewing the coding structure and themes identified. Where possible, care was taken to include sources from a variety of scales (EU, national, local) and contexts (urban, rural, different NbS types). Most data sources did not make a distinction between the practical or theoretical bases of the barriers and/or enablers. To address this limitation, particular attention was paid to include both practical (experienced) and theoretical (hypothetical) barriers and enablers by complementing literature with workshop results. Our analysis is a direct quantification of cited barriers and enablers without hierarchization or prioritization. Results should therefore be considered a framework for discussion rather than an empirical comparison of barrier importance.

3. Results

3.1. Barriers to NbS implementation

In total, 307 barriers were extracted from the analysed sources. Barriers were classified into clusters (Fig. 3, left side) and subsequently categorized into broader PESTEL categories (Fig. 3, right side) to provide an overview of the types of barriers most common to NbS implementation. A lower level of classification was first necessary to fully grasp governance barrier trends. Thirteen barrier clusters emerged from the analysed sources.

As our results indicate, the barriers to NbS implementation are manifold. The barrier cluster mentioned most frequently in the literature is the **lack of expertise and knowledge** throughout the NbS implementation stages, including NbS construction (Bernardi et al., 2019), compounded by limited standards, technical guidelines and legal norms for NbS monitoring and maintenance (Sarabi et al., 2020). Han and Kuhlicke (2019) found that there is a lack of long-term data and knowledge on NbS. Solheim et al. (2021) also noted a clear lack of skilled knowledge brokers and training programs on specialized NbS skills.

The lack of evidence on NbS delivery, performance and co-benefits is almost equally prominent. This cluster comprises both the lack of robust and consistent approaches for measuring the (monetary) value and returns of NbS co-benefits (Scolobig et al., 2021) as well as their performance (Nelson et al., 2020; Solheim et al., 2021). This is particularly problematic because there is insufficient data for decision-makers to justify the use of NbS over traditional infrastructure (Welden et al., 2021). Indeed, multifunctionality is a critical and in many ways distinctive NbS selling point, and yet fully accounting for co-benefits in cost-benefit and other analyses remains a formidable challenge (Bernardi et al., 2019). Josephs and Humphries (2018) noted that moving beyond ecological definitions of NbS success is still far in the future, particularly for the integration of socio-economic, health, wellbeing and other non-monetary co-benefits into NbS assessments.

The third most frequently cited barrier cluster was related to **equity issues, stakeholder engagement and conflicts**. Wide and just stakeholder engagement has proven to be a key success factor for NbS implementation as it entails stakeholder buy-in and ownership, which

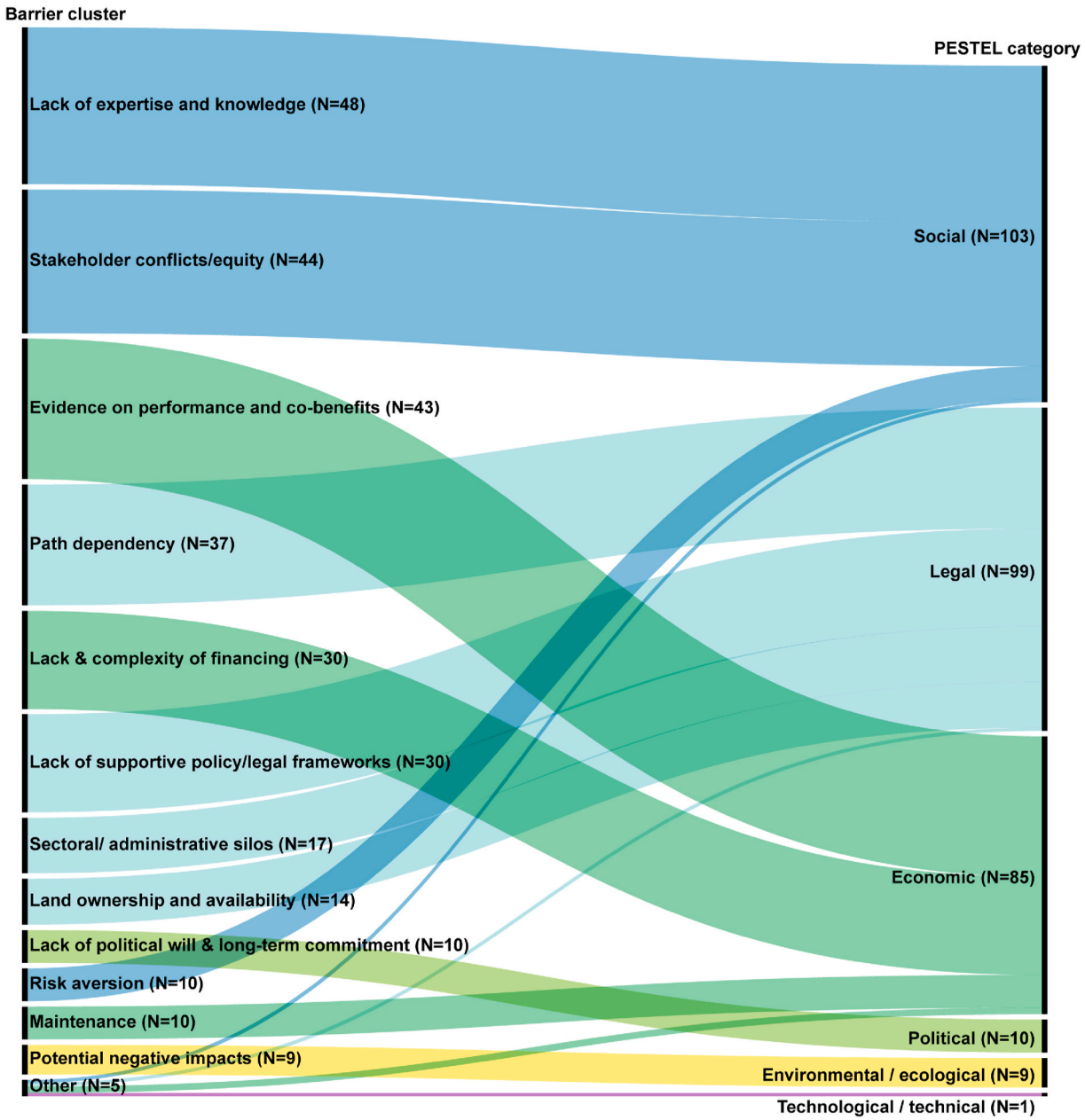

Fig. 3. Barrier clusters (left) and their PESTEL category (right) identified from literature and workshop results.

dissipates potential scepticism towards NbS (Martin et al., 2021; Raymond et al., 2017; McVittie et al., 2018). Yet, there are two sides to every coin. Indeed, the conflicting worldviews and interests of stakeholders can also lead to policy stalemates (Best and Hochstrasser, 2022; Linnerooth-Bayer et al., 2016). For example, Solheim et al. (2021) found that controversy arose in a cancelled NbS project in Gudbrandsdalen, Norway due to the economic value of gravel extracted from the Gudbrandsdalslågen river following floods. A NbS altering the river's flow and thus gravel deposition met with strong opposition from local landowners who commercially exploit the gravel. NbS can thus generate inequities in the distribution of their costs and benefits among the local population (Toxopeus et al., 2020). This is often the case for urban green spaces if NbS increase surrounding property s (Bockarjova et al., 2020) with important implications for gentrification and the displacement of low-income households (Anguelovski et al., 2019).

A further factor limiting NbS implementation appears to be (grey-measure) **path dependency** (Barnes et al., 2004), which denotes a system in which pathways are irreversibly 'locked-in' due to habituation (David, 1985). This cluster mainly refers to the difficulty in breaking away from current and deeply ingrained legal and social norms that still favour grey infrastructure. For example, Bernardi et al. (2019) found that landscape designers are more familiar with traditional infrastructure, both from a technical point of view and with respect to legal compliance. As remarked by Davies and Lafortezza (2019), many institutions have evolved in deeply set grey infrastructure cultures, which means that system reforms are rare and require substantial agents of change and transformations. NbS remain a neologism within many institutions. This cluster also includes resistance to change (Sarabi et al., 2020) and resulting behavioural lock-ins, a general clash between grey and green paradigms (International Institute for Applied Systems Analysis, 2019b).

Lack of funding **and high costs** of NbS were among the top five barriers mentioned in the analysed data sources. Most NbS are financed by often limited public funds (Sekulova and Anguelovski, 2017), which are constrained by restricted municipal budget autonomy (Toxopeus and Polzin, 2021) and difficulties in co-financing (Bernardi et al., 2019).

Even when public funds are available, NbS can be constrained by funder priorities focused on short-term returns (Favero and Hinkel, 2024). There is thus a need for reforming NbS funding models. Additionally, including local authorities, practitioners and researchers as equally funded (and independent) partners in these models is crucial (Basta et al., 2021). Most NbS are public goods in the sense that it is difficult or impossible to exclude users from their co-benefits. For this reason, private funding is severely limited since NbS cannot be priced and sold to create a revenue stream (Linnerooth-Bayer et al., 2023). As emphasized by the European Investment Bank (2023), regulations (e.g. requiring offsets) and subsidies, among other instruments, can nudge private investors toward NbS. The establishment of the EU taxonomy for sustainable activities, which is part of the EGD, seeks to enable the scaling up of both private and public sustainable investments (European Commission, 2023). The taxonomy provides a novel classification system for sustainability assessments of public and private investments, which may be a first step towards re-thinking the environmental costs and benefits of investments. The United Kingdom's recent policy on Biodiversity Net Gain (BNG), requiring developers to achieve a minimum of 10 % BNG increase for any new development, represents a further important milestone (Rampling et al., 2024). Additionally, high NbS construction and maintenance costs (or perceived high costs) compared to grey infrastructure represent a further challenge (Martin et al., 2021). This cluster also includes challenges with regards to how funding is allocated, e.g., sectoral administrations can lead to silo budgeting that disregard NbS co-benefits (Bernardi et al., 2019). Yet, many other aspects of costs exist, e.g., long-term and short-term, indirect and direct costs, all of which would need to be differentiated to better understand hurdles to financing NbS.

Beyond siloed budgets, **sectoral and administrative silos** present a difficult challenge that appears especially salient to NbS implementation (Sarabi et al., 2019; Scolobig et al., 2020; Suleiman, 2021). NbS require the collective expertise of actors, including ecologists, hydrologists, engineers and city or landscape planners. Suleiman (2021) highlight a disconnect between water and landscape planners for blue-green infrastructure implementation in Stockholm, who were not treated as professional equals when it came to NbS design and planning since water engineers had an operational role rather than a leading role. This barrier also extends to the monitoring, evaluation and interpretation of co-benefits pertaining to different disciplines. It is important to acknowledge that different sectoral backgrounds can mean different languages (not only from a terminology perspective, but also in terms of work culture and related worldviews) demanding a careful navigation of values and perspectives (Welden et al., 2021; Pascual et al., 2023).

Land ownership and availability issues were cited as obstacles in literature and workshops. Indeed, NbS usually require more land than grey infrastructures. This drives up implementation costs and creates conflicts between landowners and other stakeholders (Scolobig et al., 2020). For example, the implementation of natural flood management (as well as other NbS) often depends on privately owned or managed land (Thaler et al., 2023). Thaler et al. (2023) found that the success of flood-control NbS strongly depends on social interactions with private landowners who typically need to voluntarily agree to give up land, an enabling institutional setting, as well as trust in public administration. This is further complicated by the potential spatial mismatch between the location of the NbS and where the risk is reduced (or other upstream/downstream dynamics), as is the case for many flood measures (King and Bark, 2024). Additionally, particularly in the context of disaster risk reduction, liability for damage compensation, for instance for flooded private property, is a central issue for NbS implementation. This raises questions concerning the scalability of NbS (Scolobig et al., 2020).

Barrier clusters related to **the lack of political will and long-term commitment** as well as **lack of supportive policies** were infrequently mentioned in the included sources. This does not mean that they are not significant hurdles, yet it could point to the fact that they are related to other clusters, such as the earlier mentioned path dependency or lack of funding. Currently, many NbS policies at the EU scale are grounded in 'soft' measures, meaning that they do not require member states to implement them at local level and remain fully voluntary (Scolobig et al., 2020).

Related to this type of barrier is the **risk aversion** and scepticism that NbS often face. Indeed, many authors observe that stakeholders attribute a higher uncertainty to NbS than traditional infrastructure (Sarabi et al., 2020; Toxopeus and Polzin, 2021; Solheim et al., 2021). Kuban et al. (2018) also note that private companies have a greater incentive to provide standard solutions with reliable profits than to take on the uncertainty and risk involved in implementing or investing in innovative solutions such as NbS.

Maintenance also emerged as a cluster, although less frequently mentioned in literature and workshops, and mainly related to the potential and perceived higher costs of NbS maintenance compared to grey infrastructure (Martin et al., 2021). The lack of defined roles and responsibilities relating to NbS maintenance was also cited as a disadvantage in comparison to traditional grey infrastructure (Suleiman, 2021; Bernardi et al., 2019).

Finally, the **potential negative impacts** or 'disservices' of NbS represented the smallest barrier cluster. This includes the aforementioned risk of NbS causing gentrification and the displacement of low-income residents (Anguelovski et al., 2019; Kuban et al., 2018; Nesshöver et al., 2017) as well as NbS simply attracting more people, thus causing increased use pressure and conflicts on affected ecosystems (Martin et al., 2021).

'Other' barriers were too varied and/or context specific to form their own cluster. They include the use of certain materials in NbS construction (Bernardi et al., 2019), misalignments in the goals of citizen science and locals (Bernardi et al., 2019), the outsourcing of NbS operations hampering social learning (Suleiman, 2021), as well as biased data collection on NbS (Chatzimentor et al., 2020).

In terms of the broader PESTEL categories, results show that barriers related to social factors were the most prominent (N = 103), followed by legal (N = 99), economic (N = 85) and political factors (N = 10). The smallest numbers of barriers cited in the literature related to environmental and ecological (N = 9) as well as technical factors (N = 1). This does not mean that ecological and technical barriers are generally less prevalent, or even important than other factors impeding NbS implementation. Rather, this is in line with the chosen scope of the study focusing on governance barriers and enablers, which therefore included very few ecologic and technical barriers.

3.2. Enablers of NbS implementation

As with NbS barriers, enablers were first classified according to more specific clusters, and subsequently by PESTEL categories (Fig. 4). Identifying governance barriers to NbS implementation will help determine the difficulties inherent to NbS projects in order to overcome them, just as learning from practices that have led to successful implementation can further NbS advancement.

Among the 301 extracted NbS enablers, 13 clusters emerged. Many of the identified enabler clusters have direct counterparts as barrier clusters (and vice versa). For example, the stakeholder engagement and equity cluster is the most frequently cited enabler. The corresponding barrier, a lack of inclusive stakeholder engagement and resulting conflicts, was the third most frequent barrier. This alignment is not surprising as it demonstrates consistency across the literature and workshop results.

The **stakeholder engagement and equity** cluster includes factors relating to stakeholder involvement in the NbS decision-making process, such as social inclusion of stakeholder and citizen groups (Schmalzbauer, 2018; Nesshöver et al., 2017); a trustful relationship among stakeholders (Han and Kuhlicke, 2019); and trust in local government (Frantzeskaki et al., 2019). Other enablers included in this

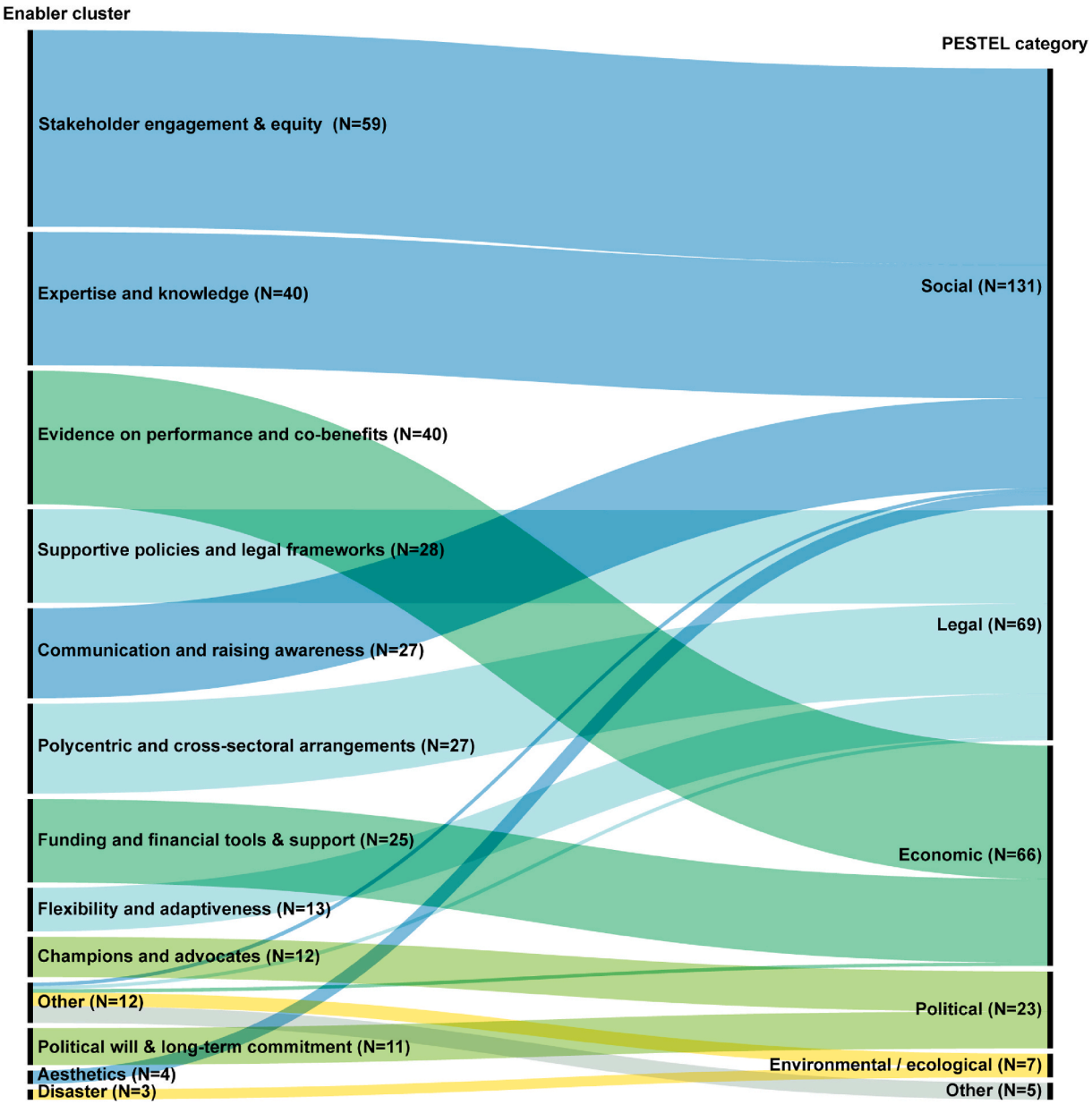

Fig. 4. Enabler clusters (left) and their PESTEL category (right) identified from literature and workshop results.

cluster relate to good practices regarding stakeholder identification, such as identifying the social networks that affect NbS governance (Albert et al., 2019). Co-creation and co-design, meaning the creative engagement of citizens and stakeholders to co-generate solutions to complex problems, were also mentioned in the analysed sources (Blomkamp, 2018). Trans-disciplinarity and equity are integral parts of this cluster, emerging principally as wide and just stakeholder involvement, voices being heard and responded to, and fair NbS benefit sharing (Nesshöver et al., 2017).

Evidence on performance and co-benefits also emerged as a prevalent NbS policy enabler. It should be noted, however, that this enabler was predominantly cited as a proposed or speculative (rather than as a proven or demonstrated) enabler. This underlines the need for further evidence on the multiple co-benefits of NbS. The need to enhance valuations of NbS versus grey alternatives was cited (Scolobig et al., 2020) as were clear quantitative and qualitative targets and indicators to track NbS performance (Scolobig et al., 2021; Huthoff et al., 2018). The enhancement and harmonisation of knowledge to support the formulation of a global NbS standard were also mentioned (Somarakis et al., 2019). Recognition of this enabler has since led to the publication of the 2020 International Union for Conservation of Nature global standard for NbS (International Union for Conservation of Nature, 2020), which intends to help practitioners design effective and standardised NbS. Due to its novelty, on-the-ground experience and evidence on the application of the standard across different regions of the world are still scarce (Châles et al., 2023).

Expertise and knowledge were the third largest cluster mentioned in the analysed sources as enabling NbS. This cluster encompasses the general need to overcome NbS knowledge gaps in terms of adapted indicators for NbS (Somarakis et al., 2019), socio-economic systems and governance structures in which NbS are embedded (Albert et al., 2019) and specialized contractor skillsets (Solheim et al., 2021). In particular, the importance of harmonized NbS guidance (Bernardi et al., 2019) and corresponding knowledge-sharing platforms were highlighted in literature (Fisher et al., 2019; Sarabi et al., 2019).

Polycentric and cross-sectoral governance arrangements emerged as a frequent NbS enabler. Polycentricity denotes a system in which decisions are taken at different jurisdictional levels and scales (e.

g., national, regional, global) and/or sectors through sometimes formally independent decision centres (Ostrom, 1999). While the concept is far from new, it has gained a renewed importance in the context of NbS that typically require the cooperation and collaboration of agents across scales and sectors (Martin et al., 2021). Polycentric arrangements are (re)surfacing to mainstream and upscale NbS implementation; yet, few examples of their practical application exist. One well-known example is the Isar Plan in Munich, which brought forth the creation of a multi-scale and multidisciplinary working group that spread the decision-making process across scales (city and state) and sectors (flood control, environmental organizations, city planning and more) (Martin et al., 2021; Zingraff-Hamed et al., 2019). Similarly, the adaptiveness of governance systems was highlighted in our results, even if it was cited less frequently than other enablers. Adaptiveness is seen as an essential part of polycentricity (Carlisle and Gruby, 2019) as accentuated by the need to retain a level of flexibility in NbS governance in light of climate change (Kabisch et al., 2016; Suleiman, 2021) and rapidly evolving societal challenges (Bernardi et al., 2019; Nesshöver et al., 2017).

Supportive policies and legal frameworks are a further enabler for NbS implementation. Legal frameworks are predominantly mentioned as salient for *potentially* enhancing NbS uptake, rather than as enablers proven to be effective. This can be attributed to the current lack of NbS-specific policies in Europe and national NbS-specific action plans (Calliari et al., 2022). Indeed, the reviewed literature and workshop findings hardly mention specific policies and frameworks. This cluster can therefore be seen as a gap more than a current enabler.

Two enabler clusters, funding **and financial tools and** support and **political will and long-term commitment**, represent the same perspective as their corresponding barriers and as such have been discussed above. One emergent cluster that does not have a corresponding barrier is **communication and awareness raising**. This cluster includes how NbS results are communicated, such as avoiding the use of jargon (Bernardi et al., 2019), adopting more clarity on NbS definitions (Scolobig et al., 2020) or similarly communicating NbS benefits in simple terms easily understood by decision-makers (International Institute for Applied Systems Analysis, 2019b). The need for further awareness raising on NbS was also highlighted, both in terms of dissipating the 'fear of the unknown' often faced by NbS projects (Schmalzbauer, 2018) and their multiple socio-economic co-benefits (Chatzimentor et al., 2020).

Findings suggest that champions and advocates can be crucial enablers for NbS. While this enabler goes hand in hand with political will and long-term commitment, 'champions' emerged as a cluster of its own, which was not the case in the barrier analysis. Here, the importance of forerunners and early adopters (Martin et al., 2021; Bernardi et al., 2019; Naumann et al., 2014) who spearhead the NbS concept was stressed as were agents of change who can transform institutions from within (Davies and Lafortezza, 2019).

Finally, the **aesthetics of NbS** was infrequently mentioned as a NbS enabler, followed by the occurrence of a **disaster** in triggering NbS actions. For example, in the case of Nocera Inferiore (Italy) which is prone to landslides, a potential grey solution was met with strong criticism, especially due to its less desirable aesthetic compared to a more natural solution (Martin et al., 2021; Linnerooth-Bayer et al., 2016). Similarly, in a disaster risk reduction context, disasters commonly trigger policy action by opening a window of opportunity. This was the case for the Natural Forest Conservation Program in China that aimed to intervene after a series of floods and landslides (Liu et al., 2008). Neither of these two enabler clusters has a corresponding barrier, thus they are distinctive enablers.

Other enablers included the historical existence of measures in line with NbS (International Institute for Applied Systems Analysis, 2019a), visiting and experiencing successful NbS projects (International Institute for Applied Systems Analysis, 2019b), the role of human agency and individual innovation in enabling NbS (Suleiman, 2021), and the acknowledgement of competing demands on resources provided by and used for NbS (Chatzimentor et al., 2020).

Results of the PESTEL classification demonstrate that social factors are the most common type of governance enabler (N = 131). Legal factors (N = 69) and economic factors (N = 66) ranked second and third respectively, followed by political factors (N = 23) and environmental factors (N = 7). The smallest number of enablers was found for other enablers (N = 5) that fit none of the PESTEL categories, with technical enablers being absent altogether. Thus, results showed that the broad types of governance enablers were similar to those of governance barriers.

4. Discussion and conclusions

4.1. Limitations

While this analysis fills an important research gap by providing an overview of NbS barriers and enablers across different governance and geographic contexts, it has also come up against several limitations.

First, as with any data classification exercise, the selection of data bins and themes remains subjective (Collier et al., 2012). Likewise, the analysis is limited by the way barriers and enablers are framed by authors or workshop participants. While a grounded theory approach was used to define themes, many barriers and enablers span multiple themes and categories, which makes definitive classification difficult. For example, there are strong overlaps between the lack of NbS-specific knowledge and evidence on NbS co-benefits. Both represent different types of knowledge; yet, the decision was made to separate them into two clusters due to the recurrence of challenges relating to quantitative NbS performance and co-benefit appraisals. Similarly, many barriers and enablers related to funding can be traced to institutional factors. This limitation was addressed by involving multiple authors in reviewing NVivo coding structures and identified themes. A further unintended bias was the inclusion of a disproportionate number of studies carried out in Europe, which reflects a bias in literature in this region. Further work could therefore be undertaken to address NbS governance enablers and barriers across different regions and countries, also including studies in languages other than English. Future analyses could assess enablers and barriers across different NbS', land use types or further categorisations.

Second, an inherent risk to systematic literature reviews (Moher et al., 2009) is bias in data sampling, for example through the exclusion of certain literature or keywords, or of data with a higher proportion of European contexts or urban NbS. Efforts were made to circumvent these biases; however, they also reflect the state of knowledge on NbS. Additionally, as NbS research is still expanding, with new studies entering the scene, the analysis cannot be fully comprehensive. However, by extracting over 500 barriers and enablers from literature and workshop sessions, we can assume that the most important factors are covered and that adding more data sources to the analysis would likely not lead to significantly different results. Related to this, the timescale chosen for the review (2010–2023) presents inherent biases that could not be analysed in detail, for instance, the research spans over the covid-19 crisis, which may have influenced NbS governance enablers and barriers (He et al., 2022; Schröter et al., 2022).

Third, our analysis presents a quantification of barriers and enablers from literature and workshops but does not include information on prioritization. While some enablers mentioned might be essential prerequisites, others might be important yet optional. Our analysis does not capture this differentiation. For instance, funding and high costs only ranked as the sixth most frequently mentioned enabler cluster, although funding is typically necessary, though not sufficient, for implementing most NbS projects.

Another important limitation is the fact that the analysed literature and workshop findings listed barriers and enablers that could be either hypothetical or experienced. For example, stakeholder conflicts might

have been cited as a barrier that was experienced in the implementation of a given NbS, or they could have been mentioned as an anticipated and therefore hypothetical hurdle. To address this limitation, data from discussion groups and interviews were included in the analysis to complement theoretical studies.

4.2. Discussion

The potential of NbS to help tackle global crises such as disaster risks, climate change and biodiversity loss is increasingly recognized. According to one estimate, NbS could provide 37 % of climate change mitigation needed to limit climate warming to below 2 °C until 2030 (Díaz et al., 2019). Due to the diverse co-benefits of NbS, the United Nations Environment Programme estimates that for every dollar invested in NbS, almost seven more can be generated within five years (United Nations Environment Programme, 2023). Yet urgent calls for NbS investments are accompanied by the sobering realisation that a significant implementation gap exists and that NbS are not yet upscaled to a level at which they can fulfil their ambitious promise. In response, the EU is introducing far-reaching reforms, particularly in unleashing significant funds, revising its taxonomy to include nature-positive investing (and nature-negative divesting), and enacting legally binding restoration targets. The same trend is observable on the global stage, where NbS are introduced in an increasing number of targets and resolutions. Additionally, an increasing number of frontrunner NbS projects, such as UNEP's Generation Restoration Cities, are advocating for public and private investment in NbS and becoming champions of restoration at scale (United Nations Environment Programme, n.d.).

As our results indicate, the novelty or immaturity of NbS, which are often not yet fully integrated in legal systems (Davies and Lafortezza, 2019), and the lack of legally binding mechanisms (Davis et al., 2018) represent formidable challenges. Yet, as part of the Biodiversity Strategy a new Nature Restoration Law entered into force in August 2024, the first of its kind insofar as it will include legally binding restoration targets across Europe (European Union, 2024) and could thus represent critical milestones for promoting the uptake and upscaling of NbS implementation.

Recognizing the pivotal role NbS could play in meeting global climate and biodiversity targets, this paper has set out the governance factors as reported in literature and workshop discussions that are facilitating or limiting NbS implementation. Our findings document the manifold barriers to NbS implementation. Our review highlights the lack of equity (both in stakeholder engagement and in NbS benefit distributions) as a key barrier to successful NbS implementation. In line with this finding, the analysis emphasizes the importance of inclusive engagement of stakeholders in co-design and co-creation during all stages of the NbS implementation process.

The further development of an evidence base on NbS performance and co-benefits emerged as a prominent NbS enabler, while a lack of this evidence was the second most frequent barrier. Indeed, further studies are needed on the long-term benefits of NbS in comparison to grey solutions. In particular, quantitative cost-benefit analyses capturing the multiple values of solutions, including those that are less tangible, are required.

A related theme across barriers and enablers is the need for knowledge products and NbS-specific expertise. Most municipalities still have little experience with NbS and little or no funding for expert staff. Possible solutions include the usage of NbS knowledge hubs (e.g., NetworkNature), accompanied by educational and training programmes specific to NbS design (mainly targeting landscape architects and designers) and NbS implementation (targeting contractors). The further development of nationally (and ideally, internationally) agreed technical standards, guidelines and legal norms for NbS design and construction can help surmount this barrier. Lack of capacity and knowledge is compounded by a lack of funds earmarked for NbS. Schröter et al. (2022) argue that NbS upscaling is mainly hindered by a lack of financial resources, which are currently limited to frontrunner cities already supportive of NbS that are therefore not representative of real-world policy settings. There is also a fundamental problem in attracting private financing given the public-good nature of NbS and thus a shortage of profitable projects and business models. The establishment of the EU taxonomy for sustainable finance, as well as other commitments to eliminate nature-harming activities, are crucial to overcoming this challenge.

Our findings suggest that a major factor limiting NbS implementation remains path dependency, i.e., the difficulty in breaking away from current legal and social norms that favour grey infrastructure and related risk aversion. Shifting the burden of proof to traditional grey infrastructure projects, for example by making the consideration of nature-based alternatives obligatory for any infrastructure project, would help reshape NbS governance. Moreover, the focus on short-term goals that bring voter support does not match the long-term stewardship needs, impact and gestation periods of NbS. Polycentric governance arrangements, which foster cross-sectoral and cross-scale cooperation, present an important enabler to overcome the barrier of siloed administrations. Since NbS implementation requires the involvement of a complex mosaic of disciplines, sectors and government levels, polycentric governance is an approach that could integrate this complexity.

Our results are in line with recent research. For example, an EEA briefing assessing the potential of NbS found that scaling projects beyond local contexts is still limited (EEA, 2023). The main barriers to NbS scaling were found to be the lack of standardized cost-benefit quantification methods and systematic monitoring and evaluation schemes (*ibidem*). A review by the NetworkNature project suggests that a key gap in NbS research is understanding, monitoring and evaluating NbS costs and benefits (El Harrak and Lemaitre, 2022). Similarly, after reviewing key policy instruments across institutional levels, Corgo et al. (2024) conclude that the monitoring and evaluation of NbS effectiveness remain a critical gap at the policy practice level.

Numerous studies also highlight the importance of NbS co-development and co-implementation with stakeholders. Indeed, more inclusive and coordinated governance was put forward as a key requirement to achieving EU policy targets through NbS (EEA, 2023). Relatedly, a panel of European experts saw educational programs to increase skills and awareness of NbS as one of the most promising strategies to bridge NbS implementation barriers (Castellar et al., 2024).

Considering the limits to NbS is crucial as well. They are not silver bullets (and were originally not proposed as such) that can fully address pressing biodiversity, climate and other societal issues, and portraying them as such can hinder their credibility and increase scepticism. NbS limitations include their trade-offs, the fact that they will not replace the phasing out of fossil fuels (Seddon et al., 2021) and their risk of greenwashing (Gałecka-Drozda et al., 2021).

4.3. Conclusions

By providing an in-depth overview of NbS implementation barriers and enablers across extensive literature, this analysis represents a first step towards understanding key pitfalls and leverage points for enhancing NbS implementation and advancing mainstreaming. To overcome the NbS implementation gap, actionable solutions that are co-designed with decision-makers, practitioners and other stakeholders are required. For this, in-depth analyses of the socio-economic conditions, institutional settings, and feasibility of the solutions (and challenges) put forward in this study are needed, ideally through stakeholder interviews and other transdisciplinary approaches. Additionally, the linkages, synergies and tradeoffs between different governance barriers and enablers should be further investigated to be able to fully map potential path dependency and other system lock-ins. This would help identify who among NbS stakeholders would be best suited to tackle NbS barriers and leverage their enablers, and at what scale. Above all, efforts should be focused on those barriers that are unique to NbS in

comparison to traditional infrastructure, as they represent the distinctive hurdles that need to be surmounted to break the grey-path dependency.

NbS have emerged as an important pathway to achieving the ambitious goals of European and global policy agendas to confront the existential risks represented by climate change and biodiversity loss. We thus need to ask if these strategies and frameworks will comprehensively address the current barriers and support the enablers to NbS implementation. This analysis illustrates that NbS are plagued by an implementation gap characterized by complex problems requiring transformations in the way we govern NbS. Our success in overcoming this gap will depend on a multi-faceted understanding of NbS governance.

CRediT authorship contribution statement

Juliette G.C. Martin: Writing – original draft, Visualization, Validation, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Anna Scolobig:** Writing – review & editing, Validation, Funding acquisition, Conceptualization. **JoAnne Linnerooth-Bayer:** Writing – review & editing, Validation, Supervision, Funding acquisition, Conceptualization. **Jenan Irshaid:** Writing – review & editing, Writing – original draft. **Julia J. Aguilera Rodriguez:** Writing – review & editing, Writing – original draft. **Alberto Fresolone-Caparrós:** Writing – original draft, Methodology, Data curation, Conceptualization. **Amy Oen:** Writing – review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Juliette G.C. Martin reports financial support was provided by European Commission. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Details on workshop results included in the analysis

Event	Date	Number of attendees	Location	Topics discussed	Documentation	Language	Case sites represented
PHUSICOS Project's Policy Business Forum 2: The role of public and private sectors in mainstreaming nature-based Solutions	April 19, 2021	20	Online	The ambition of this workshop was to better understand the current state of NbS financing and identify the reforms necessary in the public and private sectors to accelerate NbS upscaling and green transformation.	https://www.phusicos.eu/globalassets/bilder/eksterne-prosjektsider/phusicos/publications/pbf2_synthesis.pdf	English	PHUSICOS cases (Serchio river basin (Italy), Pyrenees (France/Spain), Gudbrandsdalen (Norway), Munich (Germany), Kaunertal (Austria)), Nicosia (Cyprus), Paris (France)
PHUSICOS Project's Policy Business Forum 1: Governance Innovation for Nature-based solutions	March 24, 2020	17	Online	During this workshop, participants discussed policy reforms that are necessary to drive NbS transformative action.	https://www.phusicos.eu/globalassets/bilder/eksterne-prosjektsider/phusicos/publications/pbf1_synthesis.pdf	English	Geneva (Switzerland), Lyon (France), Slovakia, PHUSICOS cases
PHUSICOS Project's 4th Consortium Meeting (five sessions)	October 17, 2019	27 (Five different world café sessions attended by 5, 7, 6, 4 and 5 site leaders respectively)	Lucca, Italy	Discussion sessions were held with the case study sites. The topics discussed included NbS governance, core themes relevant for policy business fora, and updates on NbS implementation at the five project sites.	https://www.phusicos.eu/globalassets/bilder/eksterne-prosjektsider/phusicos/publications/deliverable-d1-5.pdf	English, French	PHUSICOS cases
PHUSICOS Project's 3rd Consortium Meeting (four sessions)	May 9, 2019	25 (Four different world café sessions attended by 6, 5, 7 and 7 site leaders respectively)	Vienna, Austria	Discussion sessions were led with NbS case study sites. Questions that were addressed included: what are the enabling factors and barriers that sites face, are there synergies with other sectors? What advocacy groups are present, and what financing mechanisms exist?	https://www.phusicos.eu/globalassets/bilder/eksterne-prosjektsider/phusicos/publications/deliverable-d1-5.pdf	English, French	PHUSICOS cases

Appendix B

Table B1
Definitions and examples of barrier and enabler cluster codes for thematic analysis

Barrier cluster code	Definition	Example
Lack of expertise and knowledge	There is a lack of expertise, know-how, education or general knowledge on how to implement NbS.	There are no training programs for teaching specialized NbS skills (Solheim et al., 2021).
Evidence on performance and co-benefits	There is a lack of evidence on the benefits, co-benefits and general success of NbS.	There is a lack of clear knowledge on the monetary value and returns of NbS co-benefits (Scolobig et al., 2020).
Stakeholder conflicts/ equity	There are conflicts between stakeholders, their values, interests and worldviews regarding NbS, or issues arising from a lack of equity in stakeholder engagement processes or outcomes concerning NbS.	There is a lack of involvement of the end-users and/or communities in the blue-green infrastructure planning and system design processes (Suleiman, 2021).
Path dependency	The governance system exhibits pathways that are irreversibly 'locked-in' due to habituation, making it hard to break away from norms that still favour grey infrastructure over NbS.	Decision models for NbS investment may change slower than expected due to persisting conventions (Toxopeus and Polzin, 2021).
Lack & complexity of financing	There are insufficient financing sources for NbS, or existing financing schemes are too complex to navigate.	There is a lack of public financing for urban NbS due to limited municipal spending autonomy (Toxopeus and Polzin, 2021).
Lack of supportive policy/ legal frameworks	There is a lack of policies, regulations or legal frameworks that incentivize, facilitate or support the implementation of NbS.	There is a lack of planning legislation frameworks on how to implement blue-green infrastructure (Suleiman, 2021).
Sectoral/administrative silos	There is a lack of coordination between the different sectors or administrative bodies that could be implementing NbS.	NbS, green and grey measures involve different sectors and actors working in silos (Scolobig et al., 2021).
Land ownership and availability	There is a lack of available land on which NbS can be implemented, or there are conflicts in implementing NbS on private land.	NbS suffer from a lack of adequate suitable locations (Sarabi et al., 2020).
Lack of political will & long-term commitment	There is a lack of political will for implementing NbS, including due to a lack of long-term vision for and commitment to NbS.	There is a discontinuity between short-term policy actions and long-term plans (Kabisch et al., 2016)
Risk aversion	NbS are perceived as higher risk solutions than grey infrastructure.	The lack of confidence regarding the ability of natural infrastructure to reduce risk hampers NbS implementation (Nelson et al., 2020).
Maintenance	NbS are difficult or expensive to maintain.	NbS maintenance costs are sometimes not accounted for (Martin et al., 2021).
Potential negative impacts	NbS can result in so-called ecosystem disservices and have other negative impacts.	NbS can lead to the eco-gentrification of areas (Nesshöver et al., 2017).
Enabler cluster code	**Definition**	**Example**
Stakeholder engagement & equity	There is a genuine co-design process in engaging stakeholders in decisions regarding NbS, and/or stakeholders are involved in a just and inclusive manner.	The knowledge cocreation and re-integration of the created knowledge together with stakeholders and local experts is key (Albert et al., 2019).
Evidence on performance and co-benefits	There is evidence on the benefits, co-benefits and general success of NbS.	We need to produce stronger evidence on nature-based solutions for climate change adaptation and mitigation (Kabisch et al., 2016).
Expertise and knowledge	There is existing expertise, know-how, education or general knowledge on how to implement NbS.	Further knowledge and technical support for the construction of NbS is needed (Bernardi et al., 2019).
Polycentric and cross-sectoral arrangements	Decisions regarding NbS are taken across different jurisdictional levels and scales (e.g., national, regional, global) and/or sectors, fostering cross-sectoral and cross-scale cooperation.	Linking affected sectors and demonstrating synergies is key for NbS conception (Naumann et al., 2014).
Supportive policies and legal frameworks	There are existing policies, regulations or legal frameworks that incentivize, facilitate or support the implementation of NbS.	Having plans, acts and legislations supporting NbS development is a key enabler (Sarabi et al., 2019).
Funding and financial tools & support	There are existing financing tools, schemes and funding sources for NbS.	NbS need long-term investment and financing mechanisms to reap benefits of NbS (Nesshöver et al., 2017).
Communication and raising awareness	Communication strategies and mechanisms to raise awareness on NbS are in place.	Communicating knowledge about best practices of good NbS governance helps enabling NbS (Albert et al., 2019).
Flexibility and adaptiveness	The governance mechanisms through which NbS are implemented retain a level of flexibility, meaning that they can be adapted in case of changes in system dynamics.	We need flexibility for developing solutions for environmental pressures that might be neither fully known nor predefined (Suleiman, 2021).
Champions and advocates	There are individuals or advocate groups spearheading NbS visibility and implementation.	The recruitment of 'change agents' (key personnel working within and outside of public institutions) can enable wider NbS adoption (Davies and Lafortezza, 2019).
Political will & long-term commitment	There is political will for implementing NbS, including a long-term vision for and commitment to NbS.	Securing political support in the area where the project is implemented is indispensable (Naumann et al., 2014).
Aesthetics	NbS are seen as aesthetically pleasing.	A NbS is seen as more visually attractive in the local landscape than a grey alternative (Martin et al., 2021).
Disaster	The occurrence of a disaster (and potential failure of a previously grey solution) catalyzes the consideration of NbS.	The occurrence of a landslide opened a window of opportunity for NbS (Martin et al., 2021).

Data availability

Data will be made available on request.

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