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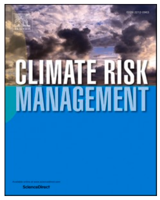

Building climate resilience through nature-based solutions in Europe: A review of enabling knowledge, finance and governance frameworks

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ABSTRACT

The European Union (EU) has firmly positioned itself as a global leader in promoting and implementing nature-based solutions (NBS). The recently released EU Biodiversity Strategy for 2030, Strategy on Adaptation to Climate Change, and Forest Strategy - all representing key pillars of the ambitious European Green Deal (EGD) - rely on NBS to both preserve and restore ecosystem integrity and increase climate resilience. Although research and policy in Europe have advanced the conceptualization and operationalization of NBS, a much wider adoption is needed to reach the ambitious goals of the EGD and fulfil its vision of transforming into a sustainable, climate-neutral, climate resilient, fair, and prosperous EU by 2050. In this paper, we review recent EU-supported research, policy, and practices to identify critical dimensions that still need to be addressed for greater uptake of NBS. While recognising the multiple societal challenges NBS can target, we build on the key messages from the '5th European Climate Change Adaptation conference ECCA 2021′ and focus our analysis on NBS for climate change adaptation and disaster risk reduction. We screen a wide range of NBS cases across the EU and identify-three core challenges to implementation: the lack of a comprehensive evidence base on the effectiveness of NBS to address targeted challenges; the need for a greater involvement of the private sector in financing

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NBS; and opportunities for enhancing stakeholder engagement in the successful design and implementation of NBS. We take these challenges as the starting point for a broader reflection and critical discussion on the role of i) knowledge, i) finance, including investments in NBS and divestments from nature-negative projects, and iii) governance and policy frameworks to enable the uptake of NBS. We conclude by identifying options for the EU to foster the uptake of NBS in research, policy and practice.

1. Introduction

As the Covid-19 crisis postponed major environmental summits originally scheduled for 2020, expectations became high for 2021 to be a 'super year' of global action in tackling climate change, halting biodiversity loss, and addressing sustainable development priorities (IIED 2021). Parties to the Convention on Biological Diversity (CBD) met in Kunming (China) for the first part of COP15 where negotiations focused on the expected adoption of a 'Post-2020 Global Biodiversity Framework' to guide actions to preserve and protect nature and its essential services to people and ensure that the vision of 'living in harmony with nature' by 2050 is fulfilled (CBD 2021). Parties to the United Nations Framework Convention on Climate Change (UNFCCC) met for COP26 in Glasgow (UK) and pledged more ambitious 2030 emissions reductions targets, enhanced action on adaptation, and the mobilisation of further finance to achieve these goals (UK 2021). Other significant events included the UN Food Systems Summit, convened as part of the Decade of Action to achieve the Sustainable Development Goals (SDGs) by 2030 (UN, 2021), and the 2021 Climate Adaptation Summit (CAS) hosted by the government of The Netherlands where the Adaptation Action Agenda was launched. In parallel, the UN Decade on Ecosystem Restoration kicked off and will run until 2030.

The challenges addressed by these global processes are deeply interconnected and do not stop at national borders, yet are often dealt with in isolation. In this context, nature-based solutions (NBS) have come to the forefront for their potential to address multiple challenges in parallel while providing wider long-term benefits. NBS are cost-effective, locally adapted and resource-efficient solutions that are supported by nature and 'simultaneously provide environmental, social and economic benefits and help build resilience' by bringing 'more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes' (EC 2015). NBS are understood as an 'umbrella concept' for other established ecosystem-based approaches, such as ecosystem-based adaptation (EbA), mitigation (EbM), and disaster risk reduction (Eco-DRR), natural water retention measures (NWRM), sustainable management and ecosystem-based management and blue and green infrastructure (BGI) (Nature 2017; Seddon et al. 2020; EEA, 2021). Central to the NBS concept is its emphasis on multifunctionality (Kabisch et al. 2016), i.e. the capacity to provide multiple and diverse benefits to people and nature in parallel (Albert, Spangenberg, and Schröter 2017), and the problem-centred approach (Potschin et al. 2016). Accordingly, NBS target specific societal challenges, such as climate change mitigation and adaptation, disaster risk, food and water security, human health, and socio-economic development (Cohen-Shacham et al. 2016).

The European Union (EU) has firmly positioned itself as a global leader in promoting and implementing NBS (Davies et al. 2021). In the last decade, the EU has placed the 'working with nature' approach at the centre of several of its sectoral policies, including those on flood management (EC 2007), climate change adaptation (EC 2009, 2013), biodiversity (EC 2011a), water retention (EC 2012, 2014), and disaster risk management (EC 2011b). The EU Research and Innovation (R&I) agenda on the environment further introduced the concept of 'innovating with nature' to stress the role NBS can play in promoting a more resource efficient and competitive economy, fostering economic growth and creating new jobs (Faivre et al. 2017). The recently released EU Biodiversity Strategy for 2030 (EC 2020a), Strategy on Adaptation to Climate Change (EC 2021a), and Forest Strategy (EC 2021b) - all representing key pillars of the ambitious European Green Deal (EGD) (EC 2019) - rely on NBS to both preserve and restore ecosystems, increase resilience to climate change impacts, and manage forests sustainably. In particular, the Biodiversity Strategy highlights the critical need for ecosystem restoration to achieve its aims and foresees the development of legally binding EU nature restoration targets, focusing on ecosystems to capture and store carbon and minimize natural disaster impacts. The Strategy on Adaptation to Climate Change (EC 2021a) places NBS and related concepts as cross-cutting priorities due to their potential to cost-effectively provide multiple benefits. It calls for further EU funding and investment programmes to support NBS uptake across EU Member States, advance research on climate change impacts to ecosystems and NBS in particular, and develop robust ecosystem management measures to reduce climate change risks. Finally, the Forest Strategy (EC 2021b) embraces a closer-to-nature forestry approach to achieve sustainable forest management (e.g. through ecosystem-based approaches) and contribute to climate change adaptation and forest resilience. By supporting major EU policy priorities, NBS are expected to play a key role in fulfilling the vision of a sustainable, climate-neutral, fair, and prosperous EU set out in the EGD. Yet, while the EU has made important contributions to the conceptualization and operationalization of NBS (Davies et al. 2021), a much wider adoption is needed to reach these ambitious goals.

In this paper, we ask whether EU-supported research, policy and practices are fit for purpose and identify key dimensions that need to be addressed for a greater uptake of NBS and the achievement of the EGD and global sustainability, conservation and climate aims. While recognising the multiple societal challenges NBS can target, we focus our analysis on climate change adaptation and disaster risk reduction (CCA/DRR), by building on the key messages emerged from the nine sessions of the '5th European Climate Change Adaptation conference ECCA 2021′, which were discussed by EU policymakers at the ECCA 2021 High-Level Conference on 22 June 2021 in Bruxelles and presented at COP26. The focus of the paper on CCA/DRR is also consistent with the increasing attention on the role of NBS for climate resilience in the EU, as exemplified by the recent European Environmental Agency publication on the topic (EEA, 2021). We review recent developments in this field and identify-three key opportunities for a greater uptake of NBS, namely: i) expanding the knowledge base; ii) enhancing synergies between the public and private sectors in financing NBS; and iii) fostering enabling governance and policy frameworks.

The paper is structured as follows. In section 2, we screen a wide range of NBS cases across the EU building on EEA (2021) and provide an overview of the types of NBS interventions implemented, their scale, climate impacts addressed and associated benefits. The screening reveals three main challenges to implementation. These include the need for improving the evidence base on the relevance and effectiveness of NBS to motivate their adoption by local authorities; the reliance on (limited) public resources for financing NBS, which calls for a greater involvement of the private sector; and opportunities for enhancing stakeholder engagement for successful NBS design and implementation. We take these challenges as the starting point for a broader reflection on the role of knowledge (Section 3), finance (Section 4), and governance arrangements (Section 5) to enable the uptake of NBS. For each of these dimensions, we take stock of the most recent developments, identify gaps, and discuss prospects for these gaps to be filled. In section 6, we consider options for the EU to foster the uptake of NBS in research, policy and practice. By doing so, the paper seeks to contribute to an emerging critical debate around what NBS initiatives are actually achieving in practice (Seddon et al. 2020) and the wider implications for society

Table 1
NBS options, benefits and climate impacts addressed (Adapted from EEA, 2021).

	NBS measures	*Key NBS benefits*	*Key Climate impacts addressed*	*Example cases*
Water management	Restoration of rivers and floodplainsCreating river buffers (e.g. vegetation strips) Eco-hydrological forest management	Regulation of water flows Reduction of floods and soil erosion Recreation and aesthetic appreciation Biodiversity Water quality Habitat restoration	Droughts Floods	Elbe dyke relocation (D);Odense river restoration (DK) ;Serchio river basin ecosystem based management (IT) ; Brague catchment (F);Isar River re-naturalisation (GER) .
Forests and forestry	Protection, connection and restoration of forest Hydrological restorationReduce scrub cover (e.g. pasture) Sustainable Forest Management Integration of trees/forest into the landscape	Regulation of water flows Reduction of floods Control of disease and pests Slope stabilisation Carbon sequestration Biodiversity Recreation and aesthetic appreciation	Droughts Floods Fires Landslides	Boscos-Menorca LIFE+ (E);LIFE resilient forests (D, PT, E) ;Small Water Retention Program in Forests (PL) .
Agriculture	Improved soil and water management Crop type diversification and rotation Agroforestry Paludiculture	Retention of water and soil Mitigation of heat stress Control of disease and pests Carbon sequestration Soil fertility Biodiversity	Droughts Floods Heat stress	Farming as a tool to restore habitats and landscapes (PT); Paludiculture - peatland restoration (D); Agroforestry - combining wheat and walnut production (F).
Urban areas	Parks, forest, street treesGreening building envelope (e.g. green roofs and walls)NBS for water management (e.g. bioswales, detention ponds)	Cooling air temperature Mitigating urban heat island effect Regulation of water runoff Carbon sequestration Biodiversity Human health and well-being Water quality	Floods Heat waves	Climate proofing in Bratislava (SK); Green roof strategy in Hamburg (D); Eco-street design, Ober-Grafendorf (A); Combating the heat island effect in Stuttgart (D); Greening the city and increasing resilience in Amsterdam (NL).
Coastal areas	Rehabilitation and restoration Barrier islands, beach nourishmentHybrid solutions (e.g. green dykes, vegetated levees)	Reduction of coastal flooding Stabilisation of coast Carbon sequestration Biodiversity Recreation	Sea level rise Storm surges Coastal erosion	Ugento case using seagrass to protect dunes (IT); LIFECOASTadapt (S); Realignment of coastal flood defences (UK).
Mountain areas	Protection and restoration of forest Reforestation and terracing Vegetation acceleration with microbes Local timber installations for water retention	Reduction soil erosion Stabilisation of slopes Protection of fish and game stocks Biodiversity Recreation and aesthetic appreciation	Floods Erosion, rockfalls & landslides Avalanches	Terracing and revegetation in mountains, preventing landslides with old techniques (F, E, I); Restoration after forest fires in ancient Olymp (GR).

(Kaufmann et al. 2021).

Although specifically focusing on the EU, our findings are relevant to other geographical contexts and hold the potential to support a wider uptake of NBS beyond this scope, thereby also contributing to global climate, biodiversity and SDGs agendas. EU-funded research on NBS matters globally for several reasons, not least that ongoing research and demonstration projects are expected to provide good practice examples that can be adapted to different local contexts and thus replicated globally (O'Sullivan, Mell, and Clement 2020). Moreover, the involvement of non-EU countries, including from the Global South, as partners in these projects represents an important channel for EU-funded research to influence NBS research and practice worldwide.

2. NBS implementation across the EU

NBS for CCA and DRR are increasingly implemented across sectors and geographic areas in Europe, particularly in those prone to the negative impacts of climate change (e.g. water management, forests and forestry, agriculture -including agroforestry-, urban, coastal and mountain areas). The increasing implementation of NBS for CCA/DRR has been evidenced by the EEA (2021) through a screening of 107 European NBS cases implemented in the past two decades. The screening was based on information retrieved from 8 knowledge platforms: Climate-ADAPT (European Climate Adaptation Platform); Natural Hazards — Nature-based Solutions; Naturvation (Nature-based Urban Innovation); NWRM (Natural Water Retention Measures); OPPLA (EU repository of nature-based solutions); Panorama (a global project on mainstreaming ecosystem-based adaptation); PEDDR (Partnership for Environment and Disaster Risk Reduction); weADAPT (a collaborative platform on climate change adaptation issues), and EUROPARC's knowledge hub (a network for Europe's natural and cultural heritage). The cases were screened and selected according to the following criteria: i) the type of NBS measures realised; ii) the social challenges addressed, and iii) the innovativeness and wider applicability of the case in Europe. The review aimed to illustrate how NBS have been applied for CCA and DRR in different sectors and geographic areas. The report also analysed in depth 11 selected cases to assess impacts and effectiveness as well as lessons learned. The screening was supported by a review of the scientific knowledge base on NBS for CCA and DRR, options for NBS, their multiple benefits, opportunities and limitations for implementation (EEA, 2021: Chapter 3).

Screenings such as this can reveal the type and scale of NBS measures implemented in practice, societal challenges addressed, and the degree of innovation and wider applicability of the measures in relation to governance and financing set-ups. It can also (to some degree) reveal the type of challenges encountered at local and regional level. Table 1 provides an overview of the type of NBS measures, benefits and climate impacts addressed in the EEA (2021), together with an exemplificative selection of screened cases. Regardless of the considered sector, most screened cases address flood risks, while other climate-related impacts assume high relevance for specific sectors, such as heatwaves in urban areas.

The screening revealed that NBS implementation is to a high degree context specific in terms of time, space and local socio-ecological conditions with different planning, financing and regulation regimes. Despite this diversity, NBS for CCA/DRR have been found to involve three major types of interventions: i) conserving and restoring existing ecosystems to increase resilience, e.g. protection of forests in mountainous areas, restoration of floodplains or protection and restoration of coastal dunes; ii) sustainably managing and modifying existing ecosystems, e.g. by introducing agro-forestry in farming, creating room for the river through changes

BOX 1
: NBS at peri-urban scale - experiences from the ground

During the past 50 years, urbanisation in Europe has produced spreading cities at the expense of natural habitats. As a result, the soil has become impermeable, intensifying flood hazards and urban heat islands. Nonetheless, some European cities already started 30–50 years ago to restore and protect part of the open space available in the city outskirts to tackle environmental problems and create more space for people to recreate. These spaces located at the periphery of a city are referred to as *peri*-urban parks. Periurban parks play an essential role especially in southern Europe, where green space is comparably lower per habitant in the inner-city than in the northern parts of Europe.

Peri-urban parks as a NBS are wilder, more biodiverse and substantially much larger than most common urban parks (Sundseth & Raeymaekers, 2006). Thus, they can deliver more diverse and better ecosystem services to city populations including cooling down temperatures, providing flood protection, offering recreation opportunities and storing greenhouse gases (Fedenatur, 2004). Many *peri*-urban parks are the natural consequence of the existence of strong physical constraints (Europarc, 2019) such as wetlands and flooding plains (e.g. Grand Parc de Miribel Jonage in Lyon, France and the Green ring of Vitoria-Gasteiz in Spain), or rough reliefs such as mountains and hills (e.g. Collserola Nature Park in Barcelona, Spain and Buda Hills in Budapest, Hungary) or a mountainous coast (e.g. Parc périurbain des Calanques outside Marseille, France). Other *peri*-urban parks were former royal hunting areas (e.g. Monte El Pardo in Madrid, Spain) or areas devoted to agriculture (e.g. Parco agricolo Sud Milano, Italy). Yet many *peri*-urban parks are the result of important restauration and reforestation works of former industrial sites and brownfields (e.g. Parco Nord Milano in Italy and Espace Nature in Lille, France).

Examples of cases actively investing in restoring *peri*-urban parcs include the Confluence park in Prague, Czech Republic, that restored brownfields, riverbanks and industrialized large scale agriculture into a *peri*-urban park, and the Forestami project in Milan, Italy, consisting of planting 3 million trees mainly in the *peri*-urban space.

in land use planning or improving protection and extending green areas and corridors in cities and towns; and iii) creating new, engineered ecosystems such as bioswales and retention areas, constructed wetlands or green roofs, green walls on buildings and greening of other urban elements (e.g. playgrounds, parking areas, railway, etc.) (Eggermont et al. 2015). For these different types of NBS interventions to reach their potential to climate-proof society, they require integration in several policies (from international to local, and across different policy areas), financial structures, engineering and built environment traditions, ranging from forestry, agriculture to civil engineering and architecture. In some cases, NBS have been successfully combined with grey infrastructure in so-called 'hybrid solutions' to achieve planned outcomes, particularly in relation to water management and urban areas (Browder et al. 2019). This can be seen, for example, in the case of the Elbe dyke relocation in Germany that helped improve the efficiency of old grey measures by creating a floodplain, opening up the old dyke and constructing a new dyke further inland.

With respect to the scale at which NBS are implemented, most of the urban NBS cases included in the EEA (2021) screening operate at the object scale, e.g. green roofs, green walls and facades, rain gardens, street trees and pocket parks. In some instances, efforts are made to combine the object scale of NBS with a wider strategy to push for the implementation of one type of NBS measure, such as green roofs in Basel and Hamburg, or to push for a combination of different types of NBS at object scale or to (re-)connect green areas to increase climate proofing towards floods, extreme temperatures and heatwaves, including urban heat island effects, as in the case of Bratislava and Stuttgart. The relative scarcity of large-scale NBS implementation (e.g. floodplain restoration, green corridors) is also documented in the literature (EEA, 2021; Vojinovic et al. 2021). Yet, emerging practices point to the potential of unbuilt *peri*-urban space to play a role in connecting different NBS and accommodating large-scale NBS (e.g. forest areas and wetlands), reducing the risk of heat waves (Marando et al. 2019) and floods (Ramirez et al., 2020) while enhancing carbon storage, biodiversity and promoting citizen's health and wellbeing (Veerkamp et al., 2021). Box 1 provides an overview of examples of cities investing in the restoration and protection of nature in the *peri*-urban space. As NBS can be implemented at different scales, from object-oriented to large scale interventions, there is an increasing recognition of the need to integrate them through systemic thinking approaches (Kabish et al., 2022).

The screening of European NBS cases revealed three main challenges to implementation. These include i) the need for strengthening the evidence base on the relevance and effectiveness of NBS, so to motivate local authorities to adopt NBS over traditional solutions; ii) a predominance of public resources for financing NBS, which calls for a greater involvement of the private sector through (innovative) economic and financial instruments; and iii) opportunities for enhancing stakeholder engagement for successful NBS design and implementation (EEA, 2021). In the following sections we take up and expand on each of these dimensions by discussing opportunities to enhance the knowledge base for NBS, strengthening synergies between the public and private sectors for financing them, and fostering enabling governance and policy frameworks.

3. Opportunities for fostering a greater uptake of NBS

3.1. Expanding the knowledge base for NBS

Several initiatives support the development of a global knowledge base on NBS to provide evidence of their capacity to deliver ecosystem services and quantify their longer-term social, economic and environmental benefits. The IUCN has supported this effort via the creation of 'The IUCN Global Standard for Nature-based Solutions' to standardise NBS design, implementation and validation (IUCN 2020). The University of Oxford NBS initiative (https://www.naturebasedsolutionsinitiative.org) and evidence-based guidelines offer further support for the establishment of a coherent evidence base, outlining four high-level messages for decision-makers about the role of NBS in addressing key societal challenges. The 2017 Eklipse working group report 'An impact evaluation framework to support planning and evaluation of nature-based solutions projects', is a seminal publication that provides an overview of the main societal challenge areas addressed by NBS along with examples of indicators of NBS performance and impact that can be used to develop an evidence base (Raymond et al. 2017). This Eklipse NBS assessment framework was subsequently expanded and updated by a taskforce comprised of experts from 17 EC-funded NBS projects and related programmes and initiatives, resulting in a comprehensive guide to the development and implementation of scientifically valid monitoring and evaluation plans for the assessment of NBS impacts and an extensive suite of indicators and methods of performance and impact assessment (Dumitru and Wendling, 2021a, 2021b; Cardinali et al. 2021). In addition, the GIZ guidebook for monitoring and evaluating EbA (GIZ-UNEP-WCMC-FEBA, 2020) provides a 4-step overview of the process needed for designing and implementing effective monitoring and evaluation. The adoption of standardised assessment protocols enables comparison among NBS of differing size and type implemented across a wide geographic region, facilitating in-depth *meta*-analyses.

At the EU level, the Horizon 2020 and Horizon Europe portfolio of EC-funded projects include targeted actions for the further development of a knowledge base on NBS. Together with projects under the Biodiversity and Climate Change COFUND Acton (BiodivERsA), these Horizon 2020 and Horizon Europe NBS projects explore the wide range of benefits and co-benefits provided by NBS and contribute essential new knowledge regarding NBS performance and impacts. The outcomes of this work are presented on various project websites and online platforms, including Oppla (https://www.oppla.eu), Network Nature (https://www.networknature.eu), BiodivERsA (https://www.biodiversa.org), and others. In addition to a multitude of scientific journal articles, several relevant European and global reports (e.g., Sudmeier-Rieux et al, 2021) and assessments summarise knowledge to date on NBS performance and impact, including their ecological and socio-economic benefits, their economic viability, and the role of NBS in addressing critical societal issues such as CCA and DRR. A series of NBS valorisation reports, commissioned by the EC, summarise the outcomes of previous and on-going NBS work exploring NBS contributions to specific challenges, including: climate change mitigation (Bulkeley 2020a); biodiversity (Naumann and Davis 2020); sustainable and socially just development (Bulkeley 2020b), air quality and urban heat islands (Calfapietra 2020); water quality (Wild 2020); and, flooding and coastal resilience (Vojinovic 2020). An overall summary of outcomes and evidence from EU research and innovation projects pertaining to NBS in critical areas of policy implementation and development is provided by 'Nature-based Solutions: State of the Art in EU-funded projects' (Wild, Freitas, and Vandewoestijne 2020).

Despite these important initiatives, several gaps remain in the NBS knowledge base. First, much evidence of NBS impact is relatively patchy, largely anecdotal in nature, limited to short-term studies, and/or lacking the requisite experimental controls to definitively attribute effect. There is an urgent need for the systematic and integrative compilation and assessment of NBS knowledge. In Europe, outcomes of NBS research are consolidated as NBS case studies on the Oppla platform along with other knowledge platforms (see Section 2). Efforts are underway in Oppla to create a searchable, online database using common indicators of NBS performance and impact and methods of data acquisition and assessment to facilitate longitudinal studies and focused *meta*-analyses across multiple NBS types, scales of implementation, climate zones, and socio-economic contexts. This NBS knowledge base will be key in providing the robust scientific evidence required for the incorporation of NBS within science-based public policy.

Second, ongoing efforts are largely focused on responding to critical knowledge gaps, including but not limited to understanding the impacts of climate change on the functioning of NBS both with respect to ecological integrity in the longer-term, and NBS performance with respect to identified challenges under increasingly variable climatic conditions. In particular, we need to better understand the interdependencies between climate change, ecosystems, biodiversity and the ecosystem services delivered. NBS can concomitantly address the interlinked challenges of climate change and biodiversity loss, but additional scientific evidence regarding the species and habitat types at greatest risk due to climate change is needed. Although the role of NBS in enhancing or preserving biodiversity while tackling climate change is clearly identified (IUCN 2020; Pörtner et al. 2021), the systematic analysis of biodiversity outcomes following NBS implementation is necessary to inform the development of improved NBS design and implementation guidelines to optimise biodiversity outcomes.

Third, referring to water management aspects, NBS are frequently employed to address flooding and enhance surface water quality (see EEA, 2021; Vojinovic, 2020; Wild, 2020 and references therein), with relatively fewer studies specifically focused on the role of NBS in addressing water scarcity. Many of the preceding concepts and practices that fall under the umbrella of NBS - e.g., low-impact development (LID), (stormwater) best management practices (BMPs), water-sensitive urban design (WSUD), and sustainable urban drainage systems (SuDs) - strongly focus on water management. This is hardly surprising, as nearly 20 % of European cities with greater than 100 000 inhabitants are highly vulnerable to flooding and flood events are expected to increase as a consequence of climate change (EEA 2012). Moreover, flood events are also particularly costly, accounting for two-thirds of the economic costs of damages attributed to natural disasters in Europe (EEA 2017). The on-going intensification of the global water cycle as a result of climate change can be expected to exacerbate the temporal misalignment between water supply and water demand, leading to greater frequency of both flooding and drought (IPCC 2021). Although there is clear evidence that NBS contribute to water security (OECD 2020a), additional information is needed to better understand and quantify how NBS ameliorate the impacts of drought.

In combination with future urban development, climate change is likely to exacerbate urban heat islands and associated extreme heat risks (Huang et al., 2019). Whilst the capacity of green and blue spaces within urban areas to mitigate urban heat stress is well recognized (e.g., Armson et al., 2012; Augusto et al. 2020; Doick et al., 2014; Kántor et al., 2018; Morakinyo et al., 2019), remaining knowledge gaps can present a barrier to the increased utilisation of NBS to enhance thermal comfort in cities. Additional research is needed to comprehensively address core design aspects of NBS intended to mitigate urban heating, including factors such as the abundance, distribution and type of green and blue spaces (e.g., Gunawardena et al., 2017; Zardo et al. 2017), the micro-climatic thermal benefits of planting densities and specific species of trees and other vegetation (e.g., Rahman et al., 2020), and social acceptability, local preferences and the integration of NBS within a built environment of high cultural heritage value (Grace et al., 2021). Issues of NBS spatial and temporal scale and extent of cooling effect similarly require further investigation to inform the establishment and scaling of NBS across urban areas (e.g., Bowler et al. 2010; Kabisch et al., 2016). Longer-term research, including modelling and spatial analyses, data collection and observations, as well as the application of comparative approaches and data sharing, is necessary to identify patterns and *meta*-level strategies to support urban planning and development focused on mitigating excess urban heat. Knowledge from scientific investigations must be integrated with technical know-how to develop robust guidelines for the optimal planning and design of NBS to address excess urban heating from building to metropolitan scale.

Finally, the socio-economic benefits of NBS require additional investigation. The health and well-being benefits of NBS are frequently referenced, yet knowledge concerning NBS impacts on mental and physical health, quality of life and social cohesion remains fragmented. Additional evidence is needed to design and implement NBS that deliver the full range of well-being benefits. It is also necessary to gather additional evidence regarding trade-offs associated with NBS implementation. For example, poorly planned urban regeneration efforts can result in social inequalities (Anguelovski et al. 2019; de Souza and Torres 2021; Shokry, Connolly, and Anguelovski 2020) or benefits may only occur after a considerable time (e.g., ecosystem restoration may take decades to deliver the desired benefits). It is essential to understand not only the multitude of benefits delivered by NBS, but also the full scope of potential trade-offs (in space and time) in order to develop effective strategies to reduce or eliminate potential negative consequences. With respect to the economic benefits of NBS, although the Dasgupta review (Dasgupta 2021) lays out a convincing argument for the economic value of natural capital, which is enhanced by NBS actions, the costs of NBS in the longer term are not fully understood at present, particularly in comparison with conventional grey infrastructure or hybrid blue-green-grey solutions.

The integrated valuation of economic, social and environmental benefits and costs associated with NBS is key to ensure they are considered alongside conventional grey solutions (Calliari, Staccione, and Mysiak 2019). For example, in the case of the Brague catchment in France, which suffers from serious flash floods causing casualties and large economic losses, the Horizon2020 NAIAD project found that NBS are economically efficient only when all the co-benefits they generate -i.e. the additional environmental, economic, and social benefits- are taken into account (Le Coent et al. 2021). Concomitantly, we need to better understand the impacts of the spatial scale of NBS implementation on derived social, economic and environmental benefits. Many NBS practitioners also note a lack of knowledge regarding NBS (co–)management and maintenance needs in the longer term (e.g., Sarabi et al., 2019, 2020, 2021). Longer-term case studies are required to both inform technical (engineering) specifications of NBS as well as management/maintenance processes and guidelines.

3.2. Enhancing synergies between the public and private sectors for financing NBS

Diverse economic and financial instruments have been developed to stimulate environmental conservation and restoration and can be used - and in some cases are - to foster the implementation of NBS for CCA and DRR. This can take the form of incentives (e.g. subsidies and payments), disincentives (e.g. taxes or charges), or risk-financing schemes (e.g. insurance and other risk transfer mechanisms). Through economic and financial instruments, the public sector orients private actors' behaviours toward environmental targets and can similarly engage private actors in implementing new NBS or contribute to the maintenance of existing ones.

The screening of NBS cases carried out by EEA (2021) revealed the use of several incentives. These include subsidies, which have been employed to co-fund small-scale NBS such as green roofs in different European cities (e.g. Hamburg in Germany and Basel in Switzerland) or co-fund different forms of sustainable urban drainage systems, green roofs, rain gardens and other green spaces in Dutch cities and Bratislava, Slovakia. Deducting stormwater fees in return for private NBS investment is another incentive found (e.g. again in the Hamburg experience). In Bologna, private companies have been funding inner city afforestation (contributing to mitigate heat waves and the urban heat island effect) in return for certificates off-setting their carbon footprint. In the Netherlands the government uses funding to stimulate (semi)-private sectors to implement NBS in private spaces (e.g. green school yards, rainwater harvesting, green roofs). It is worth noting, however, that municipalities often suffer from short-term decision-making and lack of expertise to support NBS implementation and management, whereas investments in NBS require long-term strategies and dedicated maintenance budgets (Kabisch et al., 2016). Also, since the benefits of NBS cut across different governmental departments—with each having their own budgets and objectives—it can be a challenge to coordinate and share budgets for joint effort and investment (Kabisch 2015; Droste et al., 2017). Following recession and crisis like Covid-19, ensuring public finance for NBS implementation and maintenance may also not be feasible (Konstantinidis et al., 2018).

Taxes are the most common price instruments and have been widely employed to pursue environmental objectives. There are more than 150 biodiversity-relevant taxes in the OECD countries, generating revenues of ca. USD 7.4 billion a year (OECD 2020b). The pesticide tax, for instance, is applied in various EU countries (Böcker et al. 2016) and in some cases (e.g. in Denmark and in France) the revenues are earmarked for environmental purposes and to compensate farmers. Taxes could be employed to 'penalise' grey infrastructure compared to their green alternatives, although their potential might be limited by the actual competences of the level of government willing to implement them and by stakeholder resistance (Baroni, Nicholls, and Whiteoak 2019). Other forms of instruments include land conversion fees, which have been introduced (eg. in Czech Republic, Netherlands and Slovakia) to dissuade loss of high-value agricultural land, and whose income is sometimes directed to environmental funds (Prokop, Jobstmann, and Schönbauer 2011).

There is consensus that insurance can - and should - play an increasingly important role in mitigating disaster impacts, not only through risk sharing, but also through all aspects of the risk management cycle, including risk identification and modelling, risk awareness, damage prevention, risk transfer, and recovery (Kunreuther et al., 2012; Surminski and Oramas-Dorta 2014). The EC stressed the 'insurance value of ecosystems' and defined it as the 'sustained capacity of ecosystems to maintain their functioning and production of benefits despite any disturbance' and to reduce risks to human society' caused by natural hazards, climate variability and climate change (EC 2015). While ecosystem insurance schemes have not been implemented in the EU yet, examples of partnerships between public and private actors elsewhere can provide a source of inspiration. One of the first is the scheme developed by The Nature Conservancy, the Swiss Re, the Mexican state of Quintana Roo and the Cancún and Puerto Morelos Hotel Owners Association to ensure around 60 km of coastal reef and beaches along the coastline of the Yucatan peninsula. The jointly created Coastal Zone Management Trust, which is financed through taxes collected from the tourism industry, purchases a parametric insurance to ensure these vital ecosystems are restored after having been damaged by extreme storms (Kousky and Light 2019).

Despite economic incentives for private investment, NBS are largely public goods with limited potential for the private sector to capture revenues (Spect et al., 2014; Huston et al. 2015; Droste et al. 2017; Frantzeskaki et al. 2019). Indeed, some estimates indicate that around 86 % of NBS have been publicly funded (UNEP 2021), leaving room to expand private investment across a wide spectrum of business models. At one end of the spectrum are private investors who receive a return on their investment by capturing revenues or cost savings from the NBS. This includes, for example, a private hydropower plant owner who invests in foresting an adjacent slope to reduce sediment runoff and thus reservoir dredging costs, or an investor who finances a nature park and charges entrance. While in theory this business model requires no public intervention, its potential is underexploited, which suggests a role for the government in building capacity and providing technical analyses and information on the effectiveness of NBS in providing ecosystem services, e.g., in the former case on the effectiveness of tree cover in reducing sediment flow (Wild, Freitas, and Vandewoestijne 2020). More radically, the government could mandate NBS for private investments, or require offsets to nature-negative projects, for example, by a legal requirement for new commercial developments to achieve and retain a fixed biodiversity - no net loss, or better net gain (Wende et al. 2018). At the other end of the spectrum are private investors who avoid NBS projects that do not generate 'capturable' revenues and thus positive returns. Still, the projects may have large social and ecological benefits (for example, planting trees in an urban centre), and private investors may take on these projects to fulfil their environmental, social and governance (ESG) targets. According to a recent survey, executives and investment professionals largely agree that ESG programs create short- and long-term value (McKinsey & Company 2020). In between are projects with benefits to both the private investor (but not sufficient to cover costs) and co-benefits to society, for example, a flood control project that protects the investor's assets and also enhances biodiversity. The government can provide subsidies and share the risks of the NBS project, or it can form a public–private partnership with blended financing. In addition, the public authorities could provide NBS standards and good practice codes that protect private investors from legal liability suits.

Perhaps more importantly, greater synergies between the public and private sectors are needed not only to enable investments in nature but also to enable divestments from nature-negative projects. Spurred by the success of the Task Force on Climate-Related Financial Disclosures (TCFD), a Task Force on Nature-related Financial Disclosures (TFNDs) has been established (supported by Global Canopy, the United Nations Development Programme (UNDP), the United Nations Environment Programme Finance Initiative (UNEP FI), and the World Wide Fund for Nature (WWF)), which it is hoped will better enable firms and financial institutions to understand their impacts on nature. In fact, the EC is developing a legislative package for a regulation on sustainability-related disclosures, which will include an EU wide taxonomy (classification system) for the sustainability of investments (EU Technical Expert Group on Sustainable Finance 2020). To date, however, divestment from climate-negative assets is fully voluntary, yet incentivized by investors and businesses' concern about their public image and stranded assets. The prospect of stranded assets, however, may not be as relevant with regard to nature-negative investments, which means that mandatory enforcement mechanisms may be called for. For the banking sector this could come in the form of strict divestment procedures initiated at the European Central Bank (ECB), which would extend its mandate beyond its current focus on financial stability, or in the lending policies of the European Investment Bank (EIB) and European Bank for Reconstruction and Development (EBRD). Both of these public banks are orienting strongly towards sustainable investment. The EBRD, for instance, has embarked upon a Green Economy Transition 2021–2025, which focuses largely on renewable energy investments that (increasingly) provide a positive return. Its ability to offer loans for NBS may be constrained by its private sector-oriented business model. What stands apparent is the necessity to transition the governance of the financial sector, including public banks, such that they can provide the financial capital necessary to meet European nature targets.

3.3. *Fostering enabling governance and policy frameworks*

The importance of stakeholder engagement for successful NBS design and implementation is increasingly recognized (Nesshöver et al. 2017; Eggermont et al. 2015; Faivre et al. 2017). Indeed, about half of the 107 cases screened in the EEA (2021) explicitly highlight stakeholder involvement as being key to increase awareness, to tackle potential stakeholders' conflicts more effectively and to create social acceptance and demand for NBS. Relevant examples include the Hamburg's green roof strategy, which has established a structured co-creation process with the aim of changing practices and helping create a demand for green roofs. The city runs a stakeholder group involving housing estate companies, construction firms, landscape architects and urban planners, which took part in co-designing the incentive programme in the first place, and now meets biannually to reflect and evaluate the programme. A participatory approach was also implemented in the Serchio river basin (IT) and involved a wide range of public and private stakeholders through living labs, technical discussion tables and co-decision processes. Farmers played a key role in the project, by making their agricultural land available for NBS and by sharing their specific expertise and knowledge. During the participatory process, strong emphasis was placed on ensuring coherence and possible synergies with existing plans, like the River Basin Management Plan, the Flood Risk Management Plan and the Rural Development Plan. In the case of the Pyrenees, the EU-funded Horizon2020 PHUSICOS project works closely with local communities to co-design strategies, set up funding schemes, monitoring systems, services and policies for preventing landslides through terracing and revegetation using old techniques. In the case of Amsterdam, NBS for greening the city and increasing its resilience to climate risks (in particular heat stress and floods) have been identified within the city plan 'Structural Vision: Amsterdam 2040′ also through the active engagement of local stakeholders, which have been also involved in some aspects of the implementation phase (e.g. maintenance of tiny parks on previous wasteland). Maintenance and care taking of trees and small green areas is also a central aspect of citizens' engagement of the Stuttgart strategy to mitigate extreme temperatures and combat the heat island effect.

While stakeholder engagement has emerged as a fundamental principle in NBS governance (Lupp and Zingraff-hamed 2021), other processes that lead policymaking and its implementation deserve equal attention. The breadth of benefits offered by multifunctional NBS presents formidable challenges to their governance since it requires coherency of separate and often siloed policy agendas, collaboration among administrative departments, and a 'systems approach' to policy formulation, planning and implementation (Malekpour, Tawfik, and Chesterfield 2021; Bernardi et al. 2019; Frantzeskaki 2019; Lim 2011; Koppenjan and Klijn 2004). Here, we specifically address three key -yet overlooked- challenges surrounding the governance of NBS: i) stakeholder co-generation processes that account for the complexity of many NBS policy terrains and enable inclusive and equitable procedures and outcomes; ii) the need for collaborative networked governance processes to address systemic interdependencies, and iii) developing an EU policy framework which is flexible enough to adapt to local needs, yet binding enough to evoke progress.

3.3.1. *Engaging stakeholders in complex NBS policy terrains*

Engaging interested and affected parties in EU member state policy processes has become the norm in many policy sectors (Newig and Koontz 2014; Renn and Schweizer 2009; Webler, Tuler, and Krueger 2001); however, as most observers and practitioners agree, it is not a panacea. If inappropriately designed or timed, stakeholder participation can lead to ineffective decisions, prolong the procedures and immobilise institutions (Adger, Brown, and Tompkins 2005; Parkinson 2006; Ryfe 2005; Rosenberg 2007; Wynne 2007). For example, Wamsler et al. (2020) showed that in Sweden, citizens contesting NBS based on their personal interests were among the main causes of delays in NBS planning or the abandonment of NBS projects.

Stakeholder engagement is thus not solely about creating social acceptance of and consent for NBS. Especially in highly contested NBS cases (for example, those projects characterised by a green-grey divide), deliberation is typically about reaching robust -

sometimes called 'clumsy' - compromises among stakeholders with diverse values, interests and worldviews (Linnerooth-Bayer et al. 2015; Scolobig, Thompson, and Linnerooth-Bayer 2015; Verweij et al. 2006). This means stakeholder engagement will not always lead to a 'pure' NBS. In the Isar river case further elaborated below, the stakeholders reached a compromise for a hybrid solution that piggy-backed the restoration of the river with a 'hidden' grey flood protection. Indeed, in highly contested or 'wicked' issue arenas, policy making is a constant discursive struggle over the boundaries and conceptual framing of the problem and the values and worldviews that guide shared understandings (Churchman 1968; Verweij, Luan, and Nowacki 2011; Sieber, Biesbroek, and de Block 2018; Koppenjan and Klijn 2004; Dewulf and Bouwen 2012). Stakeholders typically stand in solidarity with their institutional, political and social networks, or what some researchers have recognized as discourse communities (Hajer 1993; Dryzek 1990), advocacy coalitions (Majone 1989; Jenkins-Smith and Sabatier 1993), social solidarities (Douglas 1996) and eco-chambers (Nguyen 2020).

An NBS stakeholder process for landslide protection in Italy can serve as an example of a process that not only accommodated but also empowered those holding different frames of the issue and its solution (Scolobig, Thompson, and Linnerooth-Bayer 2015; Linnerooth-Bayer et al. 2015). Opinions and views expressed in stakeholder interviews were clustered into competing narratives that reflected diverse interests and worldviews (Thompson, Ellis, and Wildavsky 1990). Each worldview group worked separately with technical experts to co-design their preferred strategy - only one of which was a 'pure' NBS - after which the groups negotiated a compromise portfolio of risk reduction measures that included an NBS. This 'designed' co-generation process took over three years of regular stakeholder meetings and another few years before the NBS was implemented. Thus, the processes underpinning true co-creation often require more time than is given in the lifespan of NBS projects.

3.3.2. *Collaborative governance to address systemic interdependencies*

The importance of collaborative or polycentric governance processes has been illustrated by cases of implemented NBS for flood and landslide protection across Europe (Martin et al. 2021; Zingraff-Hamed et al. 2020). A number of analyses show the emergence of novel arrangements that disperse decision authority across multiple organisations including not only flood and landslide protection, but also nature conservation, urban planning, water quality, waste management, tourism, and recreation, among others (Martin et al. 2019). In one case, collaboration across public agencies proved critical in the transformation of a 'grey' flood protection project for Munich's Isar River (Germany) to a major river re-naturalization project providing flood protection, ecosystem services, biodiversity, and recreation. The collaboration was initiated by state water authorities who joined with municipal administrative agencies, grass roots organisations and experts in advocating a far broader vision for the Isar than their customary focus on grey flood defence infrastructure. This multi-scale and cross-sectoral collaboration (two characteristics of polycentric governance) - breaking the silos of water and urban planning - was initiated by ecologically committed staff members who formed a multidisciplinary working group that was unprecedented for projects of this magnitude (Martin et al. 2021; Zingraff-Hamed et al. 2020).

In the Isar NBS case the arrangements were shown to be ad-hoc, short-term, dependent on local champions, and lacking the permanency needed for upscaling. The result, which is not isolated to the Isar case, highlights the potential for establishing cross-competing priorities among agencies, cross-sectoral formal mechanisms, new dedicated institutions, as well as programmatic and regulatory mainstreaming (Martin et al. 2021). Runhaar et al. (2019) discuss the creation of new institutions devoted to adaptation and NBS promotion with their own budgets and a clear political mandate. An example could be the establishment of climate offices or secretariats to assist agencies in the implementation of climate strategies (see e.g. Braunschweiger and Pütz (2021)).

3.3.3. *Developing a flexible yet enforceable supportive policy framework*

The EU policy framework faces a dual challenge of needing to be flexible enough to allow Member State sovereignty and therewith the adaptation of actionable policies to local contexts, while also ensuring that its objectives will be met. In the case of NBS, this has resulted in a mix of voluntary and mandatory instruments across EU environmental strategies and directives, with varying levels of potential support.

Recent reviews of the EU policy framework (Davies et al. 2021; EEA 2021) reveal a predominantly non-binding instrument mix for NBS and related concepts. Policies are based largely on voluntary action and are often lacking quantitative and measurable targets for NBS deployment and quality. For example, the EU Adaptation Strategy (EC 2021a) identifies NBS and other related concepts such as BGI and SM/EbM as cross-cutting priorities and outlines the need for further studies, increased investment and the development of robust ecosystem management measures. It fails, however, to require specific actions, such as the development of national adaptation strategies integrating NBS for CCA/DRR. Similarly, the EU Green Infrastructure Strategy was meant to scale up ecosystem restoration and better integrate NBS into other policy domains and deliver on a 15 % restoration target, but has in practice failed to encourage action at scale (Gerritsen et al., 2021). Finally, the EU Urban Agenda makes explicit reference to NBS and to green infrastructure; however, Member States can choose which priority themes to focus on and are only encouraged to voluntarily involve themselves in partnerships to research and implement devised Action Plans. Within other areas, many of the reviewed policies explicitly outline the benefits of nature, allude to their potential to address societal challenges, and encourage action to adopt or promote such measures. However, these policies do not go further than encouragement and fail to set standards or mandate supportive action, relying on self-initiative and voluntary commitments from member states (Davies et al. 2021).

Such policies are increasingly viewed as being inadequate for creating the necessary political will across and within member states (Gerritsen et al. 2021). In recent policy developments, the Commission has accordingly begun to introduce more binding and enforceable legal obligations which complement its existing, largely voluntary environmental policy frameworks. The EU Biodiversity Strategy for 2030 (EC 2020a), for example, foresees the launch of an EU nature restoration plan that will include legally binding nature restoration targets, such as a roadmap for planting at least 3 billion additional trees and restoring at least 25,000 km of rivers to a free-flowing state by 2030. This move is seen in part as a response to the failure of the previous Strategy to meet its targets due to lacking mandatory requirements. Other mandatory instruments are mentioned in the WFD for flood risk management plans and the inclusion of natural retention areas, though this varies between being mandatory or encouraging voluntary action. The EU Floods Directive has been more successful in inspiring at least 26 member states to include natural water retention measures - a form of NBS - into their plans, though substantial room for improvement remains (Gerritsen et al. 2021).

Across these policies, critical gaps remain, which continue to impede a more widespread deployment and mainstreaming of NBS for CCA/DRR. Following EEA (2021), these include a lack of EU agreed standards and quantitative targets (e.g. on application, coverage, quality) to assess the progress, effectiveness and benefits of NBS and their related policies as well as a need to further communicate these to implementers and decision-makers. Finally, as adopting conducive national and local policies is central to facilitating the uptake of NBS (Trémolet 2019), the lack of EU requirements for mainstreaming GI and monitoring its implementation is a critical gap.

4. Moving forward: The role of the EU in supporting NBS uptake for climate resilience

In this paper, we reviewed recent EU-supported research, policy, and practice to identify key dimensions that need to be addressed for a greater uptake of NBS in the upcoming years. NBS are expected to play a key role in supporting the ambitious EGD's objectives and in fulfilling its vision of a sustainable, climate-neutral, fair, and prosperous EU by 2050. Although we recognise that NBS can target multiple societal challenges, we focused on their potential for CCA and DRR and used wide range of screened NBS cases across the EU to identify key challenges. In doing so, we can distinguish three dimensions that need to be addressed: i) expanding the NBS knowledge base; ii) enhancing synergies between the public and private sectors in financing NBS; and iii) fostering enabling policies and governance frameworks. While previous research has drawn attention to similar challenges (Seddon et al. 2020), we specifically focused on the EU as a case study and critically discussed potential for these barriers to be overcome to fulfil the objectives of the EGD.

With respect to the NBS knowledge base, we took stock of recent initiatives and identified remaining gaps. Key knowledge gaps within and beyond the EU context (Chausson et al. 2020) include the relatively patchy and anecdotal nature of NBS evidence, the often short-term nature of studies and/or lacking experimental controls to attribute effect, and the need for an improved understanding of the interdependencies between climate change, ecosystems and the services delivered and the role of biodiversity in increasing NBS resilience. Relevant to the EU, and specifically to water management aspects, is a predominance of studies on NBS for flood risk reduction, while less is known about the role of NBS in addressing water scarcity. NBS projects funded under the EC's Horizon 2020 and Horizon Europe schemes continue to play an important role in compiling evidence regarding NBS processes, performance and impact as will the EC Mission on Adaptation to Climate Change, including societal transformation. The greater emphasis placed by Horizon Europe in integrating social sciences and humanities as compared with previous programmes (Reiter-Pázmándy 2021) is seen as a positive and critical shift. In particular, this will allow for the exploration of some 'blind spots' in current NBS research, including the limited attention to the social justice implications of implementing NBS. These solutions are not 'intrinsically good' and need to be accompanied by social policy measures to reduce unequal vulnerability to climate risks (Mabon and Shih 2018, Breil et al. 2021) and other trade-offs. In particular, there is a need to better understand how the implementation of NBS can reinforce or mitigate existing socio-economic and socio-spatial differences and inequalities (Haase 2017), or may contribute to social exclusion through 'green gentrification' processes (Anguelovski et al. 2019).

We also discussed how enhancing the knowledge base on NBS values for CCA and DRR is a prerequisite for financing their implementation. Ecosystem services have a value, even if individuals do not directly pay for their provision and/or maintenance (Costanza et al. 2017, Díaz et al. 2018). The failure to account for the true social value of NBS leads to market distortion and, ultimately, an insufficient level of protection with lasting and - in some cases - irreversible damage. A full appreciation of the value of NBS is therefore key for attracting public investments. Yet, the scale of investment that is needed cannot be met by the public sector alone. According to a recent report by the United Nations Environment Programme (UNEP 2021), if the world is to meet the climate change, biodiversity, and land degradation targets, it needs to close a USD 4.1 trillion financing gap in nature by 2050. We discussed how private investment could be mobilised across a wide spectrum of business models and the type of supporting roles governments could play. Business model innovation on NBS has not been explored in depth (EEA, 2021), but important contributions are emerging from NBS-related H2020 projects. For example, the Connecting Nature project adapted the traditional business model canvas tool (Osterwalder and Pigneur 2010) to better capture the wider value proposition of NBS. The Naturvation project has developed eight business models for NBS (risk reduction, green densification, local stewardship, green health, urban offsetting, vacant space, education and green heritage) and specified for each the value proposition, delivery and capture as well as enabling conditions (Toxopeus 2019) and nine H2020 NBS projects have reviewed the state-of-the-art and latest advances in business models for NBS (Mayor et al., 2021). In this paper, we made a step ahead in discussing governance arrangements to enable private NBS investment. Perhaps more importantly, we drew attention not only to the need for investing in NBS but also for divesting from nature-negative projects. This point has only been made in passing in the NBS literature (Kabisch et al. 2016) and future research could examine the characteristics of governance mechanisms that create conditions for divesting for dominant solutions and leverage public and private funding for NBS.

This paper critically focused on challenges in governance and policy frameworks to enable a wider uptake of NBS. A shift in governance arrangements and policy approaches is necessary given the scale and urgency of NBS needed to sustainably address climate change, biodiversity, and land degradation targets (Watkiss and Cimato 2020) before irreversible tipping points are reached. First, we critically reviewed a key cornerstone of NBS conceptualization, i.e. the importance of stakeholder engagement in successful NBS design and implementation. The EU has stressed the importance of stakeholder participation in numerous directives, frameworks and other guidance documents, and since 2001 directly with two Environmental Impact Assessment (EIA) Directives (Directive 2011/92/EU; Directive 2001/42/EC) required for major infrastructure projects (Cohesion, Agricultural and Fisheries Policies). The EU could play a more influential role by revising the EIA and other Directives (e.g. Water and Flood Directives) to directly mandate priority on NBS.

The EU could also set out good practice guidelines and training on the purposes, designs, timing and facilitation of stakeholder engagement. Evidence suggests that stakeholder engagement on NBS is not always carried out in the most appropriate way (Toxopeus et al. 2020) and this can lead to ineffective decisions, decision deadlocks or paralyse institutions (Wamsler et al. 2020). The proposed good practice guidelines and training on stakeholder engagement for NBS might include suggestions from the EEA on the creation of a dedicated communications officer, structured co-creation processes, public information and a continuous stakeholder consultation group (EEA, 2021). These initiatives at the EU level could be particularly useful in mainstreaming stakeholder engagement practices that are not only effective but also inclusive and equitable.

Finally, we noted how the current policy framework is based on a mix of voluntary and mandatory instruments across sectoral strategies and directives. The reliance of the EC on voluntary instruments - deemed by some as inadequate for creating the necessary political will to address the challenges posed by climate change, biodiversity and ecosystems degradation (Scolobig et al. 2020; Gerritsen et al. 2021)- has been recently counterbalanced by the enactment of new binding instruments. The EC's proposal for the first European Climate Law, which will also play a role in climate change adaptation and NBS (EC 2020b), has been negotiated across multiple stakeholder networks at all scales with the intent that it will create strong political will and commitment. Following the climate law experience, the European Parliament has also recently called for a new EU biodiversity law to mandate enforceable actions to meet the EU Biodiversity Strategy 2030 and the EU nature restoration plan (EP 2021). The next hurdle, we argue, is establishing cross-sectoral legislation and mechanisms at the national and municipal scales such that NBS objectives can be mainstreamed across all sectors (Wamsler and Pauleit 2016). Indeed, the EEA finds that adopting conducive national and local policies is central to facilitating the uptake of NBS, and the lack of EU requirements for mainstreaming NBS and monitoring their implementation is a critical gap (EEA, 2021).

5. Conclusions

As this review of EU-supported research, policy and practice illustrates, NBS can play a key role in increasing climate resilience while providing wider benefits to society. Yet, we identified three main dimensions that need to be addressed to unlock the full potential of NBS. First, there is an urgent need for the systematic and integrative compilation and valuation of NBS knowledge within and beyond the European context. Global initiatives, like those led by IUCN, and projects funded under the new Horizon Europe scheme will play a pivotal role in strengthening the evidence base on NBS processes, performances, and impacts, and support their adoption over traditional grey solution. Second, as NBS largely rely on public financing -especially in urban areas- there are opportunities to further engage the private sector to substantially increase the overall level of investment in NBS actions. A wide spectrum of business models can be employed to this aim, with a role for governments to support the processes that both enable investments in nature and divestments from nature-negative projects. Third, a shift in governance arrangements and policy approaches is necessary given the scale and urgency of NBS needed to sustainably address climate change, biodiversity, and land degradation targets before irreversible tipping points are reached. Addressing the challenges that we outlined in the upcoming years will have implications on the ability of the EU to fulfil the ambitious objectives embedded in the Green Deal and its key strategic pillars.

We conclude with a call for future research to address another key dimension which cuts across research, policy, and practice and to which we only referred to in passing in this review: the issue of NBS scale. Not only the type and location, but also the scale at which NBS are applied is critical for their effectiveness in tackling climate-related risks. Yet, as the screening by EEA (2021) shows, in most cases NBS operate at the object scale (e.g., green roofs) while large-scale NBS implementation (e.g., floodplain restoration) is relatively scarce and, hence, there is a lack of evidence concerning their effectiveness. Unbuilt *peri*-urban space could accommodate large-scale NBS, yet this potential has often been overlooked and subjected to pressures by ongoing urban expansion. Additional evidence will support the accurate valuation of the full range of social, economic and environmental benefits delivered by NBS actions, providing incentive for further NBS actions including implementation of larger-scale NBS in *peri*-urban landscapes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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