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Nature-based solutions: typologies, ecological processes and benefit valuation approaches across landscapes

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ABSTRACT

Nature-based Solutions (NbS) can generate multiple benefits to society through the protection, restoration and renaturing of ecosystems across landscapes. NbS restore the ecological functions of degraded ecosystems and generate ecosystem services that can help counter challenges of biodiversity loss, climate change adaptation and mitigation, regulation of environmental pollution, health and well-being while offering an opportunity for job creation and a systemic change towards a nature-positive economy. Building on the description of NbS typologies across different landscapes, as well as the associated ecological processes that underpin NbS actions, we identify the societal challenges that NbS help to alleviate and the resulting societal benefits. This foundation allows the paper to explore diverse economic assessment methods for valuing ecosystem services, placing these methods within the context of landscapes, while also linking them to the benefits derived from NbS. By examining the connections between NbS across landscapes, societal challenges, ecological processes and NbS benefits, we are able to reposition traditional ecosystem valuation methods within a new and emerging context, emphasizing the need for enhanced interdisciplinary collaboration. Our analysis of NbS benefits and valuation methods builds targeted peer-reviewed literature, EU publications and reports, and iterative interactions with organizations partaking in NbS projects. The paper provides valuable insights crucial for well-informed resource allocation and financing decisions of policymakers. While primarily serving as a guiding framework, it also offers information to a wider audience, including practitioners seeking a deeper understanding of NbS typologies, NbS-related benefits, and their economic implications.

1. Introduction

The concept of NbS emerged in 2008 to promote innovative approaches that align the benefits of nature with societal well-being [1]. The European Commission regards NbS as nature-inspired, cost-effective solutions that provide environmental, social, and economic benefits while enhancing resilience and supporting biodiversity and ecosystem services [2,3]. NbS are applied across diverse landscapes and contexts, involving the protection and restoration of green and blue infrastructure to address societal challenges such as climate change, natural hazards, environmental degradation, and socio-economic issues. These challenges vary in scale, influencing project design and evaluation timeframes. Small-scale, site-specific interventions may yield quicker results, whereas broader, interconnected initiatives implemented across larger spatial scales often take longer to demonstrate their full benefits, but tend to deliver greater and more sustained positive impacts for biodiversity, well-being, and the economy [4–6].

There is an increasing demand to implement NbS in the context of different landscapes motivated by the benefits for biodiversity, climate adaptation, and human health. At the global level, there has been a

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significant recognition and incorporation of NbS into key intergovernmental agreements [7]. In 2022, the United Nations 5th Environment Assembly formally adopted a definition of NbS [8] and the UNFCCC COP27 recognized the potential of NbS to address climate change and biodiversity loss [9]. Moreover, the Kunming-Montreal Global Biodiversity Framework stresses the importance of NbS in achieving a world living in harmony with nature by 2050 [10]. Both the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [11] and the Intergovernmental Panel on Climate Change [12] acknowledge the importance of NbS in addressing biodiversity and the climate crisis. The recent EU Nature Restoration Law, supporting the EU Biodiversity Strategy, sets legally binding targets to restore degraded ecosystems for specific habitats and species from urban, forests, agriculture, river and marine landscapes to habitats under existing legislation such as wetlands, heath and scrub, rocky habitats and dunes [13].

Despite these important policy developments, a significant knowledge gap persists in our understanding of the economic dimensions of NbS. To make well-informed decisions on NbS investment and financing, policymakers, investors and practitioners need a sound understanding of the economic implications of NbS, considering the multiple benefits provided in various landscapes, and the methods used for their valuation. By landscapes we refer specifically to land features primarily related to land cover and landform. Landscapes are classified according to the land cover categories defined by the Corine land cover classes [14], complemented with mountains as a distinct landform. This recognition is crucial, as mountainous areas are subject to specific processes and risks such as landslides and rockfalls, which carry significant implications for disaster risk reduction, and which can be addressed effectively using Nature-based Solutions (NbS).

To this end, developing a comprehensive NbS typology aligned with a valuation framework is imperative. Some research studies have previously developed a typology of NbS focusing on sustainable development [15], natural hazards [16], environmental management [17], disaster risk reduction [18], or for NbS-related concepts such as green infrastructure [19] and urban green spaces [20]. The analysis and emergence of these typologies have helped to clarify the NbS concept and terminology, which enables the distinction of NbS actions from other blue, green or hybrid interventions [21]. In this paper, we present a refined and tailored typology by adapting existing ones to different landscape and land-uses, incorporating relevant ecosystem services and underpinning ecological processes, and aligning the different services with suitable valuation methods.

Examples of specific NbS benefits across landscapes include control of soil erosion in forests [22], flood mitigation in mountain areas [23], improved carbon sequestration in agricultural systems [4], mitigation of shoreline retreat in coastal areas [24], hydrogeological stability for enhancing water management [25], and improved air quality and human health in urban areas [26]. A systematic review of 200 papers identified the provision of multiple benefits, including biodiversity gain, as a core component of the NbS concept [27].

The characterization of benefit categories is of high relevance for the operationalization of NbS in both the global and the local policy arenas. Watkin et al. [28] developed a framework including three benefit categories: water-related benefits (e.g., flood mitigation, improved water quality), nature-related benefits (e.g., improved air and soil quality), and people-related benefits (e.g., culture, recreation, economics). These three categories offer decision makers a conceptual and general understanding of the benefits. However, their framework does not provide a methodological strategy to quantify the economic values of each benefit category. We aim to bridge part of this gap by formulating benefit categories with respect to different landscape categories that can be further assessed with suitable economic valuation methods.

The economic valuation of NbS is essential for securing, increasing, and up-scaling investments in NbS. Recent studies have shown that, including non-market benefits in cost-benefit analyses enhances the economic feasibility of NbS, raises policymakers' awareness of these solutions, and could thus accelerate NbS adoption [29,30,28]. In the literature there exists a large variety of different methodologies for evaluating the economic value of ecosystem services provided by NbS. These can be divided into market-based, cost-based, revealed preference, and stated preference methods. However, while the application of economic methods and the assessment of ecosystem services are well advanced, there is a lack of mapping the relevance of different methods systematically to a NbS typology and NbS benefits. This gap underscores the importance of informing and guiding practitioners on selecting suitable economic methods in different landscapes, contexts or for various NbS benefit categories.

The overarching purpose of this paper is to develop an integrated, refined typology of NbS and to examine different economic methods to capture ecosystem services across different landscapes, and to link these methods to multiple NbS benefits. To investigate the relationship between ecosystem services, NbS benefits, and economic valuation methods, we make use of the Ecosystem Service Valuation Database (ESVD), which offers a comprehensive collection of 1241 different valuation studies for various ecosystem types, services, and valuation approaches. For the mapping, we used the information from the database covering investigated biomes, ecosystems and ecosystem services, and then verified it through a targeted review of relevant studies. Our aim is to support practitioners in establishing a connection between economic methods and NbS benefits across different landscapes, thereby improving the economic valuation process for NbS. This should therefore serve as a compass for the selection of methods that are most relevant in a given context.

The remainder of the paper is organized as follows. Section 2 offers a detailed explanation of the methodology which includes the definition of the NbS typology, its categorization by landscape, the societal challenges associated with the underlying ecological processes, and the different NbS benefit categories. Section 3 outlines the results, mapping relevant economic valuation approaches to the specific landscapes and connecting these valuation methods to NbS benefits categories. Finally, Section 4 provides a discussion and conclusion.

2. Methods and materials

This section is divided into the following parts: (1) the definition of a typology that classifies NbS actions into three types, (2) the adaptation of the typology to landscapes, (3) the formulation of benefit categories characterized by the NbS benefits arising from addressing societal challenges with their underpinning ecological processes, and (4) a compilation of economic valuation approaches. This section serves as the foundation for the results section where economic valuation methods are linked to the benefit categories of NbS and ecosystem services by landscapes (Fig. 1).

2.1. NbS typology

We classify NbS into three generic actions associated with different forms of ecosystem intervention: i) protection or conservation of high-quality or critical ecosystems and/or sustainable management of healthy ecosystems, ii) modification and enhancement of existing ecosystems, such as the restoration or rehabilitation of degraded ecosystems, and iii) creation or establishment of new ecosystems. This categorization is inspired by the typology proposed by Eggermont et al. [17], who define three complementary types of NbS. These are characterized by the number of targeted ecosystem services and stakeholder groups, and by the level of engineering or management applied to biodiversity and ecosystems. Table 1 introduces our refined typology of NbS. The table shows each NbS type with the corresponding generic action and indicates the equivalent type in Eggermont et al. [17].

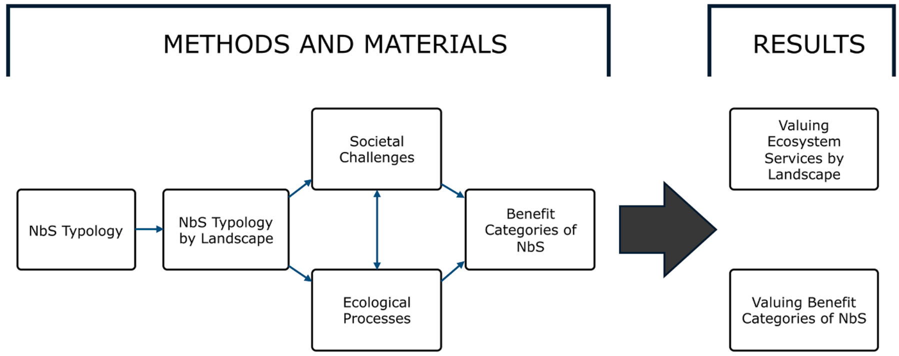

Fig. 1. Flowchart depicting the typologies and categorisations, serving as the background for the results section.

Table 1
NbS typology: Each NbS type is defined by a generic action.

NbS type	Generic action	Equivalent NbS type [17]
1	Protection or conservation of high-quality or critical ecosystems and/or sustainable management of healthy ecosystems	No or minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of ecosystem services both inside and outside of these preserved ecosystems.
2	Modification and enhancement of existing ecosystems, such as the restoration or rehabilitation of degraded ecosystems	Definition and implementation of management approaches that develop sustainable and multi-functional ecosystems and landscapes (extensively or intensively managed), which improves the delivery of ecosystem services in relation to a more conventional intervention.
3	Creation or establishment of new ecosystems	Managing ecosystems in very intrusive ways or even creating new ecosystems.

2.2. NbS typology by land cover and landform

We define landscapes according to land cover categories applied by CORINE Land Cover [14], and include mountains as a specific landform as this type of landscape represent specific processes and risks in relation to disaster risk reduction such as landslides, avalanches and flash flood. These natural hazards can be addressed by NbS effectively. The main land cover categories in the CORINE classification system that we focus on include: Urban areas, Agricultural areas, Forest areas, Inland wetlands & inland waters, and Coastal wetlands & marine waters. We identify generic NbS actions relevant for each landscape. These are further divided into examples of multiple specific NbS actions. See Table 2 for an overview.

2.2.1. Land cover: coastal wetlands & marine waters

Coastal wetlands (e.g. salt marshes, salines, intertidal flats) and marine waters (e.g. coastal lagoons, estuaries, sea & ocean) are vulnerable to several hazards such as extreme storm surges, sea level rise, droughts, heat waves, landslides and ocean acidification. This can cause land loss, coastal erosion, flooding and saltwater intrusion [31]. NbS can help reduce the vulnerability towards such climate events as well as to reduce the negative impacts. For example, the formation of vegetation, barrier islands, dunes and beaches reduce impact of coastal erosion, serving as natural barriers to waves and capable of recovering rapidly after a storm [32]. Generic NbS actions identified for coastal areas comprise: (i) protection and conservation of intact coastal ecosystems such as protecting barrier islands and sea grasses, (ii) modification and enhancement of coastal ecosystems such as managed realignment of coastal areas, and (iii) creation of a new coastal ecosystem such as green dykes or establishment of new stone reefs.

2.2.2. Landform: mountain areas

Mountains are highly vulnerable to the effects of climate change. Repercussions include increased risk of rockslides, snow avalanches, floods and water scarcity. Moreover, lower precipitation and higher temperatures at high elevations can allow, for example, vectors to inhabit new areas and, as a result, spread diseases to the population [33]. Generic actions for mountain areas include: (i) protection and conservation of mountain ecosystems such as maintenance of protection forests, (ii) modification and enhancement of mountain ecosystems such as terracing with drainage to stabilise slopes, and (iii) creation of new mountain ecosystems such as revegetation.

2.2.3. Land cover: inland waters & inland wetlands

Managing freshwater requires the integration of different landform and land cover categories involving inland water ecosystems including water bodies, water courses, inland marshes and peat bogs to regulate water flows. Climate change is changing precipitation patterns in terms of intensity and frequency, resulting in more torrential rains, floods, and droughts [34]. Freshwater ecosystems are impacted, affecting water quality and quantity. NbS have been identified to exert an important impact on water management and water availability, and to contribute to sustainable practices under climate change, but depend on the size of the NbS intervention. Generic NbS actions for water management include: (i) protection of intact hydrology and of existing high quality groundwater resources, (ii) modification and enhancement of an existing hydrological ecosystem, such as the rehabilitation of rivers, floodplains, wetlands and lakes, and (iii) creation of a new water-related ecosystem such as rainwater harvesting, and urban green space and corridors. There are interventions of water-sensitive forest management and groundwater management which can be categorized as NbS type 2 or NbS type 3. For example, afforestation, riparian vegetation and/or planting of hardwood species entail the creation of new water-related ecosystems for water-sensitive forest management. Similarly, NbS interventions for groundwater recharge enhancement and improvement of groundwater quality are more object-based (e.g., building) or within a specific site (e.g., street or plot). These can include permeable paving of footpaths, parking lots and playgrounds, porous asphalt, infiltration basins, constructed wetlands and vertical greening systems (e.g., green facades and green walls).

2.2.4. Land cover: agricultural areas

The production systems in agriculture are regularly threatened by climate hazards [35,36]. To illustrate, heat stress can cause crop and livestock loss, increase the risk of pests and disease outbreaks, and exacerbate the water scarcity during drought periods. In addition, flooding can cause damage to crop yields, transport, and infrastructure. To reduce vulnerability to hazards, NbS have been developed with the

Table 2
NbS typology across landform and landcover categories: Generic actions and examples of specific actions.

		NbS type	Generic action	Examples of specific actions
Land Cover	Coastal wetlands & marine waters	1	Protection or conservation of coastal wetlands and marine ecosystems	Protection of barrier islands, sea grasses (i.e., seafloor vegetation), salt marshes, coral and oyster reefs, and coastal vegetation
		2	Modification and enhancement of coastal wetlands and marine ecosystems	1. Managed realignment of coastal areas 2. Restoration of coastal habitats in transitional waters, e.g., dunes, wetlands and intertidal flats 3. Near-shore enhancement of coastal morphology, e.g., restoration of barrier islands, beach nourishment, dune reconstruction, cliff stabilisation
		3	Creation or establishment of new coastal wetlands and marine ecosystems	Engineered hybrid solutions, i.e., natural solutions combined with built structures, such as green dykes, wooded fences and vegetated levees, which are combined with structural dykes
	Inland waters & inland wetlands	1	Protection of hydrology and of existing inland water resources	Maintenance of safe physical environments to promote hydrogeological stability
		2	Modification and enhancement of an existing hydrological ecosystem	1. Rehabilitation of rivers, floodplains, basins, wetlands, ponds, lakes, aquifers 2. Water-sensitive forest management 3. Restoration and management of peatlands
		3	Creation or establishment of new inland water-related ecosystems	Rainwater harvesting, phytoremediation, urban green space and corridors
	Forest areas	1	Protection or conservation of forest ecosystems	Protection or conservation of primary and old-growth forests
		2	Modification and enhancement of an existing forest ecosystem (Sustainable forest management)	1. Restoration of degraded forests 2. Maintenance of forests in riparian buffers and headwater areas 3. Reforestation of revegetation, e.g., regrowth of deciduous trees
		3	Creation or establishment of new forest ecosystems	1. Afforestation 2. Integrating trees and forests into other landscapes (e.g., urban areas) and sectors (e.g., agroforestry)
	Agricultural areas	1	Protection or conservation of agricultural ecosystems	1. Protection of trees in forests and wetlands 2. Soil moisture conservation using plants for shading 3. Conservation agriculture
		2	Modification and enhancement of an existing agricultural ecosystem (Sustainable agricultural management)	1. Paludiculture including peatland and wetland restoration 2. No or minimum tillage 3. Crop type diversification and rotation
		3	Creation or establishment of new agricultural ecosystems	1. Agroforestry 2. Mixed crop-livestock systems 3. Creation of micro-relief and construction of floodplains for rain harvesting
	Urban areas	1	Protection of high-quality urban ecosystems (green and blue)	1. Protection of green infrastructure, e.g., urban trees, urban forests, urban greenspace, and urban forest parks 2. Protection of blue infrastructure, e.g., wetlands, lakes, streams, riverbanks
		2	Modification and enhancement of urban ecosystems (green and blue)	1. Rehabilitation of urban green space and corridors 2. Restoration of blue infrastructure 3. Reforestation of urban and peri-urban forests
		3	Creation of new urban ecosystems (green and blue)	1. Creation of new green infrastructure, e.g., street trees, vegetable gardens, green roofs, vertical greening systems 2. Creation of new blue infrastructure, e.g., retention ponds, SUDS, canals, rills
Landform	Mountain areas	1	Protection or conservation of mountain ecosystems	Maintenance of protection forests (a "protection forest" can prevent a recognized potential damage due to an existing natural hazard or reduce the associated risks)
		2	Modification and enhancement of mountain ecosystems	1. Terracing with drainage, slope stabilization, revegetation of steep slopes 2. Reforestation and/or revegetation
		3	Creation or establishment of new mountain ecosystems	1. Afforestation 2. Green flood barriers

principle of increasing (or at least maintaining) crop yield through the diversification of ecologically based interventions [4]. Such interventions contribute to improved soil (structure) and water management. Generic NbS actions for climate change adaptation in the agricultural sector in Europe include: (i) the protection of an ecosystem to adapt a farming practice to climate change such as conservation agriculture, (ii) the modification and enhancement of an existing agricultural ecosystem such as reduced tillage and crop rotation, and (iii) the creation of a new agricultural ecosystem such as agro-forestry. The specific NbS actions encompass multiple farming systems aiming to mitigate the impacts of heat waves, drought periods and heavy rainfall while ensuring food security and reducing the risk of flood and erosion.

2.2.5. Land cover: forest areas

Forests are fundamental for the mitigation and adaptation to climate change. The protection, restoration and maintenance of forests contribute to the regulation of water flows, the control of pests and diseases, the stabilization of slopes, the enhancement of biodiversity, the promotion of recreation and landscape aesthetics, among others. Forest-related actions can reduce the impact of floods by water absorption, can help to mitigate climate change through carbon sequestration [37], and can reduce the impact of heat waves by providing shade and by cooling surroundings through evapotranspiration [38]. NbS can be applicable at different levels: tree, stand and landscape. Landscape-based interventions can imply measures involving different ecosystems and overlapping with other landscapes and sectors, e.g., floodplain and river catchment restoration through reforestation. On the other hand, tree-based interventions have a lesser spatial extent yet still provide important environmental benefits. For example, the creation of hedges can act as noise pollution filters and wind barriers. Generic NbS actions for forest (and forestry) include: (i) the protection of forest ecosystems such as protecting old-growth forests, (ii) the modification of an existing forest ecosystem in accordance with sustainable forest management measures such as reforestation of deciduous trees, and (iii) the creation of a new forest ecosystem such as integrating trees and forests into other landscapes.

2.2.6. Land cover: urban areas

Urban ecosystems are natural systems within a city or a densely populated area. Blue-green infrastructure is a key strategy for climate change adaptation and mitigation in urban areas. For example, the urban heat island effect can be reduced significantly by enhancing transpiration and shading with street trees, green roofs, and parks [39]. Vegetation contributes to mitigation by capturing CO_2 through photosynthesis and helps to increase rainwater infiltration (storm water absorption), reduce water pollution, and decrease the level of stress to citizens. Generic NbS actions identified for urban areas comprise: (i) protection of urban ecosystems such as the protection of urban greenspace from development, (ii) modification of urban ecosystems such as the restoration of blue and green infrastructures, and (iii) creation of a new urban ecosystem such as greening the building envelope or planting new street trees. All generic actions involve green and blue infrastructure. Investments in urban NbS have proved challenging because the benefits take time to manifest [40].

2.3. Societal challenges and ecological processes

To elucidate societal challenges, our approach was anchored in the EKLIPSE report [41], which served as a valuable source for identifying the broad range of societal challenges commonly addressed by NbS initiatives: climate change adaptation, climate change mitigation, natural hazards, environmental management, and socio-economic well-being. In addition, we describe key underpinning ecological processes for the first four societal challenges just mentioned and a description of how ecosystem services through social-ecological systems also can help alleviate socio-economic challenges. A detailed description of the key underpinning ecological processes is included in the Supplementary Material.

By actively enabling ecological processes and the provision of ecosystem services, NbS can help address societal challenges at economic, social and environmental levels. Ecological processes are meant as the functions of nature that underpin the delivery of ecosystem services [42]. These ecological processes occur within ecosystems as physical, chemical, or biological changes [43], and vary depending on the landscape, type and scale of NbS, seeking to address particular societal challenges. Outcomes of NbS include not only ecological performance, but also social dimensions such as equity, well-being and livelihood security. The social outcome dimension of the social-ecological system framework developed by Ostrom [44] has increasingly been elaborated to include livelihood security in terms of employment opportunities, poverty alleviation, and stability of income; equity in terms of just distribution of costs and benefits and stability of income; and wellbeing in terms of food security, health, cultural services and social cohesion [45].

Table 3 summarises the generic and specific challenges that NbS seek to address [41]. For each specific challenge, Table 3 lists the related ecosystem services that can help alleviate these challenges. The ecological processes and functions underpinning these services are described in detail in the Supplementary Material, along with examples of benefits. For instance, processes such as evapotranspiration and thermal insulation by vegetation contribute to reducing heat stress in surrounding areas [46] and can thereby contribute to meeting the climate change adaptation challenge.

Table 3
Generic and specific challenges with corresponding ecosystem services supported by ecological processes.

Generic challenges	Specific challenges	Ecosystem services
Climate change adaptation	Flooding: riverine, pluvial, coastal	River, coastal and pluvial flood regulation
	Heat stress	Thermal control and cooling
	Adaptation to storms	Mitigate wind speed and wave energy in coastal ecosystems
	Adaptation to droughts	Water storage, water infiltration and evapotranspiration
Climate change mitigation	Carbon and GHG emissions	Carbon sequestration in terrestrial and aquatic ecosystems
Natural hazards	Avalanches, landslides, earthquakes	Slope stabilisation
Environmental management	Air pollution	Air purification
	Water pollution	Water pollution reduction
	Water physical scarcity	Water storage and groundwater recharge
	Coastal erosion, soil erosion	Coastal erosion control
	Biodiversity loss	Improved habitat/ecosystem condition
	Noise pollution	Noise absorption, deflecting or refracting sound waves

Generic challenges	Specific challenges	Social-ecological relationships
Socio-economic challenges	Unemployment Inequality Health & well-being Social segregation Economic efficiency	Provisioning, regulating and cultural ecosystem services can be harnessed through policies and individual actions to alleviate socio-economic challenges e.g. by generating new jobs, reducing inequality, improving mental and physical well-being, empowering marginalised groups, providing affordable food, offer cost savings and reduced cooling demands as well as improving affordances to engage with and learn from nature.

2.4. Benefit categories of NbS

Following the cause-effect chain of the ecosystem service cascade framework developed by Potschin-Young et al. [47], ecosystem structures and processes generate functions (intermediate services), which provide ecosystem services (final services) that flow into benefits and are ultimately expressed as values for society. NbS – through the active protection, conservation, restoration and sustainable use and management of ecosystems [8] – help enhance the effects along the ecosystem service cascade. In this cascade, ecosystem services are the contributions of nature that are directly relevant to people (e.g. flood regulation, thermal cooling or food provisioning) while benefits are what people actually experience and use as a result of those services (e.g. protection from flood events, lower temperatures and food). The formulation of NbS benefits in Table 4 expresses the actual use and welfare obtained from the delivery of enhanced ecosystem services that are enabled through NbS interventions to address societal challenges described in Section 2.3. Market and non-market valuation approaches, analysed in Section 2.5, assess the value of benefits that ecosystem services deliver to people. The benefit categories consist of five generic groups of benefits, with each group containing specific benefits. The five generic benefit categories are: adaptation to climate change, mitigation of climate change, disaster risk reduction, improved environmental quality and socio-economic benefits. Benefit categories were discussed and validated iteratively with scientific partners and public authorities partaking in NbS projects across different landscapes in Europe. Our approach also involved consulting various relevant EC publications, EU reports, and scientific literature. Table 4 lays out the benefit categories for NbS actions.

2.4.1. Adaptation to climate change impacts

Adaptation to climate change impacts refers to the capacity to react and respond to the sharp variations and shifts in temperatures and weather patterns. The enhancement of this capacity through NbS actions gives rise to reducing local temperatures, hence mitigating heat stress and urban heat island effects [48]. Another example of an expected impact of climate change adaptation is an increased flood regulation at national (meso-level) or local (micro-level) scales [49]. This translates into benefits for different ecosystems, for instance, reduced flood risks in rivers, in wetlands and in coastal areas. Similarly, the creation of NbS for flood regulation can help to enhance urban and coastline resilience to climate change. The creation of NbS measures that enhance water infiltration, water retention and rainwater storage entail benefits resulting in a reduced depletion of freshwater resources and a reduced impact of both storms and droughts.

Table 4
Benefit categories of NbS.

Generic benefits	Specific benefits
Adaptation to climate change	Reduced flood risk and damages (rivers, wetlands, sea-level) Enhanced heat mitigation (incl. urban heat island reduction) Reduced risk of storms and storm surge damages Reduced incidents of droughts and water scarcity
Mitigation of climate change	Reduced impacts of climate change
Disaster risk reduction	Reduced damage from avalanches, landslides, earthquakes
Improved environmental quality	Reduced erosion damages Improved air quality Improved water quality Enhanced biodiversity & ecosystem stability Reduced noise pollution
Socio-economic benefits	Improved economic possibilities and jobs Reduced economic challenges Improved health and well-being Improved equality, integration, environmental justice, social inclusion, including improved security and reduced crime rates Increased awareness and education Reduced energy-related challenges, enhanced sustainable transport patterns

2.4.2. Mitigation of climate change

Mitigation of climate change entails the potential to reduce greenhouse gas emissions (GHG), carbon emissions in particular, through the implementation of NbS at different spatial scales. NbS actions for mitigation span from the micro-scale (e.g., a single building), the meso-scale (e.g., city) and the macro-scale (e.g., region, planet). Reducing GHG emissions or removing carbon from the atmosphere can be achieved with NbS actions enhancing carbon storage and sequestration and avoiding carbon loss. The specific benefits of these actions are multiple and ultimately result in a reduced impact of climate change: enhancing carbon sequestration in vegetation and soil [50], reducing the temperature at a mesoscale or a microscale [51], and improving air quality [52]. Additional specific benefits that overlap with other generic benefits can be heatwave risk reduction and increased energy savings from reduced energy consumption.

2.4.3. Disaster risk reduction

NbS can contribute to mitigate the effects of natural hazards by enhancing the presence of natural resources and by maintaining healthy and diverse ecosystems. Multiple benefits emerge from the reduced risk of natural hazards. These are very similar to the benefits of *adaptation to climate change*: reduced damage value of buildings and inventory, reduced damage on infrastructure, reduced damage value of habitats, reduced cleaning up costs after natural hazards, reduced costs of evacuation, reduced costs of temporary rehousing, reduced health risks, reduced agricultural crop loss, reduced potential loss of transportation time, reduced health risks, and reduced costs of permanent relocation of buildings and infrastructure. Furthermore, the benefits of reducing the likelihood of avalanches and landslides are mostly associated with those of reduced erosion by implementing NbS actions for slope stabilisation.

2.4.4. Improved environmental quality

This generic category comprises five specific categories: reduced erosion, improved air quality, improved water quality, enhanced biodiversity, and improved noise pollution. Efforts to reduce erosion, both coastal and terrestrial, are closely aligned with climate change adaptation and disaster risk reduction strategies. These measures slow surface runoff, preserve soil integrity, control pollutants and sediments, and maintain critical habitats, thereby enhancing biodiversity and reducing risks to infrastructure and agriculture [53,54].

Air quality improvements yield substantial public health and economic benefits. By reducing air pollution, NbS can decrease the prevalence of respiratory illnesses, lower mortality rates, and reduce healthcare expenditures. Additionally, improved air quality mitigates productivity losses due to illness, enhances microclimatic regulation, and supports ecosystem services such as biodiversity preservation, recreational opportunities, and cultural value [55].

Water quality enhancement similarly provides multifaceted advantages. Preventing water pollution is more cost-effective than restoration of degraded systems and helps avoid the removal of contaminants. High water quality fosters increased recreational and tourism use, boosts property values, enhances agricultural and fish productivity, and reduces medical and productivity-related costs. It also reinforces the aesthetic, cultural, and intrinsic values associated with clean water resources [56–58].

Biodiversity conservation underpins ecosystem stability and productivity. Maintaining diverse and resilient habitats strengthens ecological connectivity, supports functional group diversity, limits invasive species, and ensures the continued provision of ecosystem services. These services contribute to the stability of crop and timber yields and serve as a natural form of insurance for environmental and societal resilience [59].

Noise reduction contributes to both human and ecological well-being. Lower environmental noise levels are associated with decreased stress, fewer sleep disturbances, and reduced incidence of related diseases such as hypertension and ischemic heart conditions. For wildlife, noise mitigation prevents adverse physiological and behavioral impacts that can disrupt migration, reproduction, and survival [60].

2.4.5. Socio-economic benefits

The majority of NbS projects implemented across Europe yield attractive social returns on investment [61] and have the potential to maximize the benefits for provision of economic services [41]. We identify seven core specific benefits arising from NbS which generate social and economic value to people. The first core benefit lies in the expansion of economic possibilities and employment. By fostering the creation of green jobs and supporting green business models, NbS can reduce social vulnerability and stimulate inclusive economic growth. These approaches often integrate traditional and local knowledge, encouraging adaptive and innovative practices. Moreover, diversification strategies such as agroforestry and varied cropping systems can reduce dependency on single income sources and enhance economic resilience, particularly for rural communities [62,41].

In addition to promoting economic opportunities, NbS can alleviate broader economic challenges. They contribute to food security through enhanced local food production, reduce healthcare costs by improving public health, increase tourism opportunities, and strengthen natural capital. These interventions can also generate higher social returns on investment and potentially reduce insurance premiums by lowering environmental and health-related risks [41].

Another essential dimension of NbS is their contribution to health and well-being. The integration of natural elements into urban and rural settings has been linked to a range of positive health outcomes. Evidence shows that exposure to natural environments can reduce stress and depression, improve mental health, encourage physical activity, and decrease risks associated with cardiovascular diseases, obesity, and diabetes. Moreover, green infrastructure such as urban trees and vegetation can mitigate the effects of extreme heat, thereby reducing heat-related illnesses and mortality [63–70].

NbS also contribute to improved social equality, environmental justice, and community integration. These initiatives support fair access to green and blue spaces, facilitate social cohesion, and promote inclusive participation in environmental governance. They help address spatial and social disparities by ensuring that diverse and often marginalized groups benefit from environmental improvements. Research indicates that greening initiatives can enhance public safety by reducing crime rates and fostering a greater sense of community ownership and trust [71,41].

Furthermore, the implementation of NbS can lead to increased public awareness and educational engagement. As communities interact more with natural environments, their understanding and appreciation of ecological systems tend to deepen. This awareness fosters pro-environmental behaviours, encourages creative and sustainable lifestyles, enhances environmental education, and strengthens emotional and cultural connections to nature [41].

Finally, NbS can help address energy-related challenges. By promoting sustainable food consumption and energy-efficient living, these initiatives can reduce fuel poverty and lead to energy savings. The reduction in overall energy consumption contributes to more stable and potentially lower energy costs, aligning environmental goals with economic and social benefits [41].

2.5. Economic valuation methods and data

Capturing the multiple benefits of NbS particularly in monetary terms is crucial for informed decision-making in environmental management and policy formulation and could accelerate the widespread adoption of NbS as an alternative to grey infrastructure [29,30,28]. To this end, a holistic economic valuation approach within the Total Economic Valuation framework [72], encompassing both tangible and intangible benefits, is crucial. Although studies explicitly valuing the multifaceted benefits of NbS in economic terms are still limited, we can draw from a wealth of knowledge on ecosystem services valuation to address this gap. We first provide an overview of methods for valuing ecosystem services. Next, we investigate the application of these methods across landscapes, showcasing how they can be utilized in diverse contexts. Finally, we link these applications to the benefit categories of NbS identified, illustrating how a comprehensive valuation approach can capture the extensive and multifaceted benefits that NbS offer.

To compile an inventory of different economic valuation methods, we conducted a targeted literature review that thoroughly examined both peer-reviewed academic literature and grey literature sources. Key reports from EEA [4], Raymond et al. [41], Dumitru & Wendling [73], and van Zanten et al. [74] were included. As the method we adopted a snowballing strategy by forward and backward citation mining. The review shows that a diverse array of methodologies exists for evaluating the economic value of ecosystem services, as evidenced by numerous reports and studies [75–77]. Common primary valuation methods are market-based methods (MBM), cost-based methods (CBM), revealed preference methods (RPM) and stated preference methods (SPM). MBM, such as market prices and production functions, are suitable when existing markets for benefits being evaluated are available, while CBM (e.g., replacement costs, costs of alternative good, opportunity costs, recovery costs, damage costs, damage avoidance) are appropriate when direct markets are lacking, and benefits must be inferred from associated costs. RPM, such as hedonic pricing, travel cost analysis and random utility, indirectly quantify non-market benefits. They derive insights from observable consumer behaviour, such as price differentials or travel expenses, to infer the value placed on ecosystem services. SPM are predominantly used for intangible benefits without corresponding markets. There are several variations of SPM, but the most common approaches are contingent valuation, involving respondents indicating their willingness to pay for a proposed option, while choice experiment methods prompt respondents to express preferences among options with multiple attributes.

All the different economic valuation methods can provide primary data for specific NbS implementation. In practice, however, many project developers opt for secondary valuation methods, such as value transfer, when time, resources or capacities for conducting primary valuation are lacking. Value transfers mean transferring pre-existing primary research from one location and time to other sites of policy significance [78].

To explore the relationship between ecosystem services, NbS benefit categories and primary valuation methods, we draw evidence and insights from the Ecosystem Service Valuation Database (ESVD). This database, developed and hosted by the Foundation for Sustainable Development and Brander Environmental Economics, provides detailed information and standardised monetary values for various ecosystem types, services, locations, valuation methods, and beneficiaries [79]. The database was primarily used to indicate the relationship between economic valuation methods, ecosystem services and NbS benefits, summarising 1241 valuation studies of ecosystem services mapped to NbS benefits. Within these studies, different methods were used 2693 times to evaluate different ecosystem services. For the mapping of methods, we assigned the ecosystem subservices from the ESVD to the developed typology of benefits of NbS. Additionally, available meta-studies were used to validate the mapping of methods.

3. Results

3.1. Valuing ecosystem services across landscapes

Fig. 2 provides a visual representation of the percentage distribution of applied methods (1a) as well as analysed ecosystem services (1b) in studies per landscape. Fig. 3 illustrates the distribution of ecosystem subservices analysed in studies across different method clusters within each landscape. Ecosystem subservices are clustered by the ecosystem service categories Provisioning, Regulating and Maintenance, and Cultural, as defined by CICES V5.1 [80]. Fig. 3 illustrates the four most prevalent subservices identified within each ecosystem service in the ESVD. Additional subservices are consolidated under the label "Other", providing a comprehensive view of the diverse components contributing to ecosystem service assessments. For mountain areas there is a lack of data within the database, indicating a gap in our understanding of NbS valuation in these environments.

3.1.1. Coastal wetlands & marine waters

As shown in Fig. 2, none of the methods were applied in >50 % of the studies in relation to coastal wetlands and marine waters. The most frequently used methods are MBM, utilised in approximately 41 % of cases, and the SPM, employed in around 38 % of cases. A significant proportion of coastal studies with 44 % focus on cultural, 32 % on provisioning and 25 % on regulating and maintenance ecosystem services. Fig. 3 illustrates that MBM are predominantly used to study provisioning ecosystem services where provisioning of food and raw materials account for about 50 % of cases. CBM are employed to investigate ecosystem services for regulating and maintenance, whereby the different ecosystem services are equally represented. RPM and SPM are the preferred tools for analysing cultural ecosystem services, with opportunities for recreation and tourism being the most relevant.

The literature reflects a similar preference for methodological approaches in evaluating coastal and marine ecosystem services. Lopez-Rivas and Cardenas [81] conducted a systematic literature review and meta-analysis of 67 studies to assess the economic value of coastal and marine ecosystem services, with predominant methods including value transfer as secondary method, market values (MBM), and contingent valuation (SPM). Ecosystem services such as recreation, tourism, and fishing were the most valued. Similarly, the review by Himes-Cornell et al. [82] on valuing ecosystem services from blue forests highlights the predominant use of value transfer and market price methods in valuation studies. Their analysis reveals a disparity in the valuation of different ecosystem services, with certain services like food, opportunities for recreation and tourism, raw materials, moderation of extreme events, and climate regulation receiving considerably more attention than others within blue carbon ecosystems. Additionally, it underscores the significance of blue forest ecosystems in providing critical services like pollination, ornamental resources, and inspiration for culture/art/design, which are often undervalued in traditional market-based assessments.

3.1.2. Inland waters & inland wetlands

Approximately half of the ESVD studies in relation to inland waters and wetlands employed SPM and 35 % utilising MBM. Provisioning and cultural services take a slightly higher share in analysed ecosystem services. MBM serve in the evaluation of provisioning services, contributing to nearly 70 % of cases. If a CBM is used is this mainly for evaluating climate regulation, moderation of extreme events and other regulating services. RPM and SPM are mainly for analysing opportunities for recreation and tourism but also for inspiration for culture, art and design as cultural ecosystem service.

Reynaud and Lanzanova [83] conducted a meta-analysis on the economic valuation of ecosystem services provided by lakes, analysing 699 values from 133 studies, predominantly utilising hedonic price (RPM) and contingent valuation (SPM) methods. They assessed a wide range of ecosystem services, including water provisioning, recreational opportunities, biodiversity support, and cultural values associated with lakes. The study delves into the intricate relationships between these ecosystem services, identifying both synergies and antagonisms among them.

3.1.3. Forest areas

For forest areas, the ESVD shows that MBM (35 %), CBM (29 %), SPM (30 %) are used in comparable quantities, whereas RPM (7 %) are not used frequently. Also cultural, provisioning and regulating and maintenance are equally represented. MBM were most used (approximately 80 %) in assessing provisioning services, particularly focusing on raw material and food. In contrast, CBM were primarily used for regulating services, where climate regulation and erosion prevention are dominant.

Binder et al. [84] conducted a review on the economic valuation of forest ecosystem services, primarily utilising integrated ecological and economic models. The study assessed various ecosystem services provided by forests, including timber production, carbon storage, water regulation, flood control, coldwater fishing, clean drinking water, safe navigation, aesthetic amenity, recreation, wildlife, and protection of rare and endangered species.

3.1.4. Agricultural areas

In the realm of agriculture there is a predominant utilisation of SPM as well as MPM within the ESVD, accounting for approximately 53 % and 32 % of all analysed services, respectively. The agriculture studies primarily focus on evaluating cultural and provisioning ecosystem services, each representing around 40 % of all studies. Approximately in 60 % of their use MBM are applied to assess provisioning services, mainly raw materials and food, while about 20 % target provisioning and another 20 % target cultural ecosystem services. Conversely, among studies utilising SPM, approximately 60 % are dedicated to evaluating

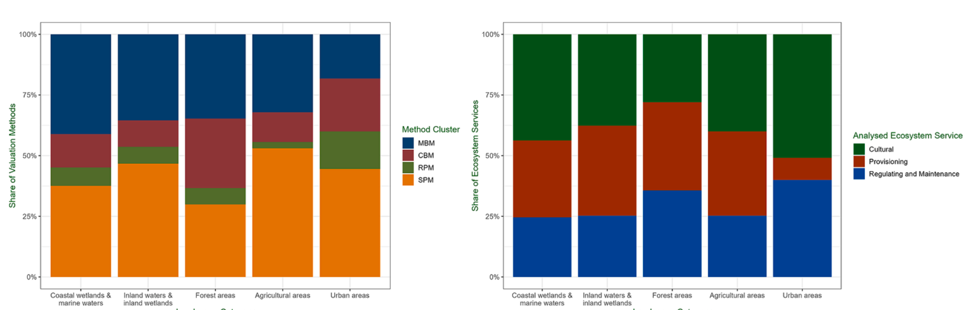

Fig. 2. Percentage of applied methods in studies per landscape category (1a) and analysed ecosystem services in studies per landscape category (1b). (n = 2693). Landscape Category: Coastal wetlands & marine waters (n = 1615), Inland waters & inland wetlands (n = 542), Forest areas (n = 311), Agricultural areas (n = 115), Urban areas (n = 110). Method Cluster: MBM=Market-based method (n = 1021), CBM=cost-based method (n = 408), RPM=revealed preference method (n = 202), SPM=stated preference method (n = 1062).

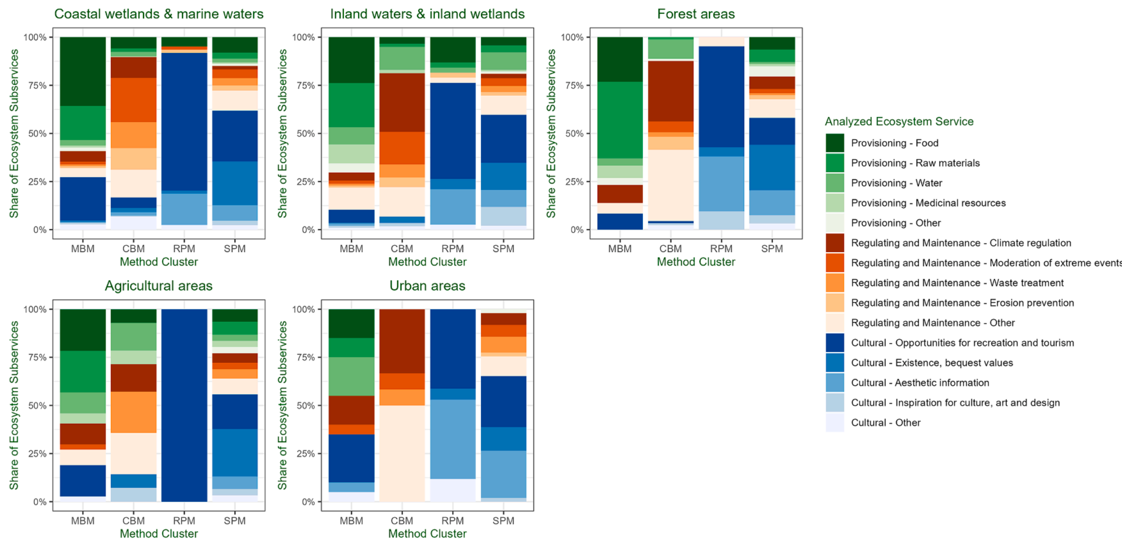

Fig. 3. Percentage of ecosystem subservice in studies per method cluster for each landscape category (n = 2693). Method Cluster: MBM=Market-based method (n = 1021), CBM=cost-based method (n = 408), RPM=revealed preference method (n = 202), SPM=stated preference method (n = 1062).

cultural services, with regulating services and provisioning services each representing about 20 %, respectively.

Comparatively, Jónsson and Davíðsdóttir [85] underscore the dominant use of conventional economic methodologies, such as market price (MBM) and replacement cost (CBM), for valuing soil ecosystem services in agricultural contexts. Their analysis reveals a significant emphasis on evaluating regulating functions like nutrient cycling; yet cultural services receive notably limited attention. This disparity in focus reflects a critical gap in understanding the comprehensive value of soil ecosystems.

3.1.5. Urban areas

As shown in Fig. 2, within urban areas SPM and RPM are most important, accounting for about 60 % of cases in the ESVD, followed by CBM with 22 %. In comparison to other landscape categories MBM are used less often. In terms of ecosystem services, more than half of the urban cases, assessed cultural services, while regulating services are addressed in approximately one-third of cases. Provisioning services only are investigated in 9 % of all cases. However, urban areas with 110 cases are not very well represented in the ESVD, therefore the results are limited.

However, contrasting the ESVD findings the literature review conducted by Croci et al. [86] gives a prevalent use of CBM for urban areas, which was used in about 50 % of analysed studies, followed by SPM, RPM and MBM. Commonly assessed ecosystem services include air quality regulation, local climate regulation, carbon sequestration and storage, and aesthetic appreciation, showcasing a distinct emphasis on cultural and regulating services compared to other landscapes.

3.1.6. Mountain areas

As only six cases from the ESVD could be attributed to mountain areas, no information on predominantly used methods could be extracted from the database. However, Mengist et al. [87] conducted a systematic literature review on ecosystem services in mountain areas, focusing on their quantification using economic methods, biophysical models, GIS-based models, empirical approaches, and integrated modelling frameworks. While the study does not address which economic methods are most appropriate for valuing ecosystem services, it covers a wide range of services, which includes climate regulation, food and fodder, freshwater, recreation and ecotourism, and erosion regulation, with regulating and provisioning services strongly represented. Gaps identified include methodological uncertainties, a lack of data and insufficient studies on the interactions between different ecosystem services.

3.2. Valuing NbS benefit categories

To analyse the link between the benefit categories of NbS and the economic valuation methods, the ecosystem services of the ESVD were matched to the benefit categories of NbS. Ecosystem services encompass the diverse benefits provided by nature to humans, including food provisioning, air quality regulation, and opportunities for recreation [42], while NbS are specific interventions leveraging natural processes or ecosystem services to address societal challenges, such as reducing flood risk, enhancing biodiversity, and improving health and well-being.

Fig. 4 depicts the share of valuation methods applied in the existing literature to assess the generic benefit categories. The first two categories, climate change adaptation and mitigation, provide a similar distribution. About 50 % are CBM, while a quarter each are MBM and SPM methods. For studies in which benefits in the disaster risk reduction category were recorded CBM are even more important. For the benefits of improved environmental quality and socio-economic benefits, SPM and RPM were used more frequently, at together 64 % and 49 % respectively, and market-based methods at 24 % and 40 %.

Fig. 5 illustrates the share of applied valuation method that has been used to address every specific benefit category. It indicates that benefits related to reduced energy and mobility challenges are almost exclusively evaluated using MBM. Improved air quality was primarily assessed using CBM. In addition, CBM was predominantly used, around 50 % of all methods, for the benefits reduced flood risk, alleviation of storm impacts, reduced impact of climate change, improved noise pollution, heat mitigation, reduced damage from avalanches, landslides and earthquakes, reduced erosion, improved air quality and reduced economic challenges. Conversely, RPM and SPM are used for assessing enhanced biodiversity, improved health and well-being and increased awareness and education.

4. Discussion and conclusions

This paper provides a guiding framework for valuing the multiple benefits of Nature-based Solutions. We present a refined typology of NbS based on how landscapes present societal challenges that are often closely linked to the characteristics of landscapes. This approach is consistent with Nehren et al. [18] who present a typology addressing the

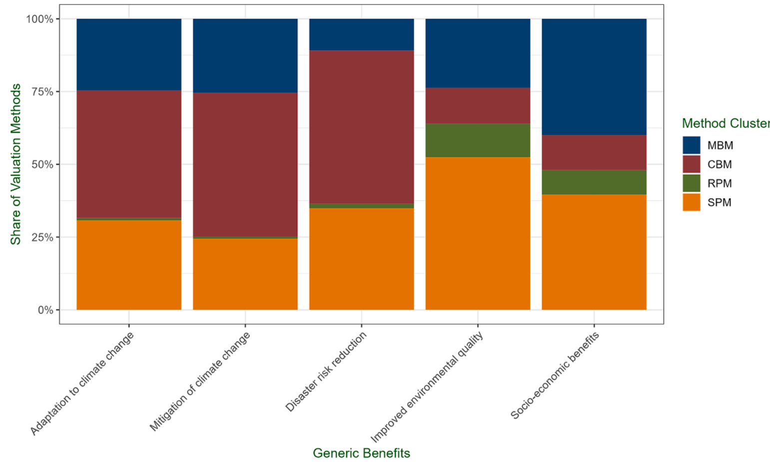

Fig. 4. Percentage of applied methods in studies per generic benefit. ($n = 2693$). Method Cluster: MBM=Market-based method ($n = 1021$), CBM=cost-based method ($n = 408$), RPM=revealed preference method ($n = 202$), SPM=stated preference method ($n = 1062$).

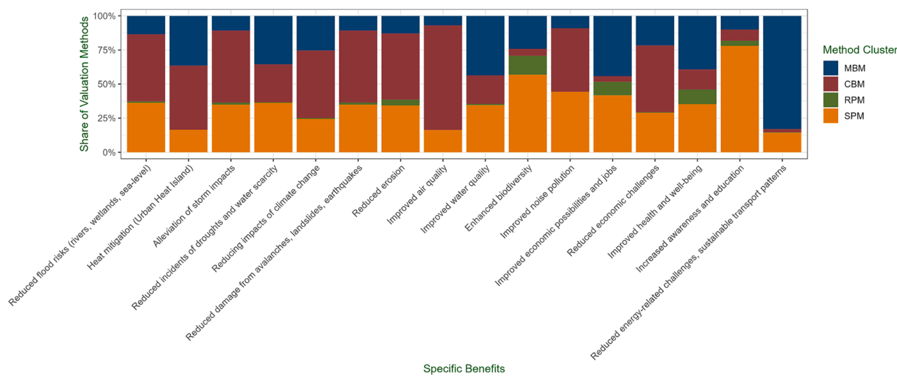

Fig. 5. Percentage of applied methods in studies per specific benefit. ($n = 2693$). Method Cluster: MBM=Market-based method ($n = 1021$), CBM=cost-based method ($n = 408$), RPM=revealed preference method ($n = 202$), SPM=stated preference method ($n = 1062$).

specific societal challenge of disaster risk reduction. One approach of their typology is based on five main landscape units with related natural hazards (i.e., high mountains, coastal areas, rivers/wetlands, drylands and volcanic) which can be subjected to different interventions depending on a rural-urban gradient (i.e., forests, agriculture, and urban areas). Our refined typology encompasses five generic societal challenges (i.e., climate change adaptation, climate change mitigation, natural hazards, environmental management and socio-economic), which ultimately lead to specific NbS actions yielding multiple benefits that can be grouped into benefit categories of NbS. This can be compared to the study of Anderson and Gough [15] where a typology is developed through the objective systemization of NbS applications, functions, and benefits, to ultimately address societal challenges connected to the United Nations Sustainable Development Goals.

We provide insights into the diverse economic methodologies employed to assess NbS benefits by drawing on the existing body of evidence from the economic valuation of ecosystem services. Common primary valuation methods include market-based methods (MBM), cost-based methods (CBM), revealed preference methods, and stated preference methods (SPM). Across different landscapes, we observe varying patterns in the application of economic methods to value ecosystem services. In coastal wetlands & marine waters, where cultural ecosystem services are prominent, both SPM and MBM are often used to capture the cultural values associated with these environments. Conversely, data availability is limited for mountain areas, resulting in a gap in valuation despite the importance of mountainous landscapes across the world. Assessments for agricultural areas predominantly utilise MBM and SPM, focusing on provisioning and cultural services. Assessments of forest areas commonly employ MBM for provisioning services and SPM for cultural services. Inland waters & inland wetlands assessments employ both MBM and SPM, reflecting the diverse range of ecosystem services involved, including provisioning, regulating, and cultural services. In urban areas, where cultural services are emphasised, SPM is predominantly used, while CBM are favoured for assessing regulating services.

On the valuation of NbS benefits, distinct trends emerge. Climate change adaptation and mitigation primarily rely on CBM due to the quantifiable nature of these benefits, while disaster risk reduction sees a mix of CBM and SPM to capture both tangible and intangible impacts. Improved environmental quality and socio-economic benefits are more frequently evaluated using SPM, reflecting the complex nature of these benefits and the need for direct stakeholder inputs. Our findings underscore the importance of selecting appropriate valuation methods tailored to specific landscape contexts and NbS benefits. Moreover, it highlights the necessity for practitioners to understand which methods value what type of benefits, serving as crucial background knowledge for carrying out the valuation, for example a value transfer.

Croci et al. [86] investigated different economic valuation methods to quantify ecosystem services from urban NbS in 25 papers and find most studies applied replacement cost and avoided damage cost followed by stated preference methods, revealed preference methods and finally market-based methods. Despite the difference in terms of the distribution of valuation methodologies between the review by Croci et al., [86] and this study, which encompass 222 urban papers, both studies find a lack of holistic assessment of NbS benefits across provisioning, regulating and cultural services.

While progress has been made in valuing ecosystem services, there remains a notable gap in NbS benefits valuation due to the absence of a comprehensive typology. This study serves as an initial attempt to bridge this gap, laying the groundwork for future research aimed at fully capturing the value of the multiple benefits of NbS in environmental decision-making processes. Consequently, it is essential to acknowledge both the number and magnitude of synergies and trade-offs to accurately assess the financial and economic performance of NbS. On the other hand, incorporating synergies presents a promising direction for future research, as they represent the added value generated through the enhancement of multiple NbS benefits. There remains an ongoing imperative to enhance and delineate the boundaries within the terminology and application of NbS. In some cases, distinguishing precisely between the three NbS types can be challenging, primarily due to the nuanced and overlapping nature of interventions that hardly fit into a single category. This complexity arises because these actions may span multiple NbS types, and determining the appropriate type based on the extent, scale, and expected outcomes of the intervention can be challenging. Furthermore, combined NbS may encompass or extend into multiple landscapes, impacting several geographical areas simultaneously. Consequently, the implementation of such NbS actions must consider the scale and scope of these interventions, recognizing their potential to influence and traverse various landscapes.

While extending the analysis beyond the European context could offer valuable insights into the global applicability of nature-based solutions (NbS), this study is intentionally focused on six specific European landscapes. Rather than a limitation, this targeted scope is a methodological strength enabling a detailed, context-sensitive analysis and the development of a clear, replicable framework. We propose that this framework can serve as a foundation for future research exploring the implementation of NbS in diverse global contexts.

Impacts and implications

The present paper addresses the three societal challenges: environmental, economic and social across six different European landscapes: Coastal wetlands & marine waters, Inland waters & inland wetlands, Forest areas, Agricultural areas, Urban areas, and Mountain areas. Based on the three societal challenges, we characterize NbS typologies and NbS benefit categories across those six landscapes. This characterization enables the linking of NbS benefits to various economic valuation methods discussed in the literature. The paper provides valuable insights on the multiple benefits crucial for well-informed resource allocation and financing decisions of policymakers. While primarily serving as a guiding framework, it also offers information to a wider audience, including practitioners seeking a deeper understanding of NbS typologies, NbS-related benefits, the different assessment methods, and their economic implications.

- Environmental challenges: our formulation across the six landscapes yields generic NbS benefit categories associated with adaptation to climate change, mitigation of climate change, disaster risk reduction, and environmental quality improvement. We also elaborate on the underpinning ecological processes that deliver the NbS benefits, addressing generic and specific environmental challenges.
- Social challenges: By addressing social challenges, we identify that NbS can deliver benefits related to improved health, improved equality, integration, environmental justice, and social inclusion (including improved security and reduced crime), and increased awareness and education. Social benefits are widely addressed using stated preference methods, underscoring the importance of taking into account perceptions of local populations.
- Economic challenges: Addressing economic challenges can offer benefits associated with improved sustainable food consumption, reduced fuel poverty, increased energy savings due to reduced energy consumption and hence potentially reduced energy prices. The surveyed literature indicate that market-based methods are normally used to quantify NbS benefits arising from tackling economic challenges.

CRediT authorship contribution statement

Julian Eduardo Lozano: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Doan Nainggolan:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Viktoria Kofler:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Michael Kernitzkyi:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Andrea Staccione:** Writing – original draft, Investigation, Conceptualization. **Chiara Bidoli:** Writing – original draft, Investigation, Conceptualization. **Jaroslav Mysiak:** Writing – review & editing, Supervision, Conceptualization. **Marianne Zandersen:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nbsj.2025.100268.

Data availability

Data will be made available on request.

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