NATURANCE

Nature for insurance, insurance for nature

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Executive Summary

Nature-based solutions can play a significant role in mitigating the impact of extreme events, which are more frequent and severe due to climate change. However, there is still a lack of understanding of the actual benefits of nature-based solutions, regarding both their risk-reduction potential and the co-benefits they provide simultaneously. This deliverable presents a comprehensive literature review of methods for assessing and valuing the risk-reduction benefits and the co-benefits of nature-based solutions.

The first section of the deliverable introduces the importance of investing in climate change adaptation and discusses the concept of nature-based solutions for risk reduction. Then, the main methods for quantifying risk-reduction (e.g. catastrophe modelling) due to nature-based solutions are presented and their main limitations are highlighted. The second half of the deliverable focuses on the available methods to assess the co-benefits of nature-based solutions.

This deliverable shows that a standardised methodology to assess NBS co-benefits is still lacking. There has been a significant increase in the quantity of academic articles focusing on assessing the benefits of nature-based solutions in recent years. All benefits that nature-based solutions provide should be taken into account to make appropriate investment decisions, both for the public and private sectors. Similarly, identifying who the beneficiaries are for each benefit is also crucial to design financing schemes. Furthermore, the analysis showcased the context-specific nature of nature-based solutions and the lack of applicability of results outside of the context where the study was conducted. Small-scale sites were the most prominent in the literature, especially focusing on riverine, urban, and forest ecosystems in the global north, particularly Europe and North America. Overall, NBS have proven effective in mitigating climate risks, although some uncertainties remain. They offer valuable co-benefits that benefit a diverse set of stakeholders. Co-benefits can vary by type of NBS, but cultural services (recreation, tourism, aesthetic value), biodiversity enhancement and carbon sequestration are the most common in the literature.

To sum up, this review suggests that the main limitations of assessing the benefits of nature-based solutions such as the lack of a standardised methodology and comparability of results, the complexity of assessing the time-frame of the benefits provided and the lack of understanding of future climate-risk trends are still hindering the upscaling of nature-based solution investments.

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1. Introduction: background and objectives

The urgent need of a transformative change for climate change mitigation and adaptation is declared at the European and international level. A transition towards a more sustainable interaction between nature and society to support human, ecosystems, and planetary health is fundamental to develop climate resilience (IPCC, 2022). To this end, nature-based solutions (NBS), nature restoration and conservation are considered crucial in achieving this transformation. NBS have a multi-functional nature. They are defined as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient and systemic interventions"[1]. NBS can play a significant role in mitigating the impacts of disasters, such as floods, drought and wildfires, exacerbated by climate change with increasing costs for society. They may mitigate natural hazards by mediating flow and nuisances, or through maintenance of stable physical, chemical, and biological conditions. For example, wetlands and floodplains can act as NBS in buffering against floods, well-managed forests in reducing the risk of landslides, and green urban areas in mitigating high temperatures (EEA, 2021).

Insurance and reinsurance companies will mostly experience indirect nature-related risks. Insured goods or activities may suffer nature-related damage, so insurers could face a higher number of claims. This could also lead to an increase in premiums (EIOPA, 2023). NBS can contribute to reducing the costs of disasters and prevent climate change impacts to society. For example, property and business disruption insurance could be negatively impacted by natural catastrophe losses where NBS are absent. This risk reduction potential can, for instance, be relevant for insurance companies to engage in NBS creation. If NBS lowers flood risk then this may trigger lower insurance claims and limit premiums in countries where flood risks are covered by insurance (EIOPA, 2023). Alternatively, in countries without flood insurance coverage, NBS creation that limits flood risk may foster the insurability of the risk and enable the introduction of new flood insurance products. Traditionally, the impact of disasters has been assessed with tools such as catastrophe modelling. Nevertheless, climate change is increasing the difficulty of predicting the probability of an event occurring, as well as its intensity. Moreover, NBS offer a wide range of benefits, such as recreational spaces, increase social cohesion, and promote educational and physical activities, benefiting human health and wellbeing. They also contribute to sustainable economic growth by creating jobs, supporting innovation, and promoting efficient resource use. These additional benefits are generally considered as co-benefits.

Co-benefits can be defined as "the goals of a natural hazard adaptation project that are additional to the project's primary function, but complementary to its objective of increasing community

[1] https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en

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resilience" (Jones and Doberstein, 2022). Assessing the value of these co-benefits and their distribution among various parties is challenging. They are often overlooked in studies and not always considered in NBS project design, implementation, or assessment, which may lead to underinvestment in NBS and distort the actual environmental, social, and economic impacts and value they provide (Jones and Doberstein, 2022). Incomplete knowledge of the various benefits is a significant barrier in the adoption of NBS. Obtaining a thorough understanding of both risk-reduction benefits and the co-benefits, and associated beneficiaries, will help to assess their cost-effectiveness and support a better comparison with traditional engineered solutions. In this way, the public sector and (re)insurance companies assess their investment options in order to reduce losses from natural catastrophes, which could potentially reduce the damage to insured assets as well as provide several co-benefits to the local community.

The Naturance project focuses on nature-based insurance and investments, which can play an important role for mainstreaming NBS implementation tackling the financial needs to meet climate change, biodiversity and land degradation targets (UNEP, 2021). In this framework, we aim to investigate the available methods to assess the potential for disaster risk reduction and co-benefits of NBS, in order to identify challenges and opportunities for their usability in the wider context of nature-based insurance and investments. Therefore, this work discusses first the models developed to assess disaster risk reduction and the main gaps and limitations identified in the literature (Section 2). Introducing the potential of NBS for disaster risk reduction and their implications for insurance, we focus on catastrophe models, being widely used in the insurance sectors. We discuss their use, development, gaps and opportunities. Secondly, the study investigates the methods used to assess NBS co-benefits beyond disaster risk reduction (Section 3). We perform two parallel systematic literature reviews to i) provide an overview of the methods used to assess environmental, social and economic co-benefits of NBS investigating their potential usability in a wider context; and ii) to deepen on the assessment of economic benefits on NBS through a meta-analysis. By assessing the current state of assessment methods, we aim to facilitate the integration of NBS into the insurance and private finance sector, alongside public sector investment. This review will help increase understanding of the risk-reduction benefits and co-benefits of NBS and how they can be valued. This will facilitate a better overview of the benefits and allow for a detailed identification of the stakeholders involved, which will facilitate the creation of financing schemes (public, private, and private-public schemes) that take all the benefits and beneficiaries into consideration. Discussion of key messages and findings is reported in section 4.

2. Focus on Nature-based solutions and Disaster Risk Reduction

Economic losses from climate-related disasters, as floods, droughts and wildfires, have increased considerably in the last decades. As estimated by a World Bank Report in 2015, economic losses from adverse weather events are in the $150 - $200 billion range annually (Tanner et al., 2015). In

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this context, NBS can be seen as preventive measures capable of reducing climate change risks, often able to address multiple hazards and simultaneously providing co-benefits to the social-ecological system. Prevention and mitigation of impacts of climate related extreme events through NBS can be more cost-effective than post-disaster compensation, reducing the overall societal costs of disasters (Costa et al., 2020). However, knowledge gaps and uncertainties regarding the risk-reduction potential of NBS, as well as other benefits, may discourage insurers and other stakeholders from investing in them. In particular, a more in-depth understanding of the cost-effectiveness of NBS compared to traditional solutions, such as dams or seawalls, is needed (Seddon et al., 2020). In order to do this accurately, the potential of risk reduction of NBS should be precisely estimated, as well as the monetization of these benefits. The economic value of risk-reduction benefits and co-benefits is crucial as it allows decision-makers to compare the economic value of NBS against other traditional engineered solutions. This helps in making informed investment choices, for both the public and private sector. As found in a recent meta-analysis, there is a high degree of confidence regarding the role of ecosystems in reducing disaster risk, with 71% of papers indicating that NBS have consistently proven to be a cost-effective option to mitigating natural hazards (Sudmeier-Rieux et al., 2021). 24% of studies showed that NBS are only cost-effective in certain conditions, depending on the type of NBS and type of hazard. There is consensus that further research is needed on the effectiveness of NBS on hazard reduction (Marchal et al., 2023; Sudmeier-Rieux et al., 2021; Shah et al., 2020).

2.1 Insurance, nature-based solutions and disaster risk reduction

In a wider strategy to respond to climate change, the protective value of NBS can be understood as an insurance value to assess the capability of ecosystems to buffer shocks that is potentially translated into premiums reduction for avoided damage and co-benefits (Costa et al., 2020). In other words, the insurance value can be viewed as the costs that a healthy ecosystem might avoid when a disruptive climate related event happens. Swiss-Re estimates that out of the USD 190 billion-worth of economic losses due to natural catastrophes in 2020, the insurance industry covered up to USD 81 billion. This would account for the fifth-highest amount in the last half-century and almost three-quarters of that amount was due to smaller-scale events (SwissRe, 2021).

The (re)insurance industry raised the interest for NBS, especially in relation to their capacity to buffer intensity of climatic multi-hazards, frequent and small events, such as heavy rainfall events and heatwaves in urban environments (Lallemant et al., 2021; Sudmeier-Rieux et al., 2021). In this context, it is increasing knowledge and promotion of preventive measure assessments through climate change risk models, exposed assets tracking, early warning information, and hazard behaviour analysis. A survey about NBS conducted in the European reinsurance sector, addressing both reinsurance firms and related sectors, such as banks and project developers, academic

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institutions, and policy-makers, reported how the (re)insurance industry is gradually innovating by having a better understanding of hazards and mitigation (Marchal et al., 2019). Generally, results still showed a lack of specific strategies to incorporate NBS in their catastrophe loss risk models (67% of respondents). Despite the survey being already four years old, which is significant in a rapidly-evolving field such as NBS, the insurance and reinsurance sector expressed the need for higher exchanges with the scientific community in order to obtain the knowledge and tools to integrate NBS into catastrophe models (37% of respondents). 41% considered that the lack of primary studies and data was the main limitation they were currently facing.

This is particularly true in the assessment of risks in the long term, where NBS are expected to have better performance (Gómez Martín et al., 2020). This means that the effectiveness of NBS on risk reduction and consequently on damage reduction will be visible within the insurance premiums pricing in a long-term perspective. Additionally, insurance models tend to underestimate the escalation of climate change impacts and do not consider future climate change, being mostly based on past events and a backwards-looking approach (Wagner, 2022). A more dynamic assessment of risk distributions could help the (re)insurance industry to support the creation of NBS-supportive insurance schemes, which would contribute to maintaining affordable insurance due to the implementation of protective measures (Gómez Martín et al., 2020). In the future, and in order to mainstream NBS investments, systematic examination of NBS by using catastrophe modelling should become a new standard practice (Marchal et al., 2023).

2.2 Catastrophe models

Insurance and reinsurance companies utilise catastrophe models to evaluate the potential risk of natural hazards and estimate their economic impact. These models are designed to anticipate the likelihood and severity of future catastrophes, enabling companies to prepare for their financial consequences (Toumi and Restell, 2014). An average annual loss can be calculated on an occurrence (e.g. the largest event in a given year) or aggregate (all events in a given year) basis and represents the loss amount averaged across all years in the event set (NAIC, 2023). Catastrophe models play a vital role for insurance companies in terms of risk selection, underwriting, risk transfer mechanisms, portfolio optimization, pricing, reinsurance decision-making, and capital allocation. According to Marchal et al., (2019), "all surveyed reinsurance companies had their own catastrophe models, on the contrary, most of the insurance companies were using models developed by private consulting companies". Additionally, there are some open-source catastrophe model platforms, such as the OASIS Loss Modelling Framework[2]. The OASIS platform allows (re)insurance companies and academics a platform to run catastrophe models, as well as a toolkit for developing, testing and deploying catastrophe models. This can potentially help to connect the academic and insurance modelling environments.

[2] https://oasislmf.org/

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Catastrophe models typically consist of four modules:

1. **Event:** Each event is defined by specific strength or size, location or path, and the probability of occurrence or event rate. The expected frequency and intensity of hazards are estimated in this phase.
2. **Hazard:** This module assesses the level of physical hazard across a geographical area at risk. Data regarding the built environment must be included for the event location.
3. **Vulnerability:** The vulnerability module evaluates the likelihood of damage to structures, their contents, and other insured properties caused by the hazard. Damage functions are equations used to represent vulnerability and compute the amount of damage estimated based on construction and occupancy characteristics of the property at risk (NAIC, 2023). Incorporating the impact of nature-based solutions can potentially reduce vulnerability to natural hazards, which has a significant impact on the economic consequences.
4. **Financial Analysis:** The financial module translates the expected physical damage into monetary loss, identifying the parties responsible for payment. This can be integrated into a cost-benefit analysis to inform policy-making and private sector investments.

Due to the increasing frequency and intensity of climate-related disasters, it is key that (re)insurance companies keep their catastrophe models up to date, using the most innovative and comprehensive approaches. Risk modelling and adequate insurance premiums are a crucial part of helping businesses and societies understand the impact of their actions and the choices they face to cope with climate and natural hazard risks. Fully understanding the strengths and weaknesses will be an important part of investments in climate risk mitigation, both for the private and the public sector. Lastly, the lack of consideration for the risk-reduction potential of NBS in traditional catastrophe modelling is crucial and will be discussed in the next section (Marchal et al., 2019).

2.3 Recent developments in climate risk assessment methods

In the past years, academic studies have focused on assessing the effectiveness of NBS against different disaster risks. Some review papers have attempted to synthesise the recent developments in risk modelling, both from the physical side and the economic impacts:

- **Dorren and Moos (2022**) assessed the methods to evaluate the benefits of Eco-DRR (ecosystem-based disaster risk reduction) in mountainous ecosystems. The review focused on gravitational hazards, such as landslides and avalanches. The authors argue that, based on the empirical hazard models reviewed, there is still a lack of understanding of the temporal variations and uncertainties, which makes it difficult to assess the costs and benefits of NBS in the medium and long term through a cost-benefit analysis.

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- **Shah et al. (2020)** produced a comprehensive review of frameworks and assessment methods for hydro-meteorological hazards, vulnerability, and risk in the context of NBS. They found that the predominant approach was index or indicator-based assessments or scoring systems. The authors argue that indicator libraries "allow the user to have readily available indicators that can be used for specific contexts (e.g., geography/hazard combinations) or that can be used interchangeably when, for example, data do not exist for one indicator". Their proposed framework, a library with 135 indicators, integrates social and ecological elements to assess vulnerability and risks in NBS project sites. It considers exposure, vulnerability, and coping capacities of the social-ecological systems. Examples of indicators are the proportion of businesses exposed to hazards in the site or the existence of previous adaptation policies/strategies.
- **Sudmeier-Rieux et al. (2021)** conducted a systematic review regarding the economic benefits of ecosystem-based DDR. The results per type of hazard were categorised based on the robustness of findings and level of agreement. 71% of studies indicated that NBS have consistently proven to be a cost-effective approach to mitigating hazards. NBS were found to be more effective for low-intensity and frequent climate events, as has also been argued in previous studies (Karanja and Saito, 2018; Beck et al., 2018). The methods for NBS co-benefits assessment are predominantly quantitative, relying on empirical/field-based measurements, modelling/simulations, and reviews/meta-analyses.
- **Kumar et al. (2021)** conducted an evidence review, focusing on the impact of NBS on five types of hazards: flooding, droughts, heatwaves, landslides, storm surges and coastal erosion. The authors highlight that the main gaps are the lack of recognised standard methodologies that can help to upscale the investments in NBS. They argue that, after reviewing several numerical models (WRF, ADCIRC, MIKE-SHE, etc.), "the performance and cost-effectiveness of NBS for hydro-meteorological risks reduction and management are not readily available". Similar to other review papers, the majority of the assessed NBS are related to flood risk reduction. Cost-benefit analysis studies comparing NBS against grey solutions for risk-reduction are still scarce.

Only by accurately assessing the economic benefits and costs, NBS can be properly assessed and compared to traditional engineered solutions. From a risk-reduction perspective, NBS decrease vulnerability to certain hazards, reducing the annual expected losses in catastrophe models that integrate NBS. This information can be used in cost-benefit analyses that assess different scenarios to estimate the economic value of NBS over time (Karanja and Saito, 2018; Dorren and Moos, 2022). There are still several challenges, such as estimating the future benefits of NBS considering increasing risks and uncertainty due to climate change or developing a holistic approach that captures all the benefits of NBS. The main caveat of using traditional cost-benefit analysis is the lack

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of an integrated assessment that considers co-benefits (Chausson et al., 2020). Moreover, current methods fail to monitor the economic performance of NBS considering all benefits, co-benefits and potential disbenefits (Kumar et al., 2021). This results from a lack of holistic models that integrate functions, benefits and costs of NBS. More recent papers have attempted to incorporate a more holistic approach (Chabba et al., 2022), by combining non-market valuation techniques with a probabilistic model for risk reduction.

2.4 Main limitations and research gaps

Improving our understanding of climate change trends and the impact of NBS on risk reduction will be critical to improving catastrophe models for the insurance sector. While catastrophe models implicitly consider climate change trends based on historical data, uncertainties associated with the estimation of future frequency and severity of extreme events still increase the difficulty of accounting for future climate-change trends (Toumi and Restell, 2014). Furthermore, these models do not always incorporate NBS or the role of existing ecosystems, and uncertainties in extreme event estimation make it challenging to fully account for climate change impacts. For example, in the United States, not only the frequency and intensity of wildfires are increasing, but the number of houses at risk has increased exponentially (SwissRe, 2021). From 1990 to 2010, the number of homes in the US in the wildland-urban interface grew by approximately 40%. Hence, relying excessively on historic data can underestimate current and future risks (Wagner, 2022; SwissRe, 2021). There is a need to be cautious of relying only on model results based on multi-decadal averages when looking at recent data provides a different perspective. This underestimation of losses can lead to a wrong adjustment of premiums causing financial difficulties for insurers (Wagner, 2022).

One of the main challenges that catastrophe models and other alternatives face when assessing the risk-reduction potential of NBS is the temporal aspect. Whereas traditional grey solutions deliver risk-reduction benefits as soon as they are finished and the level of protection is linear given correct maintenance, some NBS may need a few years or decades to start delivering an appropriate level of risk reduction. Tree plantation, for example, needs time to grow and be fully operational, or similarly wetland restoration requires time to become mature after restoration. However, other NBS will immediately reduce risk after implementation (e.g. natural water retention basins) and are not sensitive to seasonal fluctuation in effectiveness (Shah et al., 2020). There is a need for these models to account for possible lags and lack of linear effects of NBS to correctly assess the risk-reduction potential over time. The spatial aspect also poses several challenges to researchers and modellers. NBS need to be designed considering site-specific conditions to assure their effectiveness. A key limitation is that some models use global datasets to estimate risk-reduction benefits (Lallemant et al., 2021). Applying global or large-scale data can be problematic to assess small-scale NBS in areas with certain characteristics. However, gathering primary data is not always

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possible (Sudmeier-Rieux et al., 2021). Downscaling regional information and conducting primary data collection may be required for local-scale NBS projects (Shah et al., 2020).

Data collection for indicators related to ecosystem susceptibility to disasters may be challenging due to limited studies and the availability of historical records (Shah et al., 2020). In Sudmeier-Rieux et al. (2021), most of the limitations found in the meta-analysis were related to the availability of data and case studies, few validation points, and the external validity of results. It is also highlighted in the same study that there is a considerable lack of empirical studies outside of North America and Europe. More research is needed in other regions of the world since, in order to design interventions, insight from a European analysis of NBS would probably not be appropriate to be applied to other continents due to the different characteristics of ecosystems, level of vulnerability, etc. Simple standardised metrics of NBS effectiveness that work across different scales, or that comprehensively capture the social–ecological dimensions of effectiveness, are unlikely to be found (Seddon et al., 2020). Instead, the authors argue that we must devise a suite of context-specific metrics. Whereas this imbalance applies to a general overview of all types of disaster risk, a systematic review focusing on the risk of drought found that most of the research (approximately 75% of the literature reviewed) was conducted in Asia and Africa, i.e. 46% and 29% respectively (Hagenlocher et al., 2019). Climate change is posing new challenges and different areas will be increasingly subject to additional and diverse hazards. Further research is needed to investigate the effects of disaster risks in diverse regions.

To summarise, there have been considerable recent developments in hazard modelling and the assessment of economic benefits of NBS for climate risk. Nevertheless, there are still gaps and limitations to the available methodologies (see also Table 1). However, predicting future trends of climate hazards and understanding the dynamic nature of NBS remains challenging. The extensive data requirements and the spatial scale of interventions also limit current models' effectiveness when assessing the potential benefits of NBS. Several papers demonstrated with a high level of confidence and robustness that ecosystem services and/or functions are cost-effective and cost-efficient, particularly regarding flood mitigation, slope stabilisation, avalanche mitigation, and coastal storm protection. NBS have also been found to be more effective against small and frequent events. Insurance companies that participated in the survey conducted by Marchal et al. (2019) highlighted that the lack of knowledge exchange between scientists and insurers, and the differences in their models, constitute one of the main barriers to a better understanding of NBS. To continue improving our understanding of the benefits of NBS for climate risk reduction, more primary evidence outside of the Global North is needed (Sudmeier-Rieux et al., 2021). Also, holistic approaches that include non-market benefits and other co-benefits would help to make a stronger case for the investment in NBS. We delve into this topic in the next section.

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Table 1- Summary table of challenges and needs for assessing/modelling disaster risk reduction and NBS

Challenges	Description	Needs
Temporal scale	NBS need time to be effective	Consider dynamic nature of NBS, taking into account also future trends of climate hazards
Spatial scale	Large-scale datasets and models VS small-scale and case-specific NBS	Exchange knowledge and models differences between scientists and insurers to include NBS
Data availability	Primary and historical data on ecosystems and NBS limited	Downscale information and develop holistic approaches to include non-market benefits and other co-benefits

3. Focus on Nature-based Solutions Co-benefits

For the analysis of NBS co-benefits assessment methods, we focused on studies that assess NBS for limiting climate change risks. We have designed two different systematic reviews to explore the full range of methods available and the possible measures to value NBS benefits. The first review aims to provide an overview and mapping of methods available to assess environmental, social and economic co-benefits generated by NBS beyond disaster risk reduction (DRR), by investigating strengths and weaknesses for their usability. The second review instead focuses on methods that provide an economic evaluation of NBS co-benefits, to investigate the monetary value of NBS co-benefits through a meta-analysis. We focused on economic evaluation, since the direct physical impacts can also be expressed in economic terms, as there are value functions to determine the worth of increasing biodiversity and health, for example. From a business perspective, it is important to know what both the monetary values and the direct non-monetary impacts are. In line with the general aim of the Naturance project, the findings can provide insights for the potential use of these methods in the insurance field.

3.1 Methods - review protocol

Search Strategy

We performed a systematic review of peer-reviewed literature, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses – Page et al., 2021) approach, for both reviews.

The selection of studies to be included in the analysis was based on Scopus and Web of Science as search databases (search field: title-abstract-keywords). Additionally, for the meta-analysis , also the ESVD (Ecosystem Services Valuation Database - Brander et al., 2023) was reviewed. The final set of studies was updated on the 30th June 2023.

The studies to be targeted by the search should present the design, implementation, or use of different nature-based approaches that are primarily targeted to reduce the risks and impacts of climate-related hazards and disasters at different scales and in different ecosystems. Secondly, the studies should clearly address the ancillary effects generated by the NBS investigated, other than the primary goal of the solution. Ancillary effects can be environmental, social and economic and

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can be either positive or negative, including, for example, carbon sequestration, air and water quality, biodiversity, temperature regulation, recreational, social and educational opportunities, health improvement, food provision and agriculture, or risk mitigation of hazards other than those primarily addressed. Finally, studies should present models, methods and metrics that assess the effectiveness of co-benefits, privileging quantitative or semi-quantitative evaluation. Therefore, the keywords selected for the reviews refers to five main concepts: nature-based solutions, risk reduction, disasters, co-benefits, and methods (see the list of keywords in the Annex A). Keywords listed in these five domains were used in a single search query connected by the “AND” operator. Searches for both reviews shared the same set of keywords for all concepts, except for the methods that were used in the studies, for which different keywords were considered. The economic-oriented review specifically included studies that employ catastrophe models to assess the risk reduction performance and stated preference methods (choice experiments and contingent valuation studies) for the economic evaluation of co-benefits. Stated preference methods are focused upon since they allow for estimating willingness to pay for NBS, capturing both their use and non-use values, and are hence most comprehensive. A description of economic methods is reported below. In contrast, the co-benefit-oriented review included all the studies that provide a quantitative assessment of co-benefits generated by NBS, other than risk mitigation, from an environmental, economic or social perspective, without focusing on a specific type of method.

Eligibility Criteria for selected literature

We limited the review to journal articles published in English between January 2005 to June 2023. The time span was defined according to the first definition of ecosystem services as benefits that people can obtain from nature (MAE, 2005) and the successive development of related concepts, including nature-based solutions and co-benefits.

We included all the papers that study nature-based solutions designed for disaster risk reduction. But we only retained papers that provide an assessment of co-benefits, excluding those only assessing the risk reduction performance or addressing co-benefits without assessment. Specifically, for the economic review and meta-analysis, we only included studies that provide a comparable monetary value that can be converted to USD per hectare per year. Whereas the geographical scope of the Naturance project is the European Union, suitable papers for case studies from all over the world were selected; this allowed us to obtain a better understanding of the effectiveness of a variety of NBS projects in different parts of the world.

Data analysis & synthesis

In the first review we mapped the methods in terms of co-benefits, NBS, hazards, scales and types of analysis. Additionally, for each category of methods identified, we investigated the usability according to different criteria, such as the data and knowledge needs, the replicability and scalability across different scales and locations, the suitability to assess multiple co-benefits,

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disbenefits and disaster risk reduction potential, the inclusion of any climate change considerations (e.g. used for ex-ante and/or ex-post evaluations) or climate change scenarios.

In the economic review, we collected information to perform a meta-analysis in order to derive a value transfer function. The meta-analysis value transfer function allows for estimating the economic value of NBS in areas for which no primary valuation data is available or where conducting a survey is not a viable option. Value transfer (also known as "benefits transfer") allows existing economic evidence to be applied in other policy sites (Brander and Koetse, 2011). The most appropriate way to perform value transfer analysis is through a meta-analysis since it encompasses several studies and explains the variation in the values obtained in terms of observable characteristics (Bergstrom and Taylor, 2006). Additionally, a meta-analysis can identify patterns and trends in the literature, such as the geographic variation in co-benefits. It can also help to identify gaps in the research and guide future studies. The resulting economic valuation functions can be employed, together with the risk-reduction economic benefits, to produce a cost-benefit analysis. To ensure comparability, the monetary value in the reviewed studies that measure the co-benefits using their own currency were converted to USD in 2022 prices. For this purpose, official exchange rates and GDP deflators were employed.

Economic methods

In this section, the main methods of economic valuation are discussed. The resulting economic values derived from these methods can then be employed in **cost-benefit analysis** to support decision making. The number of strategies designed to measure the economic benefit of ecosystem services is rapidly increasing. A meta-analysis conducted in 2021 found over 20 monetary valuation techniques (Selivanov and Hlaváčková, 2021). Stated preferences (non-market valuation), revealed preferences and value transfer are the most prominent methods in the literature:

- **Revealed Preference (RP)** methods observe the price of goods in real markets and aim to derive a monetary value of nature that is reflected in these prices. For example, **hedonic pricing** is used to determine the extent that environmental factors affect the price of a good, and it is usually employed for real estate prices. Advantages of RP include that it captures actual behaviour rather than stated preferences, which may be biassed or influenced by hypothetical scenarios (de Corte et al., 2021). However, RP methods assume that the market is efficient, and that all relevant information is reflected in market prices. This may not be the case due to externalities and other market failures. Additionally, revealed preference methods may not capture non-use values or non-market values, such as the value of existence or bequest value, which are important components of total economic value.
- **Stated Preferences (SP)** methods require conducting primary research through contingent valuation or choice experiment surveys. SP consists of describing hypothetical decisions

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given a context in order to estimate the respondent's change in utility associated with a proposed increase in the quality/quantity of an ecosystem service (Champ et al., 2017). In contrast to RP, SP methods allow including non-use values into the total economic value of ecosystems. The two main SP methods in the literature are the following:

- In **Contingent Valuation (CV)** surveys, respondents are asked about how they would act in a certain contingent situation (Whitehead and Haab, 2013). They usually involve asking respondents how much they would pay (known as willingness-to-pay (WTP) for a hypothetical change in provision of a particular ecosystem service. The main limitation of CV is that the responses of the survey may not resemble actual behaviour. This is known as hypothetical bias. The lack of a realistic trade-off also can potentially bias the estimates.
- In contrast, **Choice Experiments (CE)** present respondents with a series of hypothetical scenarios where the attributes of a non-market good or service are varied, and respondents are asked to choose their preferred option from a set of alternatives. Choice experiments have the advantage of using an attribute-stimulus format that provides more information regarding the different levels of attributes and also makes the respondent face realistic trade-offs (Morrison and Bennett, 2000). In order to ensure realistic trade-offs, the survey must be carefully designed, since a dominant alternative or unrealistic attribute values could increase hypothetical bias. Alternatively, introducing an opt-out option can also help to reduce hypothetical bias by not asking the respondent to choose between two unattractive alternatives. Due to its advantages and its popularity, the meta-analysis will focus on CE studies to ensure comparability.

A common limitation of these methods is their external validity. The values estimated from a CE or a CV study in a particular site are specific to the site characteristics and the socio-economic situation of the region where it is performed. The output of these various valuation methods, together with the risk-reduction assessment, can be applied to obtain the **Total Economic Value (TEV)**, which can be used to perform a cost-benefit analysis. TEV accounts for the use value (e.g. timber from woodland), the option value (e.g. future use) and the non-use value (e.g. aesthetic appreciation) of environmental goods or services, which takes into account all relevant stakeholders and non-market values. Projecting the **Net Present Value (NPV**) requires a detailed understanding of trends over time in ecosystem service provision, which is certainly challenging given the uncertainty surrounding climate change. The NPV usually refers to the sum of a series of discounted cash flows (benefits and costs) over a period of time and it depends on a particular discount rate. This discounting rate accounts for the time value of money, which assumes that future benefits are worth less than

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present ones. The discount rate represents the rate at which future benefits are adjusted to their present value. This shows the opportunity cost of using resources today rather than in the future.

3.2 Results: co-benefits assessment methods

In this section, we are presenting the results of the first review, mapping the methods to assess co-benefits provided by NBSs beyond disaster risk reduction. Following the eligibility criteria, from the initial set of 480 papers, we identified 52 papers to be included in the review.

Mapping of papers and methods

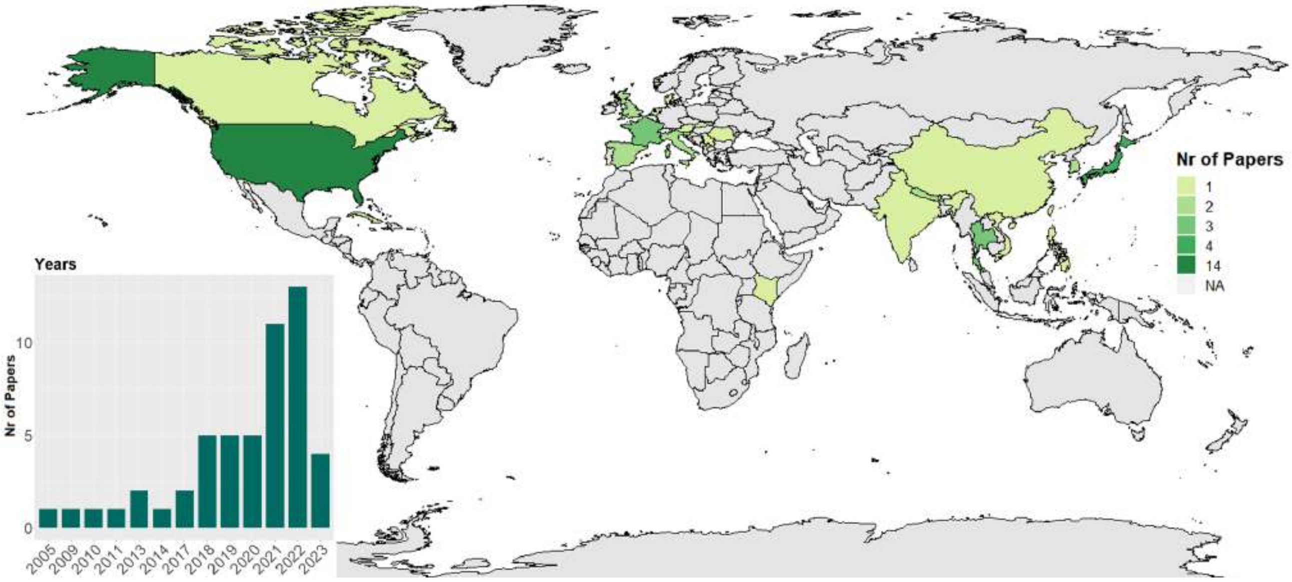

Figure 1 – Map reporting the number of papers published per year and the number of case studies analysed per country.

Most of the papers were published in the last 6 years and cover case studies in North America, Europe, South-East Asia and Africa (Figure 1), with one paper focusing on global coastal areas.

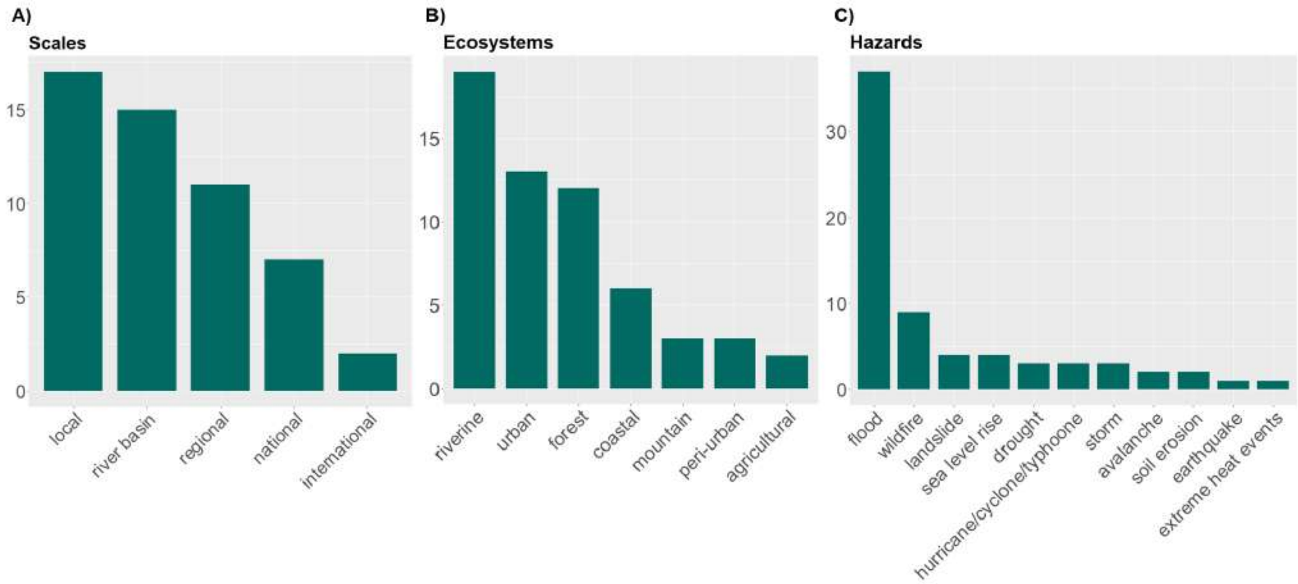

Figure 2 - Bar plots representing the number of papers that focus on different scales (A), ecosystem types (B), and addressing different hazards (C).

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The reviewed papers present case studies at the local, river basin and regional scales in freshwater, urban and forest ecosystems (Figure 2 A-B). Most of them are addressing flood risk and secondly wildfire risk (Figure 2C).

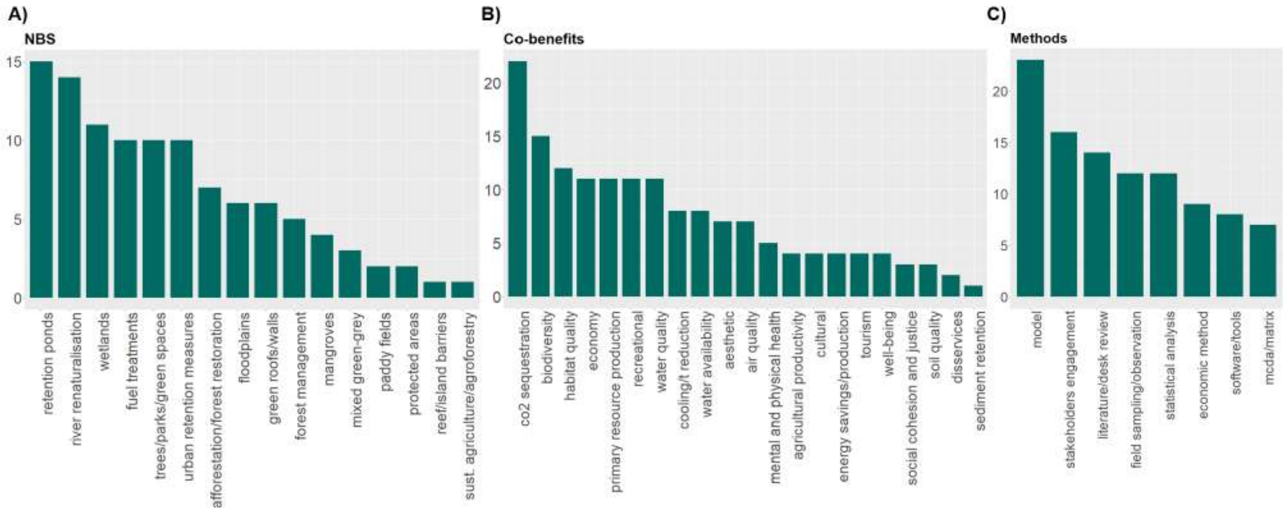

Figure 3 – Bar plots representing the number of papers addressing different NBS types (A), assessing different co-benefits (B), and using different methods (C).

Figure 3 reports an overview of the NBS, co-benefits studied as well as the assessment method used. In line with the hazards and scales investigated, the case studies mainly analysed the implementation of natural water retention measures, such as the creation of natural ponds to collect and store rainwater runoff, the restoration of wetlands and floodplains, the renaturalisation of river streams and the revegetation of banks. Secondly, we found forest fuel treatments, such as forest biomass control and management, and urban nature-based solutions, including the creation of green spaces, tree plantation, urban retention measures (e.g. rain gardens, bioswales and permeable pavements) and green roofs and walls (Figure 3A).

The co-benefits generated beyond disaster risk reduction that are predominantly assessed are carbon sequestration, biodiversity and habitat quality, followed by economic and monetary benefits, the production of primary resources and the support of recreational activities (Figure 3B).

The co-benefits assessment is mostly performed by a set of combined and diverse methods. To map the available assessment methods, they have been grouped in eight categories: 1) field sampling and observations, including methods that use the collection of physical samples of water, soil, flora, fauna or their direct observation in the fields (e.g. count of species); 2) models, including methods that simulate or reproduce behaviours, status, changes and scenarios in a simplified way based on mathematical representation; 3) software and tools, including methods that use developed and ready-to-use software, tools or packages to analyse information, run models, simulate behaviour and scenarios; 4) statistical analysis, including methods that analyse data to estimate, compare, link ecological parameters with benefits provided; 5) stakeholders' engagement, including methods that engage key stakeholders (as users, decision-makers, technical experts) through questionnaires,

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surveys, interviews and workshop; 6) multi-criteria decision analysis, including methods that use a multi criteria decision approach, usually in combination with stakeholders' engagement, to assess and rank solutions and benefits; 7) literature and desk review, including methods that collect data and information from already existing, registered and published records and knowledge; 8) economic methods, including mainly valuation methods (as contingent evaluation, choice experiment, hedonic price, replacement cost) and cost-benefit analysis used to assess co-benefits in monetary terms. A summary table of methods description, application and references is reported in Annex B. Different modelling approaches are the most applied for the assessment of co-benefits (44% of papers analysed), followed by stakeholders' engagement (31%), literature/desk reviews (27%) and field sampling and observations (23%) (Figure 3C). Generally different methods are used in combination for different analysis purposes, as the use of field sampling methods to collect data and assess the status of an ecosystem, also before and after a nature-based intervention, and these outcomes could be used to run a model to simulate future changes that can be validated in combination with stakeholders' engagement methods.

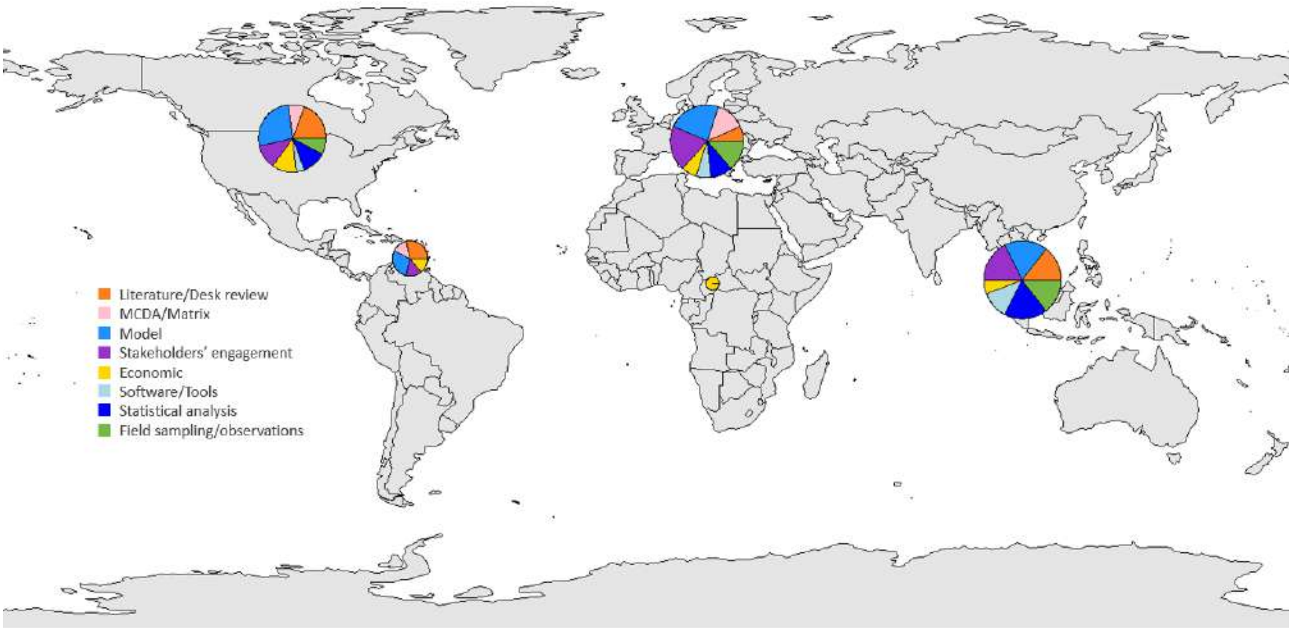

Figure 4 – Map reporting the different types of methods used to assess co-benefits in different world regions.

The use of methods is spread across case studies in all world regions (Figure 4). Studies that focused on co-benefits for NBS in Europe and South-East Asia most frequently applied models and stakeholder' engagement methods, while in North and Central America the use of models and literature and desk review seem to be predominant. Africa has only one study in Kenya, in which economic co-benefits generated by mangroves conservation has been studied. Additionally, in South-East Asia also statistical analysis, field sampling and desk review are considerably used. Not visualised in the map is the one study focusing on global coastal areas, which assesses mangroves

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conservation through field samplings/observations and statistical analysis. A detailed map reporting the methods used per country is reported in Annex B.

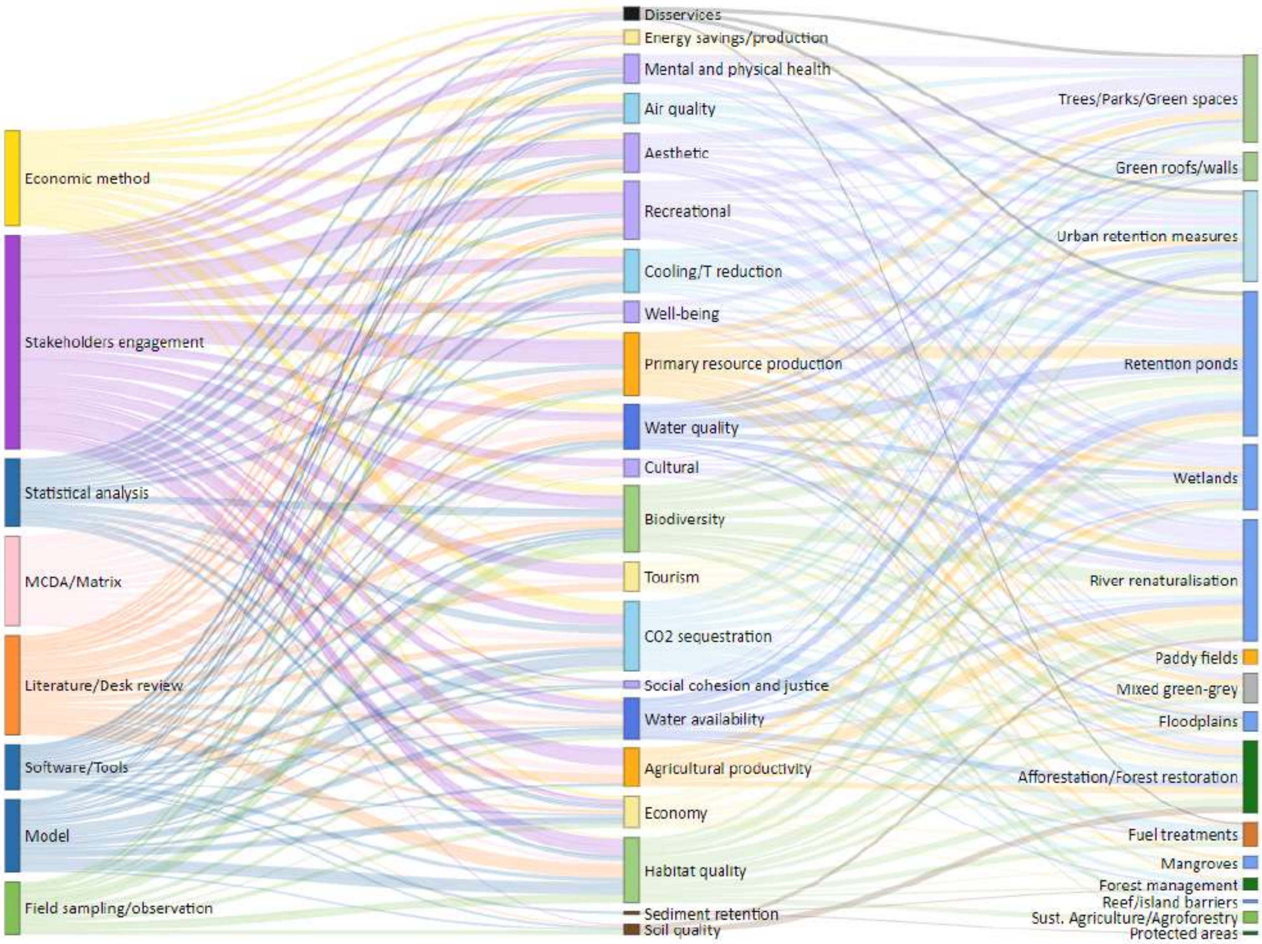

Figure 5 – Sankey diagram linking assessment methods (left column) with co-benefits assessed (central column) and nature-based solutions analysed (right column).

The Sankey diagram in Figure 5 represents the relationships between methods (left column), co-benefits assessed (central column) and nature-based solutions analysed (right column). Notably, there is not a prevalent method used to assess a specific co-benefit or NBS. Stakeholder engagement approaches are frequently applied to assess different co-benefits, especially for cultural and socio-economic benefits. Field sampling and observation are mostly used for the assessment of environmental benefits. But, overall, all the co-benefits are assessed by multiple methods. Similarly, there is not a strict relationship between co-benefits and nature-based solutions, but every category of NBS is associated with a bunch of benefits, with the exception perhaps of social and cultural benefits, which seem to be mostly analysed in urban and riverine interventions (both for water quality and quantity). While habitat quality and biodiversity seem to be more tackled in more natural environments rather than in urban ecosystems. On the co-benefits side, the review also captured the assessment of disservices (top of central column), i.e. negative or unintended effects that NBS can generate. These are mainly associated with urban NBS, water retention ponds and fuel

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treatments. Particularly, they include the increase of carbon emission related to large trees cutting (Bartowitz et al., 2022), the landscape deterioration, people safety risk, mosquitos and allergens spread, increase of housing prices, mobility issues, loss of cultural heritage and sustainability and resilience reduction potentially associated with urban green interventions (Herivaux and Le Coent, 2021). They are assessed mainly through model, desk and literature review, statistical analysis and stakeholders' engagement.

Methods assessment

Analysing our set of papers, we have collected information for each category of methods, in order to provide a qualitative and comparative evaluation of methods according to the different criteria: overall effort required, knowledge and expertise required, replicability in other locations, scalability across different scales, the suitability to assess multiple co-benefits, disbenefits and disaster risk reduction potential, the inclusion of future climate change considerations. Low, medium, high levels have been defined to assess each method category in relation to the others, according to their use in the papers analysed. The set of criteria has been defined to investigate the potential use of these methods from different perspectives. The discussion of methods in relation to each criteria follows and is summarised in Table 2.

The **overall efforts required** criterion considers the overall needs in terms of input data, software, hardware and infrastructures to perform the analysis and associated costs, time and people required to perform the assessment. This is higher for field sampling and observations. They can require several instruments for measuring environmental parameters or collecting physical samples, as well as infrastructures such as laboratories to then analyse them, which can be expensive, time consuming and human demanding. Sampling and observation campaigns can involve a large number of people, according to the size and scope of the study, and last for a long period of time, especially from a monitoring perspective. However, the overall effort required here can serve the validation and calibration of results from other methods, such as modelling and software. Similarly, stakeholders' engagement and participatory processes could also require a high effort to gather people together, making sure that all relevant stakeholders are well-represented and ethical principles are followed. This would possibly need both high economic resources and time. Time is a key resource to talk with and listen to stakeholders, to collect large amounts of data, opinions and information, to develop ideas following co-creation processes and mitigate potential conflicts. MCDA methods are strongly linked with stakeholders' engagement approaches, especially for the collection of information and to weight parameters or alternative solutions and benefits. Consequently, the overall effort can be relatively high, according to the approach used, the quality of information collected and the possibility to translate them in a more quantitative value in a simple way. This process can be supported by models and software that facilitate the analysis but require some expertise. Generally, the use of models, software and statistical analysis could need a

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lower overall effort compared to other methods, although this can vary from model to model or software to software. They usually have high needs in terms of data, preprocessing and validation procedures. Moreover, they could have high computational requirements or need under-payment licences. Literature desk review required a lower overall effort in comparison to other methods. Difficulties can be related to the availability of information, as some data may not be publicly available, and the time and costs required to obtain them.

The **knowledge and expertise required** indicates the level of expertise and knowledge needed to apply the different methods, both as technical skills and as local and scientific knowledge about the specific sites and solutions investigated. All methods need a minimum level of knowledge and expertise. Generally, field sampling can require high knowledge and expertise, especially about the specific site, to set up the protocol of the sampling campaign, to run laboratory analysis and interpret results and indicators. However, the technical skills to collect samples may not necessarily be high. Stakeholders' engagement could require some particular skills and expertise as facilitators to interact with different groups of people, and knowledge of local languages and culture to design the most appropriate way to involve stakeholders and get information. To perform MCDA, quite high knowledge about the theory and methods to be used in the interpretation and conversion of information, as well as to understand the link between cause-effects and various variables investigated can be necessary. Models, software and statistical analysis have the highest expertise requirements, especially in terms of data preparation, model parameterization and validation, although the availability of user-friendly interfaces can facilitate their use. Literature review generally would require a lower level of technical skills compared to other methods, although it is important to know about the topic to collect, analyse and process the information.

The **replicability in other locations** describes the possibility to apply the same method in multiple locations, ecosystems and regions (high) against the definition of site-specific procedures and methodologies (low). Literature review can be applied easily in multiple locations, also simultaneously. Limitations can be associated with data and information availability. Field sampling and observation approaches can be generally replicated in different locations, as long as the protocol can be adapted to site-specific conditions. Similarly, for stakeholder engagement, the potential replicability is associated with the possibility of gathering relevant stakeholders and reaching a sufficient number of people. MCDA is similar to stakeholders' engagement in terms of data collection, but the methods and analysis performed can be reproduced in different contexts more easily. Models and software strongly depend on their specific design, but mostly, if data are available and site-specific conditions are known, they are applicable in different locations. The same statistical analysis, comparing different sets of data and the potential relation among parameters and variables, can be easily applied in different locations and contexts.

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Suitability across scales investigates whether the methods could be applied at different spatial scales, from local, to regional, national and international. Whether information is available, literature/desk review is usually the easiest to use in different contexts and at different scales. On the other hand, suitability across scales is more limited for field sampling and observation. Conducting sampling campaigns on very large scales could be difficult and very expensive, they are mainly performed at local and river basin scales. Similarly, stakeholders' engagement and MCDA are mainly applied at a local scale. According to the engagement process used, however, this can vary. At the local level in-person interviews and workshops can be performed more easily, while at larger scales questionnaire and survey are mostly used. Models, software and statistical analysis can be applied at different scales in the same way they can be used in different locations and contexts, although resolution and overall model processes can vary significantly with the scale considered. So, generally different models are easily available at different scales, while it is not common that the same model is used across scales. They are mostly used at regional and country level, but there are many applications also at the local level.

The **multiple co-benefits and disbenefits** criteria explore the capability of methods to assess multiple co-benefits at the same time, as well as the possibility to capture negative or unintended effects. In field sampling and observations, the use of data as indicators and proxies can help to evaluate multiple benefits and to identify negative effects and impacts, although these should be measurable with the same parameters or variables. Similarly, the collection of data and information in literature and desk review can be used to evaluate multiple benefits and disbenefits through different sets of data, proxies or indicators. Stakeholders' engagement approaches are those that mostly address multiple co-benefits and disbenefits, also simultaneously. However, this is mainly based on people's perception and observations, generally in a post-intervention evaluation. MCDA can easily tackle multiple benefits and disbenefits, especially in a comparative way, between multiple solutions or implementation scenarios. MCDA can be also useful to understand the complex interactions, interconnections and feedback processes between NBS, co-benefits and disbenefits. Models and software can be used to assess different co-benefits and to capture potential negative effects. However, they are rarely able to address diverse benefits at the same time, multiple models/software are usually used in combination to assess different benefits. As well, statistical analysis can be easily used to look at different impacts, but more generally used for single effects or that can be described by the same variables or parameters.

The **disaster risk reduction (DRR) assessment** criterion evaluates the potential use of the methods to assess disaster risk reduction benefits of NBS together with the assessment of co-benefits. In this case, methods seem to work similarly to multiple co-benefits and disbenefits. Field sampling and observation, literature and desk review and stakeholders' engagement methods can be used to evaluate risk reduction, impacts, exposure or vulnerability. Data, indicators and information collected are especially used for a post-intervention and post-disaster evaluation. Stakeholders can

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evaluate the positive/negative impacts associated with different solutions, also with the support of MCDA. Models and software can be very specific and they rarely address both DRR and co-benefits assessment. This can be possible whether software and models have different modules tackling different aspects or analysis, or whether the same parameters can be used for both the assessments. Statistical analysis, on the other hand, can be more easily used in this case, as it can be used to estimate and evaluate the probability and relation between co-benefits, hazards and other drivers/variables.

Finally, **future climate change** criterion inspects whether the methods have been used to assess co-benefits also considering future climate change scenarios. This can be of particular interest to estimate if the NBS implemented maintain their effectiveness also in future climate change conditions and, consequently, if the value of co-benefits is ensured over a long-time frame. Generally, all methods showed a limited consideration of climate change in NBS co-benefits assessment. Field sampling and observation, literature and desk review, and stakeholder engagement are usually used for collecting historical data and to provide an ex-post assessment. This information can be used to inform and model future scenarios, but is not used in a direct way. MCDA and stakeholders' engagement can be used also for ex-ante evaluation of NBS, co-benefits and value to be maintained or preserved, but they are not able to assess their future performance. Models, software and statistical analysis, always according to their specific design, are the methods that largely provide ex-ante evaluation, simulating future scenarios or conditions. However, only very few cases included climate change and long-term scenarios.

Table 2 - Synthesis table of the potential use of methods according to different criteria. Low, medium, high levels have been used to assess each methods category in relation to the others

	Overall efforts required	**Knowledge/ Expertise required**	**Suitability across scales**	**Replicability in other location**	**Multiple Co-benefits**	**Dis-benefits**	**DRR assessment**	**Future climate change**
Field Sampling/ Observation	High	Medium	Low	Medium	Medium/ High	Medium/ High	Medium	Low
Model	Medium/ High	High	Medium/ High	Medium/ High	Medium/ Low	Medium/ Low	Low	Medium
Software/ Tools	Medium	Medium/ High	Medium/ High	Medium/ High	Medium/ Low	Medium/ Low	Low	Medium
Statistical Analysis	Low	High	High	High	Medium	Medium	Medium	High/ Medium
Stakeholders' Engagement	High	Medium	Medium	High	High	High	Medium	Low
MCDA/ Matrix	Medium	High	Medium	High	High	High	Medium	Low
Literature/ Desk Review	Low	Low	High	High	High	High	Medium	Low
Economic	Medium/ High	High	Medium	Medium/ High	Medium/ High	Low	Medium	Medium/ Low

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Since economic evaluation is particularly relevant for the scope of the Naturance project and the possible use of co-benefits value in the insurance sector, we investigated the economic assessment methods more closely, according to the same set of criteria (Table 3). Not surprisingly, among the economic methods, in our set of papers, we have identified mainly stated preference methods, that allow defining a monetary value to NBS co-benefits, beyond disaster risk reduction, also when a direct market value is not available. Therefore, we defined them as valuation methods. Among these, we identified methods as the hedonic pricing, contingent valuation and choice experiment, that are used to estimate the components of the total economic value (TEV) of social or environmental benefits. Additionally, we have identified cost-benefits analysis as an evaluation method. This provides an assessment of the costs and benefits starting from a given monetary value, potentially given by market prices or by valuation methods, and is also used to compute the NPV and TEV.

Generally, here the economic methods are used to assess multiple and diverse co-benefits together, from energy saving or production, carbon sequestration, air quality, water availability and temperature cooling to tourism and primary production, or recreation, biodiversity, and water quality. The assessment of multiple co-benefits is related to the identification of indicators and proxies to define a monetary value of diverse benefits, in order to be comparable. This can be associated with a different level of uncertainty and it is strictly connected to the quality of data and information available. In the studies analysed, economic methods have not been largerly used to assess disservices, although they can potentially identify ancillary economic losses caused by implemented solutions. In terms of scale and location, they have been mostly used at local and river basin scales, in all the continents and in different environments. Therefore, they can be applied in different locations and potentially at different scales, although uncertainty associated with co-benefits value and data could limit their use. They have been used also for both ex-ante and ex-post evaluation, but they are not usually considering climate change future scenarios in the assessment. Only one study tried to focus on this aspect addressing future uncertainty of climate change effects on investment decisions for mangrove rehabilitation, using a real options approach based on net present value (Agaton and Collera, 2022). In terms of ex-ante evaluation, they can compare different NBS alternatives with traditional solutions, especially in terms of costs and benefits defined both in terms of market prices or indirect valuation. When looking at the potential use for DRR assessment, economic methods appear to be suitable, although at different levels. Cost-benefit analysis, and consequently net present value, can work to assess impacts before and after interventions or the effects after a disaster occurred or in different scenarios. Considering their potential usability, however, they require high overall efforts and high knowledge and expertise. The main issue is related to the definition of a monetary value to the benefits, requiring a large amount of data and indicators and a high level of knowledge. To this end, experts and stakeholders' engagement, together with literature and desk literature, can be fundamental to translate

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co-benefits assessment into economic terms, by using valuation methods such as contingent valuation, choice experiments, replacement cost or hedonic pricing. Stakeholders' engagement can, on the other hand, increase the overall efforts required, but contribute to tackling the complexity of the economic valuation.

Table 3 - Focus on economic methods identified in the review papers. Synthesis table of the potential use of economic methods according to different criteria. Low, medium, high levels have been used to assess each method's category in relation to the others.

		Overall efforts required	Knowledge/ Expertise required	Suitability across scales	Replicability in other location	Multiple Co-benefits	Dis-benefits	DRR assessment	Future climate change
Evaluation method	**Cost-Benefits Analysis**	Medium/ High	Medium/ High	Medium	Medium/ High	Medium	Low	High	Medium /Low
Valuation methods	**Hedonic Pricing**	Medium/ High	Medium/ High	Medium	Medium/ High	Medium	Low	Medium	Low
	Contingent Valuation	High	High	Medium/ Low	High	High	Medium	Medium	Low
	Choice Experiment	High	High	Medium/ Low	High	High	Medium	Medium	Low
	Replacement Cost	Medium/ High	Medium/ High	Medium	Medium/ High	Medium	Low	Medium	Low

3.3 Results: economic evaluation and meta-analysis

In this section, the results of the meta-analysis of the economic co-benefits of NBS will be discussed. The final database after the screening phase consists of 127 observations. This is a similar number of observations compared to Bockarjova et al. (2020) and Koetse et al. (2017). The main reason for exclusion was the lack of a comparable monetary value. Most studies provide more than one valuation since choice experiments usually question the respondents about more than one co-benefit for a particular NBS or ecosystem.

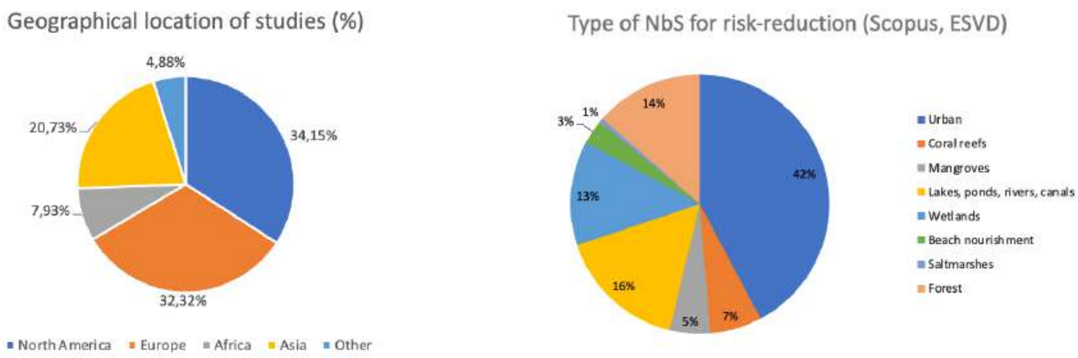

Figure 6 - Geographical location of studies included in the meta-analysis (left); Types of NBS assessed in studies included in the meta-analysis (right)

The final set of papers shows that the majority of the choice experiments have been carried out in either Europe or North America, which account for 32% and 34% of the total number of observations respectively. This is in line with the previous meta-analysis regarding co-benefits of

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NBS (Bockarjova et al., 2020; Brander et al., 2022), but also with systematic reviews about the risk-reduction aspect of NBS (Sudmeier-Rieux et al., 2021). Regarding the year of publication, we conclude that, as expected, the amount of evidence on the co-benefits of NBS has been increasing exponentially in recent years. Around 65% of the included studies were published after 2017.

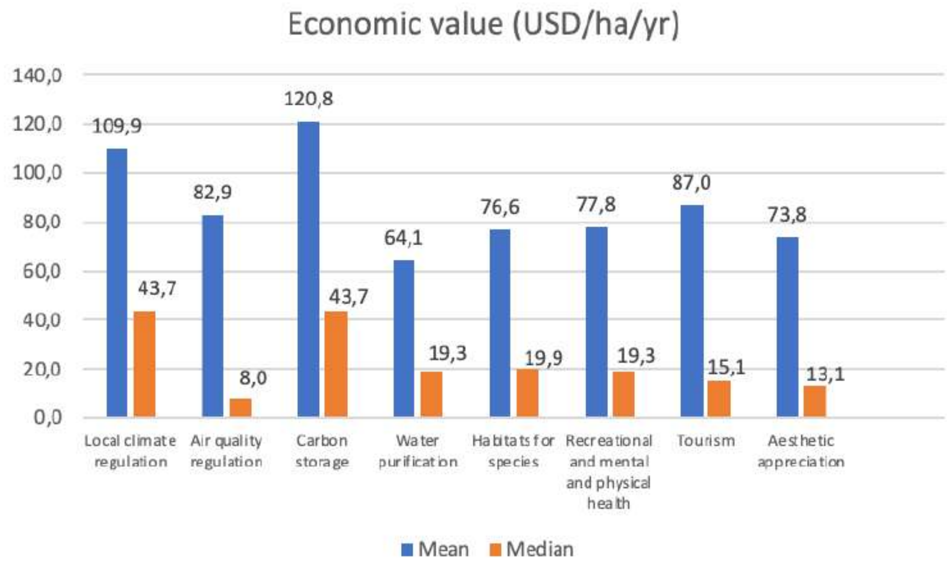

Figure 7 - Average and median valuations by ecosystem service (co-benefit)

Regarding the type of NBS, around 42% of our observations relate to urban nature-based solutions, mainly green roofs and urban parks. Wetlands and forests are also quite prominent in the literature, accounting for 13% and 14% respectively. Recreation and aesthetics were the more frequent co-benefits assessed, followed by carbon storage and habitat support. The risk addressed most commonly in the included studies was flood risk, followed by heat-waves and storm surge. Interestingly, only around 3% of the available observations corresponded with NBS for drought mitigation. In Figure 7, we can observe the average and median values (USD 2022) associated with each ecosystem service provided by NBS. As we can observe, the presence of considerably high valuations in some particular studies drives up the average value.

This meta-analysis builds upon (Bockarjova et al., 2020), which focused on urban NBS. The dependent variable, similarly to previous meta-analyses, is the 2022 USD value prices of co-benefits of NBS per hectare per year (Bockarjova et al., 2020; Brander and Koetse, 2011; Magalhães Filho et al., 2021). This is the most comprehensive way to conduct this kind of meta-analysis since most studies provide some indication of the price value, the size of the site and the time component. To convert the values to a comparable figure, we employ official exchange rates and GDP deflators from the World Bank[3].

[3] World Bank GDP deflators: https://databank.worldbank.org/source/world-development-indicators/Series/NY.GDP.DEFL.ZS

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The following meta-regressions consist of a series of OLS (Ordinary Least Squares) models, where the dependent variable is the logarithm of the monetary value (USD/ha/year) attributed to co-benefits of NBS. The logarithmic transformation addresses the skewness of our dependent variable and residuals. In other words, the lack of symmetry around the mean caused by the outliers shown in the descriptive statistics. The five models presented below include several key variables by groups, starting from the basic specification in Model 1 to the full specification in Model 5 (Table 4). The last models show a higher R-squared compared to the basic specifications, which means that there is a higher percentage of the dependent variable variation explained by models with the co-benefits, continent dummies and the types of NBS. Model 1 shows the basic specification, where we can observe that our findings are in line with the ecosystem services literature (Bockarjova et al., 2020; Brander and Koetse, 2011). First, the size of the NBS shows diminishing returns. The larger the size of the NBS, the lower the economic value per hectare. Since this is a log-log coefficient, it shows an elasticity. In other words, a 1% increase in size is associated on average with a 0.79% decrease in the value per hectare, keeping everything else constant. Another common finding is that an increase in GDP per capita has a positive impact on the attributed economic value. A 1% increase in GDP per capita is associated with a 0.64% increase in value per hectare per year. This is reasonable since wealthier households are more likely to accept a tax increase to improve or expand the nature in their surroundings, as they are likely to have their main necessities already covered. Lastly, higher population density is also associated with a higher value per hectare. The rest of the specifications show some interesting findings. Model 2 shows that CE that were conducted in Europe show a higher value on average, whereas the GDP per capita coefficient is no longer statistically significant. This could be explained by Europe being wealthier compared to other regions. The Variance Inflation Factor (VIF) did not flag any multicollinearity issues when adding continent variables and GDP per capita in the same specification, or population density and the “urban NBS'' dummy variable (VIF<1.5). This indicates a low level of correlation between variables. Usually, a VIF around 5 or higher would be problematic for our models since the covariates should be independent and this can undermine the statistical significance of our independent variable.

Regarding the co-benefits, we can observe in Model 4 that recreation and aesthetic appreciation show positive and statistically significant coefficients. This means that NBS that provide these benefits will be, on average, more valued by respondents. Hence, respondents are willing to accept a higher tax (or other payment) to develop these NBS. On the other hand, Models 4 and 5 show that air quality regulation has a negative coefficient while also being statistically significant. This indicates a lower average per hectare value associated with this co-benefit, while keeping everything else constant. A plausible interpretation is that respondents are more likely to be willing to pay for co-benefits that they can enjoy daily whereas air quality could not be perceived as valuable despite the long-term negative health consequences. The coefficients for the size of the NBS, population density and the continent dummies also remain statistically significant in Model 5.

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Table 4 - Meta-regression models (OLS, ln USD/ha.year)

	Model 1	Model 2	Model 3	Model 4	Model 5
Ln Area (ha)	-0.793*** (0.0772)	-0.643*** (0.0803)	-0.799*** (0.0782)	-0.782*** (0.0717)	-0.695*** (0.0781)
Ln GDP per Capita	0.664*** (0.209)	0.166 (0.361)	0.275 (0.243)	0.661*** (0.203)	-0.0288 (0.380)
Population Density per km2	0.000109*** (3.66e-05)	0.000129*** (4.30e-05)	9.54e-05** (4.08e-05)	9.85e-05*** (3.42e-05)	0.000156*** (5.25e-05)
Urban			0.0381 (0.973)		-0.168 (0.975)
Coral Reefs			1.675 (1.423)		0.397 (1.397)
Mangroves			-0.703 (1.366)		2.413 (1.896)
Wetlands			0.182 (1.102)		0.363 (1.087)
Lakes, Ponds, Rivers, Canals			-1.171 (0.926)		-1.472* (0.870)
Forest			-0.198 (1.056)		-0.287 (1.053)
Beach Nourishment			-5.076*** (1.531)		-7.561*** (2.332)
North America		0.375 (1.082)			2.995* (1.743)
Europe		2.650*** (0.997)			4.381*** (1.603)
Africa		-2.572* (1.513)			4.553 (2.439)
Asia		0.207 (1.042)			1.454 (1.552)
Local Climate Regulation				0.984 (0.683)	-0.402 (0.701)
Air Quality Regulation				-2.624*** (0.622)	-2.722*** (0.606)
Recreational and Mental/ Physical Health				1.293** (0.561)	0.859 (0.646)
Tourism				-0.338 (0.702)	0.670 (0.734)
Aesthetic Appreciation				1.579*** (0.564)	1.127** (0.531)
Bequest				-0.392 (1.388)	-0.619 (1.378)
Habitat for Species				0.156 (0.622)	0.443 (0.583)
Maintenance of Genetic Diversity				0.712 (0.692)	0.504 (0.744)
Constant	6.903*** (2.172)	10.04*** (3.657)	11.46*** (2.776)	5.920*** (2.164)	10.36*** (3.940)
Observations	127	127	127	126	126
R-Squared	0.491	0.577	0.574	0.609	0.718

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4. Discussion and conclusions

The lack of a standardised methodology, set of data and indicators can be critical to develop a common evidence and knowledge base for NBS and boost and mainstream their use (EEA, 2021; Viti et al., 2022). A better understanding of the risk-reduction benefits and co-benefits of NBS and their value to different stakeholders contribute to facilitating the integration of NBS into the insurance and private finance sector, alongside public sector investment. Catastrophe models are mostly used in the insurance sector to investigate risk reduction potential, but they are still lacking in including NBS. Main challenges refer to diverse spatial and temporal scales usually associated with NBS and catastrophe models. NBS are usually implemented and designed at smaller scales and could require time to be effective. Additionally, the lack of primary data, especially on ecosystems and NBS functioning, can be a limitation. Therefore, there is the need to better understand the dynamic nature of NBS, also in relation to future climate conditions, and to integrate scientific and insurers knowledge in order to apply larger scale catastrophe models to small-scale and site-specific NBS. As well, the development of an holistic approach to include non-market benefits and other co-benefits could be beneficial for a more comprehensive assessment. On this scope, the review on co-benefits assessment showed that various methods can be used, from field-based approaches to modelling, from participatory processing to economic valuation. Applied singularly or in combination, all the methods provide a quantitative or semi-quantitative assessment of co-benefits. Investigating their usability in a wider context, methods showed a good suitability at different scales and locations and to assess multiple benefits as well as disservices. However, some limitations could be associated with the complexity and high effort required to implement the method and the low consideration of future climate change. Similarly, in the meta-analysis, we observe that the context where the NBS is developed impacts the attributed economic value, making the impact estimates of one site difficult to apply in other policy sites. As observed in the meta-regression, when NBS are either located in densely-populated areas or areas where the GDP per capita is higher, the economic value per hectare increases, keeping everything else constant. Additionally, the regression results show that respondents are more likely to be willing to pay more for natural sites they can use for recreation purposes or for aesthetic appreciation.

The study showed there is no specific method to assess individual co-benefits from NBS. Co-benefits can be analysed from different perspectives and quantified in different ways according to scope and context of the study. In the papers analysed, methods are often combined, to tackle different aspects and to join the effort required, both in terms of time and resources. Although there is flexibility associated with co-benefits assessment, it can be important to collect a comprehensive and multidimensional (environmental, social, economic) value of NBS and co-benefits. The heterogeneity of approaches makes the comparison of NBS effectiveness and

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value hard, limiting their integration in different sectors, as in the insurance and financial one, and in decision-making processes (Chausson et al., 2020; Ommer et al., 2022). This is especially true for non-tangible and non-market benefits, such as biodiversity and well-being (Viti et al., 2022). Economic methods such as choice experiments allow for estimating a monetary value of the co-benefits of NBS. The main methods available in the literature are stated and revealed preference methods. Stated preference methods have the advantage of being able to identify non-use values and, in the case of choice experiments, to estimate individual economic values for different co-benefits. The main advantage of choice experiments is that they allow measuring the WTP for a different combination of attributes of environmental goods at several levels. Also, compared to contingent valuation, there is less potential for strategic behaviour in the answers. Dealing with large outliers, which can occur with contingent valuation studies, is also not a problem in choice experiments, since the respondents choose from a set of choice cards. However, it is also important to note that choice experiment studies still have some key limitations that should not be neglected, such as hypothetical bias or the lack of external validity. Around two-thirds of all the studies included in the meta-analysis were either from Europe or North America. Due to the difficulties in using monetary value estimations in other contexts, the lack of case studies in other regions of the Global South is a key limitation in co-benefits assessment. The results of the meta-analysis also indicate that NBS in more densely populated areas tend to be associated with higher economic value per hectare, while keeping everything else constant. This is in line with previous meta-analysis on ecosystem services (Bockarjova et al., 2020).

Additionally, NBS, and consequently co-benefits, analysis are predominantly context-specific and case-to-case based. A wide range of co-benefits and NBS are addressed in the literature in different environments, scales and locations. But smaller scale NBS resulted to be favoured in the analysis, with a particular focus on riverine, urban and forest ecosystems in the north developed emisphere (especially US and EU). This is in line with previous literature, highlighting limitations related to location and climatic context of most of the studies (Sudmeier-Rieux et al., 2021; Chausson et al., 2020). The contextualisation in terms of climatic and environmental conditions as well as in terms of socio-economic factors is critical to design effective solutions, but further development is needed to ensure NBS and co-benefits scalability and replicability (EEA, 2021). In this perspective, the potential use of similar methods at different scales and different locations can be helpful. Methods investigated generally showed to be applied in different locations and environments, according to the availability of data and information, but a slightly lower flexibility in terms of inter-scale suitability. A more replicable approach across sites and scales could possibly identify broader effects or trends in the region/country and support the implementation of NBS as a wider strategy for climate change adaptation and disaster risk reduction, and not only as a site-specific solution (Viti et al., 2022). This can be observed in the meta-analysis results. The lack of representation of studies that take place in the Global South hinder the applicability of values from

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one context to another. Hence, the meta-analysis can correct this issue by creating a value function in order to capture trends and effects of different variables (region, population density, etc.). This function could be applied to inform policy-making by introducing the specific policy-site characteristics.

Methods showed the possibility of dealing with multiple benefits and possibly disservices. The co-benefits assessed cover the social, environmental and economic spheres, responding to a wide range of stakeholders' interests. This is particularly relevant to have a complete overview of value and needs, facilitating the creation of financing frameworks that take into account all the benefits and stakeholders. Participatory process and stakeholders' engagement play a key role both in the design, implementation and assessment of NBS and co-benefits (EEA, 2021). Also in a quantitative evaluation, the integration of stakeholders' knowledge, opinions and perceptions can be fundamental to value and quantify NBS benefits. In many of the papers reviewed, stakeholder's engagement approaches were combined with different quantitative assessment methods. This is helpful also to the need of aligning data and indicators to the interests of stakeholders and main beneficiaries of NBS (Ommer et al., 2022). The involvement of stakeholders can be important also to understand NBS functioning and contribution, in order to improve their acceptance and possible investments. Particularly, this can be important when looking at NBS effectiveness and profitability in the short and long term. NBS can take time to become effective, being linked to vegetation growth rate for example, or to recover after extreme events, influencing also the profitability for investors in the short term (EEA, 2021). As well, it could also lose effectiveness in the long term if the NBS is not adequately managed.

A main limitation related to NBS and co-benefits assessment is the lack of future climate change and long term perspective consideration. Studies mostly performed an ex-post assessment of NBS benefits and effectiveness. When an ex-ante assessment is presented, it simulates possible effects associated with NBS, but they rarely consider the NBS resilience in future conditions and the possible change in the benefits provided. As living solutions, NBS can be subjected to climate- and weather-related hazards and their resilience influenced by ecosystem and biodiversity conditions. Therefore, the integration of this aspect in the assessment could support long term planning that considers uncertainties concerning future climate change impacts and societal needs for adaptation (EEA, 2021). Having a complete evaluation of benefits and understanding of NBS functioning is important also for the development of sustainable financial instruments, schemes and investments, especially in the context of insurance and risk prevention.

The research presented in this report gives an overview of the state-of-the-art concerning the methods to assess the benefits of NBS for climate risk reduction. The next step of the research planned in Work Package 4 of Naturance is to address this research gap and develop a more accurate risk reduction assessment framework for NBS, as well as develop an assessment

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framework for the co-benefits of NBS for climate risk. This planned research will focus on newly constructed NBS measures in the Dutch province of Limburg, which were initiated after devastating floods in the area in 2021.

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Annex

A. Keywords list

NATURE-BASED SOLUTIONS: studies should present the design, implementation, or use of different nature-based approaches at different scales and in different ecosystem types.

List of keywords: "nature-based solution*" OR "green infrastructure*" OR "blue infrastructure*" OR "ecosystem-based" OR "natural infrastructure*" OR "green roof*" OR "natural water retention measures" OR wetland* OR "coral reef*" OR saltmarsh* OR river OR watershed* OR park* OR "sustainable urban drainage system*" OR mangrove* OR forest* OR garden* OR "beach nourishment*" OR "water bod*" OR canal* OR lake* OR seagrass* OR "green corridor*" OR "ecological corridor*" OR dune* OR "rain garden*" OR "green wall*" OR "vegetated buffer strip*" OR "water retention pond*" OR "protected area*" OR "nature restoration" OR "nature conservation" OR "nature protection" OR "integrated coastal zone management" OR "integrated water resource management" OR floodplain

RISK REDUCTION: studies should address the risk mitigation role of nature-based solutions.

List of keywords: "risk reduction"

DISASTER: studies should investigate nature-based solutions that are primarily targeted to reduce the risks and impacts of disasters and climate-related hazards.

List of keywords: disaster* OR flood* OR drought* OR heat* OR storm* OR rainfall* OR "extreme precipitation" OR "extreme weather" OR "forest fire*" OR wildfire* OR hail* OR "sea level rise" OR landslide* OR avalanche* OR erosion OR typhoon* OR cyclone* OR tsunami* OR "natural hazard*" OR "water scarcity" OR “climate change”

CO-BENEFITS: studies should clearly address the ancillary effects generated by the NBS investigated, other than the primary goal of the solution. This can be environmental, social and economic. Secondary effects can be either positive or negative. Co-benefits could be related to carbon sequestration, air and water quality, biodiversity, temperature regulation, recreational, social and educational opportunities, health improvement, food provision and agriculture, or risk mitigation of hazards other than those primarily addressed.

List of keywords: "co-benefit*" OR disbenefit* OR "ecosystem service*" OR "water quality" OR aesthetic* OR "air quality" OR carbon* OR "non-use value*" OR "urban heat*" OR cool* OR "thermal control" OR "thermal regulation" OR "soil quality" OR recreation* OR tourism OR biodiversity OR health* OR "social cohesion" OR "social justice" OR job* OR noise OR food OR pollination OR "habitat quality" OR "well-being" OR gentrification* OR disservice* OR "pest control" OR timber OR "urban regeneration" OR "land regeneration" OR pollution OR benefit* OR “energy”

METHODS: studies should present models, methods, metrics that assess the effectiveness of co-benefits in terms of disaster risk reduction and co-benefits generation, prioritising quantitative and semi-quantitative evaluation. The economic-oriented review specifically included studies that employ flood damage modelling or catastrophe models for risk reduction performance and stated

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preference methods (choice experiments and contingent valuation studies) for the economic evaluation of benefits. Stated preference methods are privileged since they allow for estimating willingness to pay for NBS, capturing both their use and non-use values, and are hence most comprehensive.

List of keywords for ‘economic’ review: “choice modelling” OR “choice experiment” OR “stated preferences” OR “model” OR “estimat*” OR “assess*” OR “willingness-to-pay”

List of keywords for ‘co-benefits’ review: "assess*" OR "evaluat*" OR "valuat*" OR "estimat*" OR "comput*" OR "model*" OR "calculat*" OR "quantif*" OR "method*" AND NOT "framework*"

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B. Co-benefits assessment methods – results

This Annex includes additional information related to the results of the review ofco-benefits assessment methods.

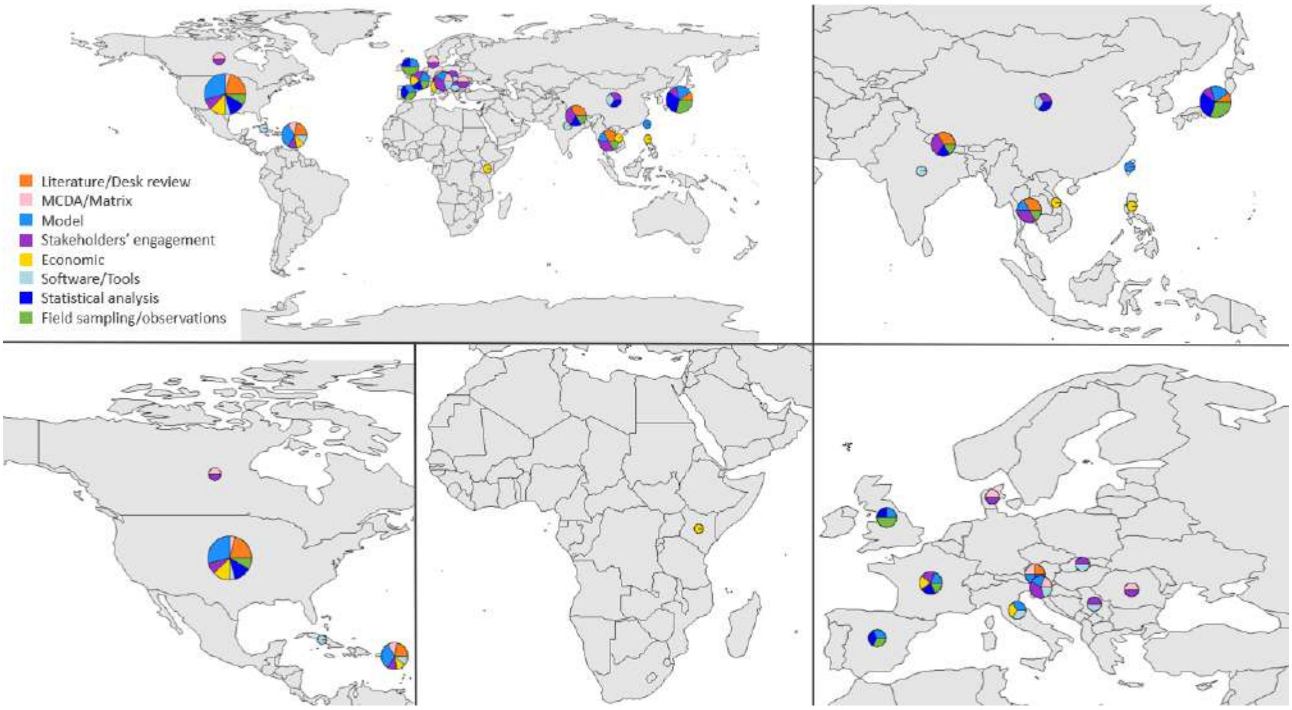

Figure 6 - Map reporting the different types of methods used to assess co-benefits in different countries.

Table 5 – Summary description of methods categories.

Method category	Description
Field Sampling/ Observation	Methods that use the collection of physical samples of water, soil, flora, fauna or their direct observation in the fields (e.g. count of species). Physical samples are generally processed/analysed in the laboratory for physical, biological, and biogeochemical analysis. These methods can be used to assess conditions or biodiversity/environmental parameters pre and post interventions (Gosch et al., 2014; Robotham et al., 2023; Schick et al., 2018; O'Donnell et al., 2020; Straatsma et al., 2017), or to serve as indicators/proxy of certain conditions (Andrés et al., 2021). These information can be also used and combined to feed model, software and tools to simulate future changes (Kasada et al., 2022; Sorensen et al., 2011), to compute statistical analysis to estimate for example biomass/species richness changes (Jones et al., 2020; Yamanaka et al., 2020) or to support stakeholders' engagement (Watkin et al., 2019).

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Model	Methods that use data and information to simulate or reproduce behaviours, status, changes, scenarios in a simplified way based on mathematical representation/equations. Models can investigate forest and vegetation growth, yield, and management and carbon sequestration capacity (Oneil and Lippke, 2010; Bartowitz et al., 2022; Couture and Reynaud, 2011; Sorensen et al., 2011; Alcasena et al., 2021; FBDC model - Lee et al., 2018, 2020; FEE-FVS - Foran et al., 2018); the effects of coastal restoration/protection projects on habitat quality, carbon sequestration, ecosystem functioning); the effects of interventions on biodiversity (Kasada et al., 2022; Shih et al., 2022; Akasaka et al., 2022; BIOSAFE - Straatsma et al., 2017) and habitat quality (Cislaghi et al., 2021; Habersack et al., 2015); water yield and availability (Lee et al., 2020 - SWAT; O'Donnell et al., 2020 - Rainwet); to assess the effectiveness of solutions against heat stress (ENVI-met - Majidi et al., 2019) or water pollution (SWMM model - Dutta et al., 2021; Wang et al., 2022); or to compare alternative solutions (Foran et al., 2018; Alves et al., 2020). Lastly, models can be combined with participatory processes to assess co-benefits produced (Pagano et al., 2019).
Software/Tools	Methods that use developed and ready-to-use software, tools modules or packages to analyse information, run and apply models, simulate behaviour and scenarios. Software and tools can support the analysis ecosystem services (InVEST - Meraj et al., 2022; Lee et al., 2018; i-Tree - Schneider et al., 2022; TESSA - Perosa et al., 2021), the trophic interactions and biomass (Ewe - de Mutsert et al., 2021), root growth (MATLAB rootFORCE package - Cislaghi et al., 2021), population health and social cohesion (Teeb-Stadtool - Wang et al., 2022), to statistically analyse stakeholders' surveys (SPSS 22.0 - Lin et al., 2022).
Statistical Analysis	Methods that analyse data to estimate, compare, link ecological parameters with benefits provided. They can include algorithms/analysis to characterise sample population - especially for biodiversity analysis (Gosch et al., 2014), to analyse distributions, correlation and characteristics of data associated to environmental conditions, alternative interventions or scenarios (Yamanaka et al., 2020; Kasada et al., 2022; Alcasena et al., 2021; Huang et al., 2013; Adams and Charnley, 2020), to compare different set of data and information(Jones et al., 2020; O'Donnell et al., 2020), to analyse stakeholders' surveys and questionnaires (Herivaux and Le Coent, 2021; Lin et al., 2022), to validate model and analysis results (Lee et al., 2020). As well they can include regression analysis to define the relationship between interventions and benefits provided according to ecological/environmental variables (Schick et al., 2018; Akasaka et al., 2022), and to estimate

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	probability and future changes of benefits variables/indicators (Belle et al., 2018).
Stakeholders' Engagement	Methods that include the engagement of key stakeholders (as users, decision-makers, technical experts) of implemented/planned solutions through questionnaires, surveys, interviews and workshops. These methods to collect information based on local knowledge (Schick et al., 2018; Watkin et al., 2019; Gómez Martín et al., 2020; Teramura and Shimatani, 2021), to weigh and assess and validate data, information and alternatives using expert judgement (Alves et al., 2020; Coletta et al., 2021; Pagano et al., 2019; Perosa et al., 2021), to identify needs and preferences (Herivaux and Le Coent, 2021), assess perceived/provided benefits and impacts (Yildirim et al., 2021; Jones and Doberstein, 2022; Lin et al., 2022; Adams and Charnley, 2020) and evaluate effectiveness of solutions both to compare before and after their implementation and to plan future interventions (Alves et al., 2020, 2018; Thapa et al., 2022; Habersack et al., 2015). As well they can be used to provide/estimate a monetary value based on stakeholders' opinion or willingness to pay for certain services (Reynaud et al., 2017).
MCDA/Matrix	Methods that use a multi criteria decision analysis approach, usually in combination with stakeholders' engagement, to assess and rank solutions and benefits. They can use fuzzy logic approach and causal loop diagram (Gómez Martín et al., 2020; Coletta et al., 2021), participatory system dynamics modelling (Pagano et al., 2019) and evaluation matrix (Habersack et al., 2015) or be based on direct stakeholders' engagement (Alves et al., 2020).
Literature/Desk Review	Methods used to collect data and information, like field sampling and observation, but looking for already existing, registered and published records and knowledge. They can be used to collect historical information and compare conditions, economic costs/benefits or biodiversity/environmental parameters pre- and post- interventions (Alves et al., 2019; Straatsma et al., 2017), to rank solutions and collect evidence (Suttles et al., 2021; Habersack et al., 2015), as well as to model alternative scenarios (Schick et al., 2018; Baustian et al., 2023; Bartowitz et al., 2022; Dutta et al., 2021; Sorensen et al., 2011) and to inform stakeholders in participatory processes and evaluations (Watkin et al., 2019; Alves et al., 2018; Thapa et al., 2022; Alves et al., 2020; Teramura and Shimatani, 2021).
Economic	Methods used to provide an economic evaluation (i.e. in monetary terms) of co-benefits. They can be used to compare interventions in terms of costs, benefits and value generated (cost-benefits analysis - Alves et al., 2019; net present value - Nordman et al., 2018; Stroud et al., 2023; Agaton and Collera,

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	2022; Huang et al., 2013; total economic value - Agaton and Collera, 2022; Stroud et al., 2023; Karanja and Saito, 2018; Dung and Le, 2022). In these cases, values are derived from market values of associated products, costs of implementation and maintenance, cost of their use, avoided costs or potential damages/losses. Methods to compute the total economic value included replacement cost method, direct market prices, opportunity and management costs, hedonic pricing. When a direct market price is not available, methods such as contingent valuation and choice experiments are used to estimate monetary value of environmental resources through stakeholders' engagement (Majidi et al., 2019; Reynaud et al., 2017).

*List of acronyms in the table: FBDC (Forest Biomass and Dead organic matter Carbon), FEE-FVS (Fire and Fuels Extension and Forest Vegetation Simulator), NECB (net Ecosystem Carbon Balance), ICM (Integrated Compartment Model), BIOSAFE model (Spreadsheet Application for Evaluation of Biodiversity), SWAT (Soil and Water Assessment Tool), SWMM (Stormwater Management Model), InVEST (Integrated Valuation of Ecosystem Services and Trade-offs), TESSA Toolkit for Ecosystem Service Site-Based Assessment), EwE (Ecopath with Ecosim), Teeb-Stadtool (The Economics of Ecosystems and Biodiversity tool for cities), SPSS 22.0 (Statistical Package for Social Science)

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C. Coding and description of key variables for the meta-analysis

The dependent variable, similar to previous similar meta-analyses, is the 2022 USD value prices of co-benefits of NbS per hectare per year (Bockarjova et al., 2020; Brander and Koetse, 2011; Filho et al., 2021). This is possible since most studies provide some indication of the price value, the size of the site and the time component. This approach will also allow comparing our results with previous meta-analyses. First, to derive this variable, all values should be converted to 2022 USD through official exchange rates and GDP deflators retrieved from the World Bank. Regarding the spatial component (per hectare), if a study reports the value of the site as a whole, we divide the total value by the hectares of the study site. This is retrieved either from the study or from external sources of information in order to convert the value to USD per hectare. When studies provided WTP per visit instead, the preferred option is to convert it to an annual basis by multiplying the WTP per visit by the annual number of visitors (Brander and Koetse, 2011). The aggregate WTP value was obtained by multiplying the "per year per household value" by the number of households in the area. When the value was reported per person instead of "per household", the average household occupation was retrieved from official sources. In the regressions, we perform a logarithmic transformation of the dependent variable to deal with the skewness of the willingness-to-pay.

The main independent variables of interest in our meta-regression will be the different types of NbS and the co-benefits or ecosystem services. The co-benefits are coded as binary variables (take value 1 if the site provides that ecosystem service and 0 otherwise). It is important to note that one site could provide several ecosystem services. Similarly, the types of NBS are also coded as dummy variables, where it takes value 1 when the site matches a certain type, and 0 otherwise.

The size of the nature site, geographical location, and other socioeconomic variables such as the income of respondents or population density were also included in the meta-regression. Whereas some papers include information about the income of respondents, this information has been retrieved from the World Bank data for consistency. The GDP per capita at the lowest level was used as a proxy for the income of respondents. These variables will also be converted to USD 2022 values. The geographical location is determined by using continent dummy variables and the size of the nature site is measured in hectares. Population density is defined as the number of people per square kilometre.

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D. Table of papers included in the meta-analysis

Study ID	Author	Year of publication	Title
1	Robinson et al	2022	Understanding the determinants of biodiversity non-use values in the context of climate change: Stated preferences for the Hawaiian coral reef
2	Netusil et al	2022	Valuing the public benefits of green roofs
3	Ando et al	2020	Willingness-to-volunteer and stability of preferences between cities: Estimating the benefits of stormwater management
4	Christie and Raymond	2009	Estimating the willingness to pay for regulating and cultural ecosystem services from forested Siwalik landscapes: perspectives of disaggregated users
5	Torres et al	2017	Framing Decisions in Uncertain Scenarios: An Analysis of Tourist Preferences in the Face of Global Warming
6	Chau and Chung	2010	A choice experiment to estimate the effect of green experience on preferences and willingness-to-pay for green building attributes
7	Koetse, Verhoef, Brander	2017	A generic marginal value function for natural areas
8	Collins, Schaafsma, Hudson	2017	The value of green walls to urban biodiversity
9	Hampson et al.	2017	River Water Quality: Who Cares, How Much and Why?
10	Hagedoorn L.C., Koetse M.J., van Beukering P.J.H.	2021	Estimating Benefits of Nature-based Solutions: Diverging Values From Choice Experiments With Time or Money Payments
11	Acong	2016	Measuring Households' Willingness to Pay for Water Quality Restoration of a Natural Urban Lake in the Philippines
12	Chaudhyr, Tewari and Singh	2008	Urban forestry in India: development and research scenario
13	Che, Yang and Jiang	2012	Assessing Local Communities' Willingness to Pay for River Network Protection: A Contingent Valuation Study of Shanghai, China
14	Chen and Jim	2011	Contingent valuation of ecotourism development in country parks in the urban shadow
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