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Quantifying co-benefits and disbenefits of Nature-based Solutions targeting Disaster Risk Reduction

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ABSTRACT

Nature-based Solutions function (NBS) as an umbrella concept for ecosystem-based approaches that are an alternative to traditional engineering solutions for Disaster Risk Reduction. Their rising popularity is explained partly by their entailing additional benefits (so-called co-benefits) for the environment, society, and economy. The few existing frameworks for assessing co-benefits are lacking guidance on co-benefit pre-assessment that is required for the NBS selection and permission process. Going beyond these, this paper develops a comprehensive guidance on quantitative pre-assessment of potential co-benefits and disbenefits of NBS tackling Disaster Risk Reduction. It builds on methods and frameworks from existing NBS literature and related disciplines. Furthermore, this paper discusses the evaluation of the quantified results of the pre-assessment. In particular, the evaluation focuses on the significance of change of the estimated co-benefits and disbenefits as well as the sustainability of the NBS. This paper will support decision-making in planning processes on suitability and sustainability of Nature-based Solutions and assist in the preparation of Environmental Impact Assessments of projects.

1. Introduction

Nature-based Solutions (NBS) function as an umbrella term for ecosystem-based approaches. According to the recently universally agreed-upon definition by the United Nations Environment Assembly (UNEP/EA5/L9/REV.1), NBS are 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social,

Abbreviations: CBD, Convention on Biological Diversity; DRR, Disaster Risk Reduction; EIA, Environmental Impact Assessment; LULCC, Land Use and Land Cover Change; NBS, Nature-based Solutions; SDGs, Sustainable Development Goals.

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economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits.' NBS are increasingly adopted for Disaster Risk Reduction (DRR) considering that healthy ecosystems can cope better with occurring hazards and reduce the magnitude, duration, or frequency of hazards [1,2]. NBS are further implemented to tackle other societal challenges including climate change mitigation and adaptation, biodiversity loss, and health and well-being [3].

NBS are known and promoted for their entailing co-benefits - referred to as positive side effects or unintended effects [4]. They gained popularity in the context of climate change as positive side effects of climate change mitigation policies on health and well-being [5]. In the context of NBS for DRR, co-benefits range from ecological to socio-economic sectors assisting global frameworks such as the Sustainable Development Goals (SDGs), the Paris Agreement, or the Convention on Biological Diversity (CBD). However, negative side effects, so-called disbenefits, often remain unmentioned in the shadow of co-benefits. Nonetheless, they are more frequently integrated into decision-making on NBS [4,6].

To date, a broad spectrum of NBS co-benefits and a smaller number of disbenefits were identified and reported within NBS research [7–12] (depicted in Fig. 1). Ecological co-benefits are largely representing regulating ecosystem services defined by Maes et al. [13] such as the improvement of air, water, and soil quality, climate regulation, and carbon sequestration. While recreational and touristic areas are associated with cultural ecosystem services. Green spaces and the co-design of NBS can further support social cohesion and inclusion [14]. Other co-benefits of NBS can be the attenuation of noise through vegetation or the reconnection of existing habitats benefiting biodiversity. However, some ecological co-benefits may be perceived as disbenefits such as increased pollen in the air or mosquito populations [15]. Moreover, NBS can serve societies and economies by creating job and business opportunities or lowering energy expenses through greened buildings. Overall, NBS, especially in urban areas, can increase the attractiveness of an area leading to boosting property prices. In some cases, a co-benefit may cause disbenefits (e.g., a rise in property prices can cause segregation or social exclusion [16–18]) or a co-benefit may turn (partly) into a disbenefit, for instance, basins can have a cooling effect on the microclimate during the day but a warming effect during the night [19]. Another example is high density planting of trees that can lead to a barrier for air pollutants rather than enhancing sequestration [20]. Rising tourism and property prices but also new jobs and businesses can be beneficial for local tax revenues and the overall socio-economic development. Whilst ecological and socio-economic co-benefits and disbenefits are influencing the health and well-being of the citizens. For instance, increased air and water quality but

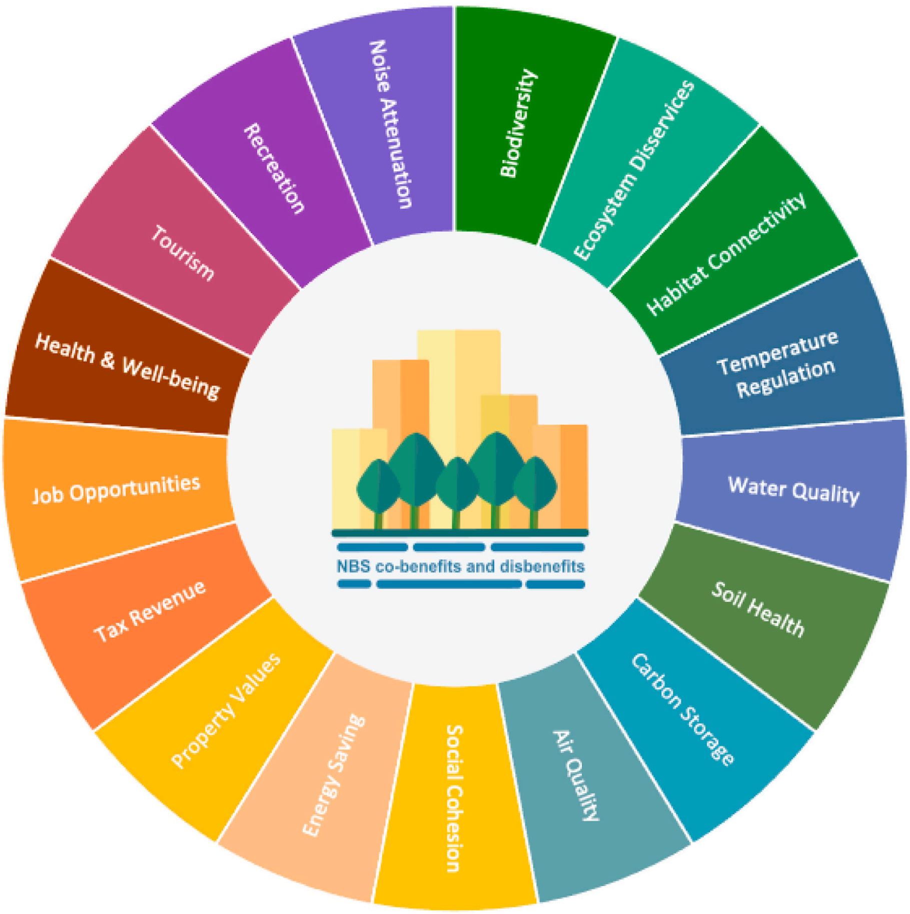

Fig. 1. Commonly reported NBS co-benefits and disbenefits.

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Table 1
Summary of existing frameworks and tools related to co-benefit and disbenefit assessment (Type: M&E (Monitoring & Evaluation); M/A (Mapping/Assessment); Pre-A (Pre-assessment)).

Source	Focus	Type	AirQuality	CarbonStorage	SoilHealth	WaterQuality	TemperatureRegulation	HabitatConnectivity	EcosystemDisservices	Biodiversity	NoiseAttenuation	EnergySavings	Recreation	Tourism	JobOpportunities	TaxRevenue	PropertyValues	Health&Well – being	SocialCohesion
Co-benefits Assessment Framework [9,37]	Climate Mitigation and Adaptation Water Management Coastal Resilience Green Space Management Air Quality Urban Regeneration Participatory Planning and Governance Social Justice and Cohesion Health & Well-being Economic Opps and Green Jobs	M&E		✔	✔		✔	✔		✔		✔	✔		✔		✔	✔	
Integrated valuation of NBS [21]	Water Pollution	M&E		✔		✔				✔				✔					
Benefit of NBS Assessment Framework [27]	DRR	M&E	✔	✔		✔	✔	✔		✔	✔		✔		✔		✔	✔	✔
Environmental Impact Assessment of Projects (EIA) [31]	Climate Change DRR Biodiversity	Pre-A	✔		✔	✔	✔			✔			✔	✔				✔	
Evaluating the impact of Nature-based Solutions [7]	Climate Resilience Water Management Natural Hazards Green Management Biodiversity Air Quality Place Regeneration Sustainable Urban Transformation Participatory Planning Social Justice & Cohesion Health & Well-being Economic Opps & Green Jobs	M&E	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
EU Ecosystem Assessment [13,32]	Ecosystem Services	M/A	✔		✔	✔	✔						✔	✔					
Recreational Opportunity Spectrum [34]	Ecosystem Services	M/A											✔						
Urban Ecosystem Service Assessment [33]	Ecosystem Services	Pre-A	✔	✔			✔				✔		✔						
i-tree Tool [29]	Climate Change Mitigation	Pre-A	✔	✔															
Benefit Estimation Tool (B£ST) [30]	Flood Management	Pre-A	✔	✔		✔				✔	✔		✔	✔	✔			✔	
InVEST Tool [35]	LULCC Ecosystem Services	Pre-A		✔		✔	✔						✔						

also noise attenuation can have positive effects on health while attractive and recreational areas or regulated temperature can boost their well-being. Nonetheless, perceived ecological disbenefits such as pollen or mosquitoes can cause health issues or distress, respectively.

To identify suitable NBS for DRR, NBS are advised to be selected based on their potential to reduce the magnitude, duration, or frequency of the targeted hazard(s) [9,21] considering their effectiveness in current and future climate [22–24], with respect to place-based characteristics, perceptions and needs of citizens and stakeholders [23–26]. Recent frameworks highlight the importance of integrating co-benefits (and partly disbenefits) into decision-making [4,6,7,9,26]. However, the expected impact of co-benefits is communicated only in qualitative terms (e.g., low to high) as their quantification remains a great challenge in NBS research. Quantification is vital to evaluate, firstly, the significance of the potential impact of side effects and, secondly, the sustainability of the NBS considering their contribution towards other societal challenges. Existing NBS co-benefit assessment frameworks [7,9,21,25,27] focus primarily on assessment, monitoring, and post-project evaluation while largely neglecting disbenefits. Hence, guidance on quantitative pre-assessment of co-benefits and disbenefits is urgently needed to answer the following questions to support decision-making in the NBS selection process:

1) How significant is the actual impact?
2) When can co-benefits turn into disbenefits?
3) How sustainable is the NBS in the area of interest?

This paper builds on existing research to provide guidance on quantifying co-benefits of NBS and on answering the above questions to support decision-making in the NBS selection processes. Therefore, in Section 2, we reviewed existing co-benefit assessment frameworks and quantification methods from NBS literature and related research fields for the co-benefits and disbenefit indicators introduced above. Building on the existing knowledge, Section 3 presents guidance on the quantification of each indicator while Section 4 discusses the evaluation of the quantitative results to respond to the questions above.

2. Assessment frameworks and tools

This Section presents a narrative review of existing co-benefit assessment frameworks and quantification methods from related disciplines. The aim of this review is the identification of methods that can be adopted for the pre-assessment of NBS co-benefits and disbenefits. Table 1 summarises these frameworks and tools introduced in this Section along with their focus, assessment type, and approached indicators.

Multiple frameworks and methods for assessing co-benefits were developed within NBS research: Raymond et al. [9] developed a seven stage assessment framework built on the work of Kabisch et al. [28], but remains superficial when it comes to the quantification. Liquete et al. [21] proposed a multi-criteria analysis for assessing co-benefits with emphasis on integrating multiple interests of stakeholders. This framework primarily aims to ease decision-making on NBS based on multiple criteria by assessing different alternatives towards the interests. Watkin et al. [27] targeted the quantification of the rate of change with a scoring approach where co-benefits are classified into five scores from low to high by also allowing negative scores. An issue unravelling here, is the fact that the proposed assessment frameworks are primarily designed for monitoring and post-project assessments; thus, they cannot be directly adopted for the pre-assessment of co-benefits and disbenefits. The indicators incorporated in the frameworks introduced above are covering direct benefits and co-benefits, but do not always separate between these. In the context of climate change mitigation and flood reduction, two tools were developed to estimate and monetise potential carbon storage and air pollution mitigation (i-Tree tool series [29]), and sustainable urban drainage systems (Benefit Estimation Tool (B£ST) [30]).

At EU-scale, guidance for pre-assessment is provided in context with the Environmental Impact Assessment (EIA) (Directive 2014/52/EU) [31] and within the NBS impact evaluation handbook [7]. The planning of NBS projects incorporates the assessment of potential impact on the environment as new projects must undergo an EIA to receive permission for it. Nonetheless, the guidance on the EIA Directive is neglecting the quantification of indicators. While the NBS impact evaluation handbook [7] offers guidance on the pre-assessment, monitoring, and evaluation of co-benefits, but specific assessment methods for each indicator are orientated towards monitoring and evaluation – oversighting the pre-assessment.

Also at EU-scale, the ecosystem service assessment framework [13,32] provides guidance on mapping and assessing the current status of ecosystems (and their services) along with an extensive list of European scale datasets that can assist in finding baseline data. This framework is broadly applied by researchers, for instance, Balzan et al. [33] quantitatively pre-assessed a number of regulating ecosystem services to support the prioritisation of NBS for dense urban areas, while a few cultural ecosystem services were qualitatively estimated by experts using a scoring approach. Their method for regulating ecosystem services could be adopted for assessing co-benefits, but pre-assessed co-benefits are limited to air quality, carbon storage, temperature regulation, noise reduction and socio-economic factors. Paracchini et al. [34] aimed at mapping cultural ecosystems in Europe, in particular the recreation potential. The GIS tool InVEST [35] was developed for decision-making support by monetizing potential ecosystem service provisions calculated based on land cover types. This tool is applicable e.g., for the assessment of potential impacts from Land Use and Land Cover Changes (LULCC).

The review and Table 1 highlight the fact that pre-assessment of ecological indicators is more commonly practiced than of socio-economic indicators. This phenomenon mirrors global challenges of socio-economic data collection and availability [36]. The following Section aims at balancing this difference by suggesting proxies and methods for the pre-assessment. Outputs of the assessment frameworks vary between indicator units [7,29,33], monetized values [29,30,35,37], dimensionless values [34] or scores [27], and qualitative results from experts, interviews and surveys [21,27]. This diversity in outputs challenges the integration of

Table 2
Summary of quantification approaches for co-benefit and disbenefit indicators along with suggested baseline data, and thresholds.

Indicator	Quantification/Reported Values	Threshold	Baseline Data
Air Quality Proxies: NO_2, PM10, SO_2, O_3	*Quantification:* changes in air quality can be estimated with the Pollutant Flux [39,40] based on estimations of the leaf area index or directly with the i-tree tool [29] *Reported values:* Horton et al. [41] summarised average pollutant uptake values for the above-mentioned proxies by trees and green roofs	Directive 2008/50/EC	Air Quality Statistic maps by the European Environment Agency
Carbon Storage & Sequestration by Vegetation	*Quantification:* sequestration by vegetation can be estimated with allometric equations based on dry weighted (above ground) biomass as applied by the i-Tree tool [29] *Reported values:* the Urban Nature Navigator [42] summarises carbon storage values per square meter for different urban NBS	Vegetation tolerance: air pollution tolerance index	Carbon sequestration (by forests) by the Joint Research Centre
Carbon Storage & Sequestration by Soil	*Quantification:* carbon stocks in soils are dependent on land cover and land use [35,43], climate regions and soil types [43], and urban-rural areas [44]. InVEST [35] provides estimates for different land uses/covers	Topsoil organic carbon contents/capacity depends on the soil	Soil organic stocks by the European Soil Database
Noise Attenuation	*Quantification:* the Noise Attenuation Potential by Tiwary et al. [40] can be used to estimate noise reduction with average leaf biomass and canopy area of trees and hedges *Reported values:* a buffer of 15–30 m width can attenuate about 6–10 dB while an avenue reduces about 4 dB [45,46]. In comparison, a 3 m high wall can reduce road noise by 15 dB [45]	Directive 2002/49/EC	NOISE maps by the European Environment Agency
Water Quality Proxies: Nitrate, Phosphor, and Sediments	*Quantification:* nutrient retention by vegetation can be estimated with the InVEST tool [35] *Reported values:* e.g., nutrient load reduction by riparian buffer strips [47]	Directive 76/160/EC	Waterbase Water Quality by the European Environment Agency
Soil Health Proxy: Bulk density	*Quantification:* bulk density can be used as a proxy for soil quality. Bulk density is dependent on the soil type but also the land cover. *Reported values:* e.g., Vandecasteele et al. [48] reports on examples of bulk density changes due to LULCC	Bulk densities of 1.47–1.8 g/cm3 are restricting root growth	Topsoil physical properties data by the European Soil Data Centre
Temperature Regulation Proxy: Thermal Comfort	*Quantification:* universal thermal climate index (UTCI)	UTCI Index	UTCI (1981–2010) by Copernicus Climate Store
Habitat Quality Proxy: Habitat Connectivity/ Fragmentation	*Quantification:* green spaces can be implemented to connect habitats and therefore, increase their quality. Habitats are fragmented by built environments including roads (so called Fragmentation Geometry). The mesh density is a measure to determine the wildlife corridors and fragmentation	Minimum habitat sizes for animal species	Mesh density by the Joint Research Centre Ecosystem map by the European Environment Agency
Ecosystem disservice Proxy: Pollen	*Quantification:* can be calculated on local changes e.g., tree species	Daily mean concentration per m3 [49]: low (1-10), moderate (10–100), high (100–1000), and very high (>1000)	European Aeroallergen Network
Ecosystem disservice Proxy: Mosquito	*Quantification:* can be estimated based on area of standing water or in extreme low flow river/stream sections. Different habitats and distribution areas need to be considered *Reported values:* Sunahara et al. [50] reported that mosquito larvae in habitats smaller than 0.1 m^2 have a better chance to survive (in regard to predators) as in water areas greater than 0.1 m^2. Mosquito breeding is also dependent on habitat connectedness and water temperature	Nuisance Thresholds	European Center for Disease Prevention and Control
Recreation	*Quantification:* according to Lee et al. [51] and Schägner et al. [52], the attractiveness of a space for recreational purpose is depending on the size of the area, the proximity to	A few sources (i.e., Abdullah et al. [53] or Niemelä et al. [54]) report on minimum sizes of recreational spaces for different	Recreational Opportunity Spectrum by the Joint Research Centre

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Table 2 (*continued*)

Indicator	Quantification/Reported Values	Threshold	Baseline Data
	population, the accessibility in terms of transportation but also the quality and aesthetic of the space. This indicator shall estimate visitor numbers of green or blue spaces which can be further linked to health and well-being but also socio-economic development. Usage can be estimated in different ways, for instance, the travel cost method or with the Recreational Opportunity Spectrum [34]	activities and the maximum distance to the space	LUISA base map by the Joint Research Centre
Tourism	*Quantification:* the Recreational Opportunity Spectrum concept can be used to assess the NBS area based on its naturalness, proximity, and other factors (e.g., species richness) [34]	*No threshold was found but a limitation could be the maximum number of people per km2 to preserve the naturalness of the place*	Recreational Opportunity Spectrum by the Joint Research Centre
Job Creation	*Quantification:* the number of employees in green space maintenance can function as a proxy for job creation. However, this co-benefit also includes job and/or business creation for the implementation of an NBS. Estimations could be based on average monthly/annual maintenance hours per unit of green space or from reported impact in NBS case studies	*No threshold found*	Unemployment data by Eurostat or local data or from local datasets
Property Values	*Quantification:* air quality, noise levels, thermal comfort, and the proximity to green/blue spaces are influencing property prices which can be calculated with the hedonic pricing method	Unaffordable housing costs can function as a threshold which lies around 40% of the disposal income within Europe [55]	Property Values: local datasets from e.g., housing gencies. Income by households: by Eurostat or local data
Tax revenue Proxies: property/real estate transfer tax (or tourism, tax income from increased number of jobs)	*Quantification:* tax revenue benefits from increased property values. Increased tax revenue can be calculated based on e.g., transfer taxes *Reported values*: Property/Real Estate Transfer Tax for Europe can be found in Barrios et al. [56]	*No threshold found*	*No baseline data found*
Social Cohesion/Inclusion	*Quantification:* social inclusion can be enhanced by green spaces promoting social contacts and the feeling of inclusion. While the co-creation of NBS can increase social cohesion and feeling of ownership of the place. Equal access to green space can be estimated by assessing households in proximity and the diversity of incomes. Other estimates of the cohesion and the feeling of ownership of the place can be made based on the potential of co-creation of the NBS. The type of green/blue space can imply the potential interactions (e.g., playgrounds may offer more possibilities to interact with others than a wetland)	*Threshold for exclusion - see property values*	Local household income data is needed
Energy savings	*Quantification:* InVEST [35] suggests an energy saving equation comparing baseline temperature and estimated temperature reduction *Reported values:* Santamouris et al. [57] provides global energy cost examples for 1 K increase in temperature	Energy Performance of Buildings Directive (EPBD)	Energy prices and consumption statistics by Eurostat or local datasets
Biodiversity Proxy: Birds	*Quantification:* biodiversity is influenced by soil health, habitat connectivity, water quality, and ecosystem disservices. Many proxies are identified for biodiversity like species richness of specific taxa or the number of distinct plant functional types, but they must be integrated with other metrics to fully capture biodiversity. EASAC [58] defined a set of biodiversity indicators including population trends, land use change, threatened species, coverage of protected areas, and trends in abundance and	Species (Plant and Animal) Thresholds	Bird Atlas by European Bird Census Council (EBCC)

(*continued on next page*)

Table 2 (*continued*)

Indicator	Quantification/Reported Values	Threshold	Baseline Data
	distribution of selected species. For urban environments, the city biodiversity index is another option [59,60]		
Health & Well-being	*Quantification:* this indicator is determined considering several aspects: increased recreational areas, reduced heat stress (e.g., quantifiable with the Universal Thermal Climate Index), air quality improvement, noise attenuation, ecosystem disservices but also by enhanced social cohesion and inclusion or the created jobs and income from tourism. Literature has been focusing on monetizing this indicator, for instance, by estimating avoided costs in the health sector or with the willingness to pay method. Health thresholds: see air quality, noise attenuation, thermal comfort		

different approaches. To counteract this, the following pre-assessment guidance aims at calculating a numerical value (in its actual unit) for each indicator. The numerical values can then be used for evaluation or further analysis (e.g., monetization, composite indicators).

3. Quantification of co-benefits and disbenefits

The quantitative pre-assessment of co-benefits and disbenefits shall support the overall NBS selection and permission process. As introduced above, NBS are commonly selected based on a broad range of criteria. The pre-assessment of potential side effects shall further complement the evidence-based decision-making on suitable NBS. Before quantifying the side effects, co-benefit and disbenefit indicators need to be selected: co-benefits and disbenefits are greatly dependent on the NBS intervention and the local context, hence, prior to the quantification, a strategy is to narrow down the number of indicators. Potential indicators can be selected by using developed matrices [8,11,37] or by reviewing case studies from NBS databases such as the OPERANDUM NBS Catalogue [38]. Selected indicators can be further aligned to the needs and interests of citizens and stakeholders who represent the main beneficiaries of an NBS. For instance, Giordano et al. [25] and Liquete et al. [21] incorporate stakeholders' and citizens' perceptions and needs by integrating weighted criteria considering the level of importance of each indicator to the community.

After narrowing down the list of indicators, the actual pre-assessment of co-benefits and disbenefits can be processed. The expected impact of each NBS can be calculated for every indicator based on methods introduced in Table 2. The methods introduced are largely acknowledging interlinkages between indicators. For instance, property prices are not only calculated based on the distance to green spaces but further incorporate improved air quality, reduced noise, and thermal comfort. In some cases, it might be more suitable to use proxies (e.g., nitrate and phosphor concentrations as proxies for water quality) which are introduced in Table 2. For the calculation of potential changes, a baseline approach [31,32] should be adopted. In many cases, it might not be necessary to assess the baseline directly due to existing data repositories at European scale with representative and openly available baseline data. In this context, Table 2 suggests a baseline dataset for each indicator. Considering local contexts, these baseline maps may be partly too coarse as a baseline, but comparable datasets might be available at (sub-)national level. The quantified outcomes can then be evaluated (as discussed in Section 4) and integrated into the comparison of different alternatives. Also, Table 2 lists thresholds found for some indicators to support the evaluation of significance (see Section 4).

4. Evaluation

The resulting numerical values calculated for each indicator need to be evaluated to fully understand the expected extent of co-benefits and disbenefits – i.e. how significant is the change and whether the change is positive or negative, or how sustainable is it considering long-term effects and contribution to SDGs and other global environmental frameworks. In this Section, we discuss the three research questions by drawing on existing frameworks and data manipulation methods to answer them.

1) How significant is the actual impact?

Significance plays a major role in the context of the EIA Directive where projects with significant impact on the environment need to undergo this process. However, it does not define a threshold for significance – i.e. which rate of change counts as significant? As part of the ecosystem assessment framework, Maes et al. [32] approached the analysis of significant change statistically by calculating decadal trends and defining a '5% per decade rule' - meaning that changes from±5% within a decade are of significance.

To be able to assess the significance of change, the quantification should encompass a first assessment of the pre-NBS situation of the area (baseline) for each of the selected indicators [31,32]. A great amount of baseline data are available at European scale as introduced in Table 2. Additional baseline data can be obtained from e.g., remote sensing, numerical modelling, social media analysis, or crowdsourcing. Despite the large amount of available data worldwide, they can be lacking sufficient quality in terms of accuracy, metadata, or appropriateness. In case that no sufficient data are available, a baseline can be assessed e.g., according to Maes et al. [32]. The results of the pre-assessment of co-benefits and disbenefits can then be compared to the baseline and the rate of change can be calculated.

Furthermore, co-benefit and disbenefit values can be evaluated regarding certain thresholds (enlisted in Table 2). In particular, it can be evaluated whether they are meeting the local needs by setting the resulting value into local context. This will further help to understand the significance of change. As an example, if the noise pollution level is 69 dB due to traffic, introducing treelines along the road shall diminish the traffic noise. Grown trees may then be able to reduce the noise by 9 dB which would be a reduction of 13%

which is not sufficient to reduce the noise to an acceptable (EU threshold) level of 53 dB.

2) When can co-benefits turn into disbenefits?

Co-benefits may evoke certain disbenefits such as social exclusion due to raising property prices while in some cases co-benefits can turn into a disbenefit. As exemplified in the introduction, high leaf density of a hedge or avenue can function as a barrier for air pollutants causing high levels on one side and low levels on the other side [20,61].

In Watkin et al. [27], the rate of change is calculated in percentage and translated into a score ranging from 0 to±5 (low to high) while 0 indicates no change. This approach further allows negative scores that can unveil when a co-benefit may turn into a disbenefit. Applying the statistical method by Maes et al. [32], the percentage of change can also indicate whether the change is positive or negative. For instance, in the above example, a negative change of air pollution would indicate a 'good' change while a positive rate of change would indicate an increase in pollution.

3) How sustainable is the NBS in the area of interest?

Considering the range of co-benefits and disbenefits, it is obvious that they are covering the three pillars of sustainability (economy, society, and environment). For a specific analysis about how co-benefits cover and support them, a composite indicator can be calculated [62]. Furthermore, quantified outcomes of the indicators can be discussed in context with global frameworks such as the SDGs or the targets of the CBD, but also local/municipal goals. This will establish an understanding of how the NBS simultaneously address other challenges and goals.

Sustainability also refers to addressing the needs of the future. In order to evaluate how an NBS will perform in the future considering changing climate, Calliari et al. [22] proposes a framework for backcasting NBS to pre-assess direct and indirect benefits linked with costs and to evaluate the suitability of NBS in projected future climate conditions.

Schaubroek [63] questions whether NBS are sustainable referring to the temporal aspect of their impact. In this context, it needs to be understood how the impact is to be expected in time (but also in space). Raymond et al. [37] highlights the issue of uncertainty of the effect in time due to local changes or changes in climate but considering the impact in time and space is non-neglectable. In accordance with the above example, reaching a 9 dB reduction is highly dependent on the tree height, canopy density, and the season – in the view of existing differences between evergreen and deciduous trees. For some indicators, a difference in effectiveness may even be detectable between day and night. Nonetheless, the time scale over which an NBS becomes effective depends primarily on the growth time of vegetation. Overall, it should be considered whether the NBS has short- or long-term impacts [28].

Also, co-benefits and disbenefits can have different spatial effects which are further dependent on local characteristics e.g., rural and urban growth differences but also on the size of the intervention, and on the indicator characteristics itself. Taking into account the vegetation growth time, impact may vary between urban and rural areas due to restrictions in vegetation growth [37,64,65].

5. Conclusion

This paper highlighted the need for quantifing co-benefits and disbenefits for NBS selection and permission processes. We reviewed available co-benefit assessment frameworks as well as tools and guidance from other disciplines such as the ecosystem service assessment. Available frameworks were found to be focusing primarily on monitoring and post-project evaluation of co-benefits by largely neglecting potential disbenefits. Whereas a number of tools were suggesting methods for pre-assessing co-benefits. Building on the existing research, this paper provides pre-assessment guidance to support decision-making on NBS for DRR by quantifying potential impact and evaluating its significance. The guidance was designed to assist in decision-making on suitable NBS and for the preparation of an EIA for NBS projects.

The variety of quantification methods for indicators discussed in this paper underlines the need for an integrative model or tool by incorporating the existing interrelationships. As regards specific categories, the prediction of biophysical indicators as well as the availability of baseline data with sufficient quality and suitable resolution is at an advanced stage. Whereas this does not account for most of the socio-economic indicators. To overcome this lack of data, more research is needed for estimating socio-economic indicators i.e., based on new data sources such as social media. An additional challenge is the resolution of baseline data at European scale as fine resolutions are associated with large files. Fine resolution datasets likely exist at municipal level but are often not openly available. Another key point of this paper was the investigation of potential disbenefits and the need to include them into the assessment process. Additional studies are needed to unveil disbenefits to fully integrate them into decision-making and impact assessment.

Nature-based Solutions are of increasing importance around the world due to their co-benefits for the environment, society, and economy. While NBS are addressing Disaster Risk Reduction, co-benefits are rather supporting the SDGs, targets of the Paris Agreement and the CBD. This trend of NBS is a significant step towards the aforementioned global frameworks. However, to fully grasp the contribution of NBS to these frameworks, it is necessary to quantify the co-benefits and the disbenefits. Only with the quantification of those it is possible to make evidence-based statements on the impact of NBS on those frameworks.

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Declaration of competing interest

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

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