An assessment framework for climate-proof nature-based solutions

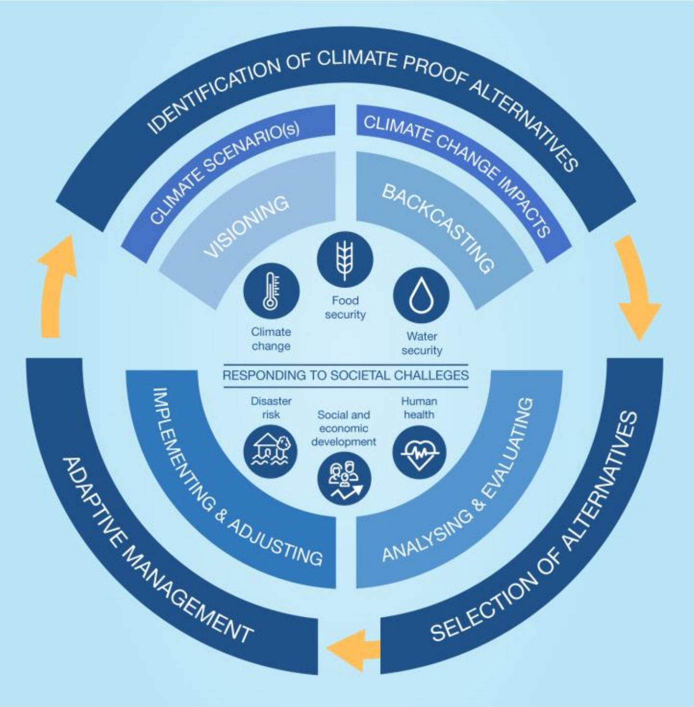
Elisa Calliari[1,2], Andrea Staccione[1], Jaroslav Mysiak[1]

[1] Euro-Mediterranean Center on Climate Change and Ca' Foscari University of Venice

[2] University College London

Corresponding Author: Elisa Calliari, e.calliari@ucl.ac.uk

Graphical Abstract



Abstract

Raising interests in ‘nature-based solutions’ (NBS) inspired attempts to organise their principles and qualities within comprehensive and internally consistent evaluation frameworks, so as to demonstrate the superior performance of ‘working with nature’. However, the proposed frameworks stop short of taking into account the changing conditions in which NBS are set to operate. Climate change, in particular, can alter ecosystems and their services, and may undermine the performance of green solutions that rely on these. We present here a ‘dynamic’ assessment framework explicitly accounting for the impact of climate change on the effectiveness of the proposed NBS. The framework is based on an innovative approach integrating system analysis and backcasting. Although it has not yet applied within the NBS context, backcasting is well-suited to seize the transformational character of NBS, as it encourages ‘breakthrough’ leaps rather than incremental improvements. Our framework factors in NBS’ multifunctional character and is designed to capture associated direct benefits/costs and co- benefits/costs. It is meant to be applied ex ante to ideally support the choice between innovative NBS and traditional options, in an effort to respond to the societal challenges identified by the EU Research & Innovation agenda on the environment.

1. Introduction

The ‘working with nature’ method has gained increasing prominence across the EU policies over the past decade. Ecosystem-based initiatives have been pursued under different domains such as adaptation to climate change (EC 2009, 2013), biodiversity protection (EC 2011a), integrated water resource management (EC 2012, 2014), and disaster risk reduction (EC 2011b). More recently, the narrative of ‘working with nature’ has been flanked with that of ‘innovating with nature’ as promoted by the EU Research and Innovation (R&I) policy agenda for Nature-Based Solutions and Re-Naturing Cities (EC 2015a).

Nature-based solutions (NBS) have been given centre stage as a way to respond to societal challenges through innovative actions inspired or supported by nature (EC 2015b). A stated objective is to position the EU as a global leader on NBS-enabled innovation (EC 2015a). The European Commission (EC) expects that NBS can facilitate a transition towards a more resource efficient and competitive economy, foster economic growth and create new jobs[1]. NBS are seen as a way to reconcile the dichotomy between economic growth and socio-environmental concerns, thus offering a realistic transition path toward a sustainable economy (Maes and Jacobs 2015). With around three quarters of European citizens living in cities, NBS also feature among the priorities of the New Urban agenda for the EU (EU 2016). Renaturing and greening urban areas are expected to play and essential role in improving citizens’ quality of life.

Curiously enough, and despite benefits ascribed and expectations raised, NBS still lack a widely-agreed upon definition. The emerging academic literature largely frame NBS as ‘an umbrella concept’ for other established ecosystem-based approaches, like ecosystem-based adaptation (EbA), mitigation (EbM), disaster risk reduction (Eco-DRR) and Green Infrastructure (GI) (Nature 2017a). Yet, the actual distinction with these terms is disputed and the lack of precise criteria to identify NBS risks making them seem conceptually arbitrary and impractical (Albert et al. 2017).

In an effort towards the operationalization of the concept, several frameworks have been recently proposed to narrow down NBS’ scope and assess their effectiveness. Liquete et al. (2016), Raymond et al. (2017b), and Zölch et al. (2017) focussed on assessing NBS in European urban or peri-urban environments, while Reguero et al. (2014) and Narayan et al. (2017) analysed NBS in relation to avoided losses of coastal hazards in the United States. The above frameworks consider NBS as static over time. Even when different socio-economic and climate change scenarios were considered (e.g. Reguero et al. 2014), the effectiveness of NBS has been assessed as if they were “immutable” and unaffected by changing future conditions.

Yet, ongoing environmental changes may undermine the integrity of ecosystems and affect the capacity of a NBS to deliver the expected outcomes. It is therefore important to design ‘dynamic’ assessment frameworks which do not only account for the impact climate change will have on the frequency and/or intensity of the hazards of interest, but also on the way the effectiveness of the proposed solution will be affected. In this paper, we propose a framework which addresses such feedback effects. The framework reconciles and complements previous efforts, and proposes an innovative approach that builds on the integration between systems analysis and backcasting. The latter is useful to capture the (potentially) transformational essence of NBS within societal system, as it encourages ‘breakthrough’ leaps rather than incremental improvements (NEAT 2018). The framework explicitly factors NBS’ multifunctional character, i.e. the capacity to deliver simultaneous benefits for the society, economy and the environment, and is designed for capturing associated direct benefits/costs and co- benefits/costs. It is meant to be applied *ex ante* to ideally support the choice between innovative NBS and traditional options. In this paper, we focus on disaster risk reduction and climate change adaptation (DRR/CCA) as the main challenges to be tackled through NBS, but we recognise the potential for

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[1] See: https://ec.europa.eu/research/environment/index.cfm?pg=nbs

the framework to be applied across virtually all the societal challenges identified by the EU R&I agenda on the environment and also including sustainable urbanisation and climate change mitigation (EC 2015a).

The paper is structured as follows. In the first section we explore the conceptual boundaries of NBS and review common features. We identify constitutive elements that need to be captured in the assessment framework and we scrutiny the literature on NBS' effectiveness at various spatial and temporal scales. As next, we review the recent assessment frameworks and discuss their features, scale of application, and methods used (Section 3). In section 4 we outline a framework for ex-ante assessment of direct benefits/costs and co- benefits/costs of NBS. Section 5 is devoted to discussion of the main conceptual and operational challenges as well as opportunities in the application of the framework.

2. NBS: a primer

2.1 Definitional and conceptual aspects

While the debate on definition of NBS is not yet settled (Nesshöver et al. 2017), most conceptualizations build upon or refer to those elaborated by IUCN and the EC. IUCN defines NBS as "*actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (Cohen-Sachman et al. 2016). Eight foundational principles are provided and encompass the endorsement of nature conservation norms, consideration of local natural and cultural contexts, fairness and equity in delivering societal benefits, application at the landscape scale, and a forward-looking attitude in considering ecosystems evolution and associated benefits. The EC's definition embraces cost-effective, locally adapted and resource-efficient solutions that are "*inspired by, supported by or copied from nature*" and "*simultaneously provide environmental, social and economic benefits and help build resilience*" by bringing "*more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes*" (EC 2015b).

A common denominator is a recognition that nature can play in tackling major societal challenges, including climate change adaptation and mitigation, and disaster risk management. The terms "solutions" implies a problem-centred approach (Potschin et al. 2016a) and builds upon an anthropocentric view of the benefits that natural resources management can bring to humans (Nesshöver et al. 2017). Another shared distinctive trait concerns NBS' capacity to deliver simultaneous benefits for the society, economy and the environment (Albert et al. 2017), a feature that is often referred to as "multifunctionality" (Kabisch et al. 2016). The EC, in particular, emphasises the way NBS can contribute to green growth by providing business opportunities. Other complementary characteristics proposed in the literature include cost-effectiveness (EC 2015b; Keesstra et al. 2018), adaptability (Cohen-Sachman et al. 2016), the application of participatory processes for the co-design, co-creation and co-management (Pauleit et al. 2017), and reliance on multidisciplinary, evidence-based strategies (Nature 2017b). In terms of the scale of the intervention, NBS are usually applied on urban and/or landscape/seascape scale.

Several aspects remain unclear. A main challenge is where to draw the line between what can be considered as 'nature' or 'natural' and what cannot (Nesshöver et al. 2017). This both concerns the level of human intervention on ecosystem processes that can be deemed acceptable as well as the inclusion within NBS of action solely inspired by nature as biomimicry. The latter, for instance, is explicitly excluded in the definition provided by IUCN (Cohen-Sachman et al. 2016) while possibly endorsed in that of the EC (2015). The relationship between NBS and innovation is also contested, with some considering the latter at the heart of this kind of solutions (eg., the EC (2015) (Potschin et al. 2016b)) and others not even mentioning it (eg, IUCN (2016) and Keesstra (2018)).

An even trickier issue is the relationship between NBS and more established ecosystem-based approaches. For some, the emerging NBS stream only reframes the long-established objectives to maintain and restore ecosystems and their services from a human-centred perspective (Eggermont et al. 2015) and emphasise the social and economic benefits of resource-efficient and systemic solutions that combines technical, business, finance, governance, regulatory and social innovation (Raymond et al. 2017b). This is the stance taken by IUCN that labels as NBS interventions like ecological engineering, EbA, EbM, Eco-DRR, Natural and GI, Integrated Coastal Zone Management (ICZM), Integrated Water Resources Management (IWRM) and protected areas management. Others instead try to differentiate NBS from the above related approaches. Faivre et al., (2017) note that EcoDrr, NWRM, EbA, and GI focus on short-term economic benefits and effectiveness, while NBS offers an integrated perspective for addressing societal challenges. Pauleit et al.(2017) consider NBS, EbA, Urban Green Infrastructure (UGI) and ecosystem services as closely interrelated, overlapping and complementary concepts. The EC recognises that NBS build on other ecosystem-based approaches but stresses the distinctive premises the former are based on: i) some societal challenges originate from human activities that failed to recognize ecological limitations; ii)sustainable alternatives to those activities can be found by taking inspiration from nature. An innovative application of knowledge about nature becomes therefore a foundational element of NBS, which is not found in other related approaches.

We adopt the definition of NBS provided by the EC (2015) and propose an assessment framework suited to capture multifunctionality; simultaneous delivery of economic, environmental and social benefits; cost-effectiveness; and co-production of scientifically sound knowledge through multi-stakeholder engagement. We restrict our scope in considering only those solutions actually based on ecosystem services and not solely inspired by nature as biomimicry. By focusing on the living components of ecosystems, we further stress the need for NBS to be “climate-proof”, i.e. able to deliver their expected outcomes under future climate conditions.

2.2 NBS in practice

Despite the growing attention NBS received from civil society groups, donors, decision-makers, investors and insurers (WB 2017), a more comprehensive evidence base is needed on their social, economic and environmental effectiveness (EC 2015b).

The growing literature on NBS has primary focused on their effectiveness for DRR /CCA or pollution control purposes. It suggests that they best perform in the case of high-frequency, low-intensity events. For instance, Zolch et al. (2017) assess the potential of UGI in regulating urban surface runoff against current and projected climate conditions in Munich and find that their contribution is limited unless all available spaces are greened and anyway decreasing under future climate conditions due to limited water storage capacities. A similar conclusion is drawn by Reguero et al. (2014), who assess different options against coastal erosion and flooding in the Gulf of Mexico. The study compares NBS (eg. wetland restoration and conservation, oyster reef restoration, beach nourishment), artificial defences, and policy measures under different climate and socio-economic scenarios and derives cost-benefit ratios estimates for avoided damages up to 2030. It finds that NBS as oyster reef and marsh restoration are particularly cost-effective, although this very much depends of where they are used. Moreover, NBS seems to show the highest benefits in the case of high-frequency, low-intensity events. More recently, Narayan et al. (2017) employ high resolution flood and loss models to estimate the contribution of coastal wetlands to avoided property damages during Hurricane Sandy and find that their presence reduced total damage by 1% only.

The spatial scale considered for planning NBS substantially affects their ability to deliver expected outcomes. Often, ecosystems cannot be sustained by managing individual sites in isolation as the delivery of associated services might depend on processes taking place at a larger scale (Andersson et al. 2017; WB 2017). Larger planning processes are therefore necessary to build connectivity among interventions and create a ‘green network’ enhancing overall system resilience. This is challenging to be achieved where little space is available for NBS, as in the case of urban contexts. The temporal scale is also important. Ecosystems are living entities and, as such, evolve over time as the result of natural processes or as responding to external pressures. Global environmental changes, including urban sprawl and amplified extreme climate phenomena, fall in the latter category. The value of ecosystem services in Europe is expected to decrease by the 2020 of 0-5% and 10-15% by the 2050 as driven by the current trend of land conversion and soil sealing (Maes et al. 2015). In addition, climate change will alter the temporal and the spatial distribution of ecosystem processes and functions and thus modify the delivery of associated services (Nelson et al. 2013). Changes might not be necessarily negative and can considerably vary across geographical areas and sectors (Polce et al. 2016; EEA 2017). Yet, this suggests that the effectiveness of a NBS designed at a certain point of time might dynamically vary, as a result of external impacts on ecosystems' living components. Finally, the time it takes for NBS to be finalised or becoming effective should also be considered as growth rate of its living components and stage of maturity can substantially affect its effectiveness. Given both spatial and temporal constraints, hybrid interventions combining NBS and traditional options might be appropriate, especially at the urban scale (Depietri and McPhearson 2017).

3. Review of key NBS assessment frameworks

For NBS to be "preferred" over other conventional grey or hybrid intervention, comprehensive assessment frameworks are needed to prove their effectiveness and efficiency while capturing the diverse benefits they provide to the society. As discussed below, this complexity is only partially rendered by recently proposed assessment frameworks.

Kabisch et al. (2016) and Xing et al. (2017) have examined indicators of NBS effectiveness at the urban scale, but kept a level of abstraction that does not support a comparison with different alternatives. The World Bank (2017) has developed a guidance for NBS for flood risk management, as alternative or complementary to conventional engineering measures. The document describes the timeline and activities needed to implement NBS and thus starts from the assumption that they have been identified as the best option. While assessing the effectiveness of NBS against traditional options falls out of its scope, the guidance importantly highlights several factors which are specific to NBS and should be considered by comprehensive assessment exercises. In particular, it draws attention to the spatial and temporal scales of NBS, including to the dynamism of NBS' risk reduction functions. Indeed, it might take years for a NBS to be finalised or unfold its DRR potential. It further states the need for the additional economic, environmental and social benefits associated with a NBS to be considered as a way to enable a more holistic comparison to traditional engineering approaches.

The guidance follows the general cycle of traditional flood risk management projects and it is made of eight steps. The first entails the identification of the flood hazard(s), relevant stakeholders, the scale of the natural system which is suitable to problem solving, and the definition of measurable project objectives. Step 2 concerns the identification of the financing resources available for implementing NBS, while Step 3 is devoted to the assessment of flood risk, taking into account ecosystem types in the area, their DRR potential and anticipating future trends in their stability and resilience against different socio-economic scenarios. In step 4, different management options are identified as consistent with the acceptable level of risk deliberated in step 1 and the available resources. Step 5 is devoted to an estimation of the costs, benefits and effectiveness of the selected measure in relation to the risk reduction target and by taking into consideration current and future climate and socio-economic projections. The most effective and appropriate option should be selected through cost-benefit analysis and by considering local needs and capacity (Step 6). Finally, Step 7 involves the implementation and construction of the measure, and step 8 the monitoring of its effectiveness over time.

Much of these solicitations are accommodated in the NBS assessment frameworks proposed by Raymond et al. (2017b) and Liquete et al (2016). Raymond and co-authors assess co-benefits (and costs) of NBS across elements of i) socio-cultural and socio-economic systems, ii) biodiversity, iii) ecosystems and iv) climate and physical environment and with a specific focus on urban areas. They consider ten challenges which can be positioned within or across these domains and propose a framework to assess the impact of specific NBS actions within and across the ten challenges. For each potential NBS action, expected economic, environmental and social impacts are identified as direct benefits and costs, together with related indicators and examples of possible assessment methods (Raymond et al. 2017a). The strength of the framework is to draw attention not only to the direct benefits delivered by NBS but also to capture the diverse positive (co-benefits) and negative impacts they can bring within the same and across other challenge areas. However, it was not design to support the choice between NBS and grey/hybrid interventions, as the aim was to propose a seven-stage participatory process for implementing NBS. The process involves the following steps: i) identifying the problem to be addressed or opportunity to be seized; ii) selecting and assessing NBS and related actions; iii) designing NBS implementation processes; iv) implementing NBS; v) frequently engaging stakeholders and communicating co-benefits; vi) transferring and upscaling NBS; (vii) on monitoring and evaluating co-benefit. Step i) prescribes to identify what NBS and alternative grey/hybrid solutions can address the problem at hand, based on a comparison of the benefits they respectively bring. This should inform the choice of a specific NBS action (eg. renaturing urban waterbodies to reduce flood risk) that is eventually assessed in stage ii). Yet probably, the comparison should be made at this latter level to assess the identified NBS action and its alternatives against the same expected outcomes and indicators. This aspect could pose issues in terms of operationalization and application to a specific case study. It is worth noting that the same authors stress that the framework has not been applied to date and that it will require further operationalization and refinement, also in order to capture different elements of NBS effectiveness across temporal and spatial scales.

Liquete et al. (2016) perform an *ex post* assessment of the environmental, social and economic benefits of a multi-purpose NBS for water pollution control in Northern Italy by embracing an ecosystem service approach and by applying an integrated evaluation based on multi-criteria analysis (MCA). MCA is chosen as a methodology to establish preferences among different options, the latter being: i) the creation of a series of constructed wetlands surrounded by a park (the NBS) ii) a conventional first-flush and buffer tank (grey infrastructure); and iii) keeping the existing poplar plantation (doing nothing). The MCA is based on the analytic hierarchy process (AHP) (Saaty 1987). The application of the AHP to the case study involves the following five steps. The first step aims at identifying the problem and structuring it as a hierarchy, with this meaning identifying the objective to be achieved (water pollution control), the criteria (social, environmental and economic benefits) and sub-criteria that contribute to attain it. The sub-criteria are identified by stakeholders through a dedicated workshop and represent what they consider to be important benefits that the interventions should provide. These include: reducing flood risk; improving people recreation and health; improving water quality; supporting wildlife; producing goods (wood) and reducing public costs. In the case of the NBS, all the former can be read as the ecosystem services provided by the wetland (excluding the one about costs). For each sub-criterion, relevant indicators are identified. Finally, the authors group sub-criteria into the three pillars of an integrated valuation (environmental, economic and social). As a second step, the three alternatives are assessed against a number of indicators which were monitored throughout one year (eg. peak flow reduction (%)). Sub-criteria are then pairwise compared by stakeholders (step 3) and these judgments used together with the alternatives assessment to develop overall priorities for ranking alternatives (step 4). As a final step, a sensitivity analysis of the sub-criteria weights is run. The authors find that the implemented NBS ranks first among the grey and doing nothing alternatives. Although construction and maintenance costs slightly exceed those of a traditional grey infrastructure, the NBS provides additional economic, environmental and social benefits of interest for local stakeholders and that make it preferable to other options. While the assessment framework is used retrospectively in the case study, the authors stress it could also be employed for ex ante assessments.

Table 1 synthetises key features of the frameworks reviewed in this section and in section 2.2, by highlighting the societal challenges considered, the NBS proposed, the aim and scale of the assessment framework, the approach and methods used and the consistency with the modified EC (2015) definition adopted in this paper.

Table 1: Synthesis of key characteristics of NBS assessment frameworks

	Societal challenges considered	Scale	NBS	Aim of the framework	Approach and methods	Counterfactual	Check list analysis
Liquete et al. (2016)	Water pollution control	L	GI (i.e wetlands surrounded by a park)	To assess multiple benefits (environmental, social and economic) provided by a multi-purpose green infrastructure	Multi-criteria analysis (MCA) based on the analytic hierarchy process (AHP)	"Doing noting" (i.e. maintaining the original poplar plantation) and grey infrastructure	☑ Integrated valuation ☑ Multifunctionality (only co-benefits, no co-costs) ☑ Stakeholders' involvement ☒ Climate change scenarios considered (hazard) ☒ Climate-proofing of the NBS ☑ Support for decision-making across alternatives
Zolch et al. (2017)	DRR (flood)	U	GI (trees and green roofs)	To assess the potential of Urban GI in regulating urban surface runoff against current and projected climate conditions ()	Micro-scale modelling approach using the integrated hydrological model MIKE SHE. Two scenarios are considered: i) small rain events with a return period of two years; ii) average heavy rain events consistent with climate models' projections for 2030-2060.	Current greening situation in the case study area and associated runoff	☒ Integrated valuation (only physical) ☒ Multifunctionality ☒ Stakeholders' involvement ☑ Climate change scenarios considered (hazard) ☒ Climate-proofing of the NBS ☒ Support for decision-making across alternatives
Raymond et al. (2017)	CCM and CCA; WRM; CR; GSM; AQ; UR; PPG; SJC; PHWB; GJ	U	No specific measure assessed. Reference to wider categories of ecosystem-based approaches, such as ES, 'green-blue infrastructure', 'ecological engineering', 'ecosystem-based	To assess NBS economic, environmental and social co-benefits and costs	For each challenge, potential NBS are identified together with expected impacts, indicators of impact, related metrics and assessment methods (eg. monetary and non-monetary, environmental and integrated assessments)	Alternative green or grey/green solutions	☑ Integrated valuation ☑ Multifunctionality ☒ stakeholders' involvement ☑ Climate change scenarios considered (hazard) ☒ Climate-proofing of the NBS ☒ Support for decision-making across alternatives

			management’ and ‘natural capital’				
Roguero et al. (2015)	CR, CCA, DRR	R	Wetland restoration; wetland conservation; oyster reef restoration; beach nourishment	To assess the role and cost-efficiency of adaptation measures in the Gulf of Mexico (USA)	Three-steps approach based on the Economics of Adaptation (ECA) Framework i) probabilistic assessment of hazards; ii) estimation of damages; iii) cost-benefit analysis of different DRR/CCA options	Artificial coastal defences (floodwalls, levees, storm surge barriers)	☒ Integrated valuation (only physical) ☒ Multifunctionality ☒ Stakeholders’ involvement ☑ Climate change scenarios considered (hazard) ☒ Climate-proofing of the NBS ☑ Support for decision-making across alternatives
Narayan et al. (2017)	CR, DRR (flood)	L, R	Coastal wetlands (regional study)/ salt marshes (local study)	To quantify the contribution of coastal wetlands in avoiding direct flood damage to property in Northern USA	High resolution flood model (Mike-21) and loss models	No coastal wetlands/salt marshes	☒ Integrated valuation (only physical) ☒ Multifunctionality (only economic) ☒ Stakeholders’ involvement ☒ Climate change scenarios considered (hazard) ☒ Climate-proofing of the NBS ☒ Support for decision-making across alternatives
WB (2017)	DRR (flood)	L, R	Interventions implying managing the present ecosystem or actively intervening on/creating new ecosystems	To provide a guidance for the planning, assessment, design, implementation, monitoring, management, and evaluation of NBS	Flood risk management project cycle	-	☑ Integrated valuation ☑ Multifunctionality ☑ Stakeholders’ involvement ☑ Climate change scenarios considered (hazard) ☑ Climate-proofing of the NBS ☒ Support for decision-making across alternatives

Acronyms: CCM= Climate Change Mitigation; CCA=Climate Change adaptation; WRM=Water Resource Management; CR= Coastal Resilience; AQ=Air quality; GSM: Green Space Management; UR= Urban Regeneration; PPG=Participatory planning and governance; SJC= Social justice and cohesion; PHWB=Public health and wellbeing; GJ= economic opportunities and green jobs; GI= Green Infrastructure; ES=Ecosystem Services; L=Local; R=Regional; U=Urban; ☑=Present; ☒=Missing.

4. Proposed assessment framework for climate-proof NBS

Building upon the review in section 3, we propose a framework for an *ex-ante* assessment of the direct benefits/costs and co-benefits/costs of NBS. The framework makes it possible to assess NBS suitability across most societal challenges identified in the EU Research and Innovation (R&I) agenda on the environment (EC 2015a). It is designed to explicitly account for NBS' constitutive elements including: multifunctionality; simultaneous delivery of economic, environmental and social benefits; multi-stakeholder engagement. It address the impacts of future climate change on the ecosystems and ecosystem services on which the proposed NBS are grounded. By "climate-proofing" NBS, our framework overcomes limitations identified in section 3.

The framework integrates system analysis and backcasting. Systems analysis supports decision makers when facing complex choices under uncertainty (Miser 1994) (Enserink et al. 2010). Systems are defined by a problem situation, typically involving nature, man and his artefacts -including technology, law and social customs (Miser 1994)-, and are characterised by many variables, feedback loops and interactions (Walker 2000). The societal challenges NBS are called to tackle fall within this category of problems (Raymond et al. 2017b). System analysis helps to structure complex policy choices by identifying a set of logical stages that the analysis should follow. While there are many variations, the stages can be grouped into four main blocks including i) problem definition, ii) identification of solution alternatives; iii) analytical comparison of alternatives; iv) choice of the most preferred alternative (Larichev 1983a). Building on Shell (1971), Walker (2000) and Enserink et al. (2010), we design a sequence of seven steps: i) baseline definition; ii) setting of the objective(s); iii) identification of enabling factors and constraints; iv) definition of alternative courses of actions; v) climate-proofing of alternatives; vi) identification of evaluation criteria; vii) performance analysis; viii) evaluation.

To capture the potentially transformational character of NBS, system analysis is integrated with backcasting. Developed by Robinson (1982) for soft path energy development, backcasting aims to support future-oriented decision-making process in complex and transforming systems. In contrast with forecasting, which addresses the identification of most likely futures, backcasting is explicitly normative and concerned with the identification of solutions for achieving a desirable and preferable future end-point (Wilson et al. 2006). Backcasting has gained traction in sustainability studies as dealing with uncertain and complex issues end embracing a long-term perspective (Dreborg 1996). In particular, it has been used in management and planning to support system innovation processes (Quist 2007), as encouraging 'breakthrough' leaps rather incremental improvements (NEAT 2018). Backcasting is preceded by the visioning stage, aimed at designing comprehensive, practical and plausible desired future states (Wiek and Iwaniec 2014). Visioning is well-establish step in planning processes (Shipley 2002), and encompasses a wide range of approaches and styles. When coupled with backcasting, it serves for the construction of a baseline reflecting the business-as-usual projection, together with a series of images of desirable future in the longer term (25–30 years) (Soria-Lara and Banister 2017). Visioning is a group exercise and a wide and representative range of stakeholders should be involved in it (Wangel 2011). Given the wide range of expertise involved, it calls for a transdisciplinary approach. We acknowledge that the spectrum of stakeholders' involvement can be very wide, from passive roles to genuine partnerships with decision makers. Here, we endorse the EC's call for NBS to be based on knowledge co-production, with this implying a sustained, reiterated and equal engagement of stakeholders in the development and decision-making processes related to the delivery of public goods and services. Finally, the multiplicity of actors required for the visioning stage allows for overcoming a recognised limit in systems analytical approaches, that is to be oriented towards the choice of a single decision maker (Larichev 1983b).

In practical terms, the visioning and backcasting stages might be undertaken together, although they are here conceptually distinguished for the sake of clarity. We subsume steps i) ii) and iii) identified through systems analysis under the visioning stage, while steps iv) and v) are comprised within backcasting. We add an additional stage 'quantifying and selecting' to comprise steps vi), vii) and viii) as informing the selection of the preferred alternative. The overall NBS assessment framework is presented in Figure 2.

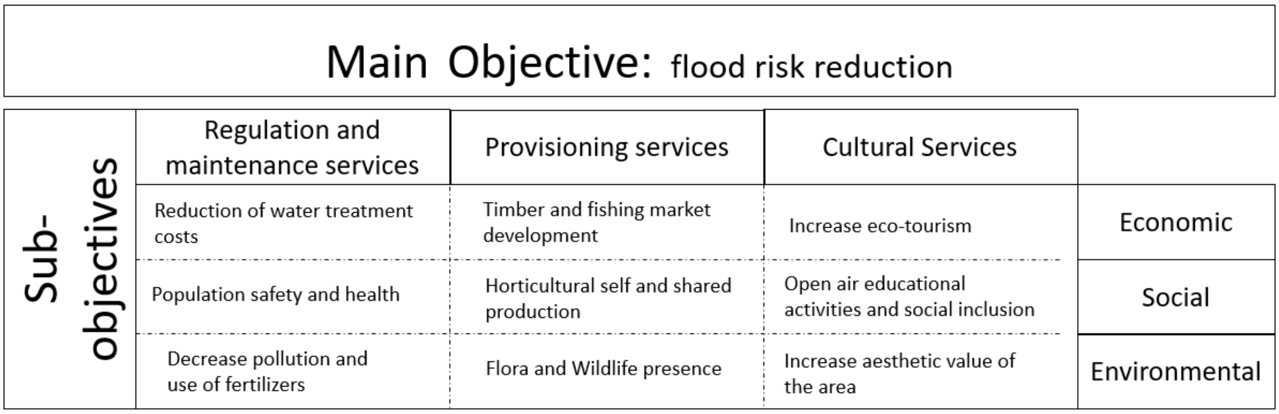
4.1 Visioning

By working with stakeholders, visioning seeks to transform a commonly perceived unsatisfactory situation (O'brien and Meadows 2007) through the definition of a shared vision for the future (Shipley and Michela 2006). Different time horizons can inform the exercise. Typically, decision makers engaged in "forward planning" have concentrated on a time span of 10-20 years into the future (EC 2017). Choices connected to CCA or DRR might involve a longer time horizon, being this way consistent with those considered in impact studies (typically half of the 21st century).

1) Define the baseline. The starting point is an accurately described and analysed the unsatisfactory situations that should be transformed. This step implies setting the boundaries and structure of the system of interest, by accurately describing the present situation, including in its social, economic, ecologic and governance dimensions, as well as the prevailing trends at the chosen geographical scale. Attention should be drawn on eliciting the way systems component are interconnected, in order to later identify possible second order effects of the chosen course of action. The output of the step is the creation of a baseline that, under the current discussion on NBS, conceptually corresponds to the societal challenge (eg. disaster risk) or problem (Enserink et al. 2010) that needs to be addressed.

2) Set the objective(s). The objectives describe the desired situation and therefore the concrete goals that an action or a set of actions (i.e. a policy) wants to attain. The main objective corresponds to overcoming the problem identified in step 1 (eg. reducing disaster risk). However, the solution put in place to solve or reduce the problem could positively or negatively affect other system components. It is thus important to identify a number of sub-objectives that an 'archetype solution' should deliver (eg. reducing disaster risk while concurrently providing economic opportunities). In other words, the definition of sub-objectives allows for identifying opportunities to be harvested and side-effects to be avoided as associated to the problem resolution.

Sub-objectives should be identified by adopting an integrated valuation approach, concurrently considering environmental, economic and social aspects (Boeraeve et al. 2014) and by accounting for the multifunctionality of an ideal solution. Figure 1 provides an example of how the mapping of sub-objectives could be undertaken.



Main Objective: flood risk reduction

	Regulation and maintenance services	Provisioning services	Cultural Services	
Sub-objectives	Reduction of water treatment costs	Timber and fishing market development	Increase eco-tourism	Economic
	Population safety and health	Horticultural self and shared production	Open air educational activities and social inclusion	Social
	Decrease pollution and use of fertilizers	Flora and Wildlife presence	Increase aesthetic value of the area	Environmental

Figure 1 : Exemplificatory mapping of objective and sub-objectives in a urban area. In this illustrative example, we consider a city surrounded by agricultural land and subject to flood risk from the river crossing the city. In the case of a NBS, expected benefits correspond to different categories of ecosystem services (Regulation and maintenance, provisioning and cultural).

3) Enabling and constraining external factors. The external factors that can enable and/or constrain the desired future situation should be considered. This means drawing attention to wider political, economic, demographic and environmental trends that can affect the system of interest. At a more practical level, it also implies developing a financing strategy and reflecting on how budget constraints could be overcome.

Importantly, the consistency of the preferred future situation with expected climate change impacts on the system should be factored. The choice of the time horizon and scenario(s) under which climate change impacts on the alternatives is to be assessed is not straightforward as entails different (and equally plausible) visions on how the future might unfold. A common practice is to compare climate change impacts under the IPCC's scenarios Representative Concentration Pathways (RCP) 4.5 and 8.5, as representatives of an intermediate and a pessimistic evolution of greenhouses emissions levels respectively. Yet, risk averse decision makers/stakeholders might go for a RCP 8.5. For instance, in a study about adaptation options in delta and coastal environments, Kebeded et al. (2018) focus on the global RCP 8.5 scenario as maximising the sampling of uncertainty and in future climate change and providing a challenging yet plausible scenario against which the robustness of adaptation measures can be tested.

While presented as subsequent to one another, it is worth noting that steps i). ii) and iii) are part of a cyclic and re-iterative process through which decision-makers, stakeholders and experts continuously go back to the problem and revise the desired objectives in the light of external factors.

4.2 Backcasting

Backcasting stage works backwards to the present in order to determine how they can be achieved (Dreborg 1996). This basically means identifying the set of concrete action that can lead to the desired situation. The following three steps are included in this stage:

4) Identify the alternatives. Alternatives include different actions through which the main objective and sub-objectives identified in the visioning stage can be reached. This step thus implies moving from the 'archetype solution' of step 2 to concrete ones. Alternatives can be traditional, nature-based or hybrid solutions. For example, given flood risk reduction as the main objective, alternatives to stabilise riverbanks could include i) concrete retention walls (traditional); ii) willow spiling (NBS); or iii) vegetated concrete blocks (hybrid). They always encompass a 'doing nothing' scenario, as baseline to appreciate the change brought by different courses of action.

As nature-based (and hybrid) solutions are grounded in the services provided by ecosystems, the identification of this type of alternatives implies matching stakeholders' desires and needs (ES demand), as developed in the visioning stage, with what local ecosystems can deliver (ES supply). Ecosystems are typically multifunctional and provide a variety of (potentially interacting) ES. When a set of services appears together repeatedly in time and/or space, it is referred to as a 'bundle' (Raudsepp-Hearne et al. 2010) and the positive and negative associations among its services as synergies and trade-off (Mouchet et al. 2014). Given that NBS imply managing ecosystems for delivering societal and environmental benefits, the way this will affect associations among ES should be considered. A methodological guide for quantifying ES synergies and trade-off has been proposed by Mouchet and co-authors (2014). A review of emerging evidence on ES supply bundles has also been recently published (Saidi and Spray 2018).

The bundle analysis can usefully test the correspondence between the actual services delivered by the NBS/hybrid alternative and the objective and sub-objectives outlined in stage 2. In this respect, attention should also be paid to the ecosystem disservices that a management choice could deliver. For instance, urban green spaces provide a number of ecosystem services like reducing the heat island effect, improving air quality, contributing to carbon sequestration and offer recreational opportunities (Chang et al. 2017). However, these come with potential disservices in terms of health (asthma and vector-borne diseases), high maintenance costs for infrastructures and buildings nearby, perception of unsafety by local population (Lyytimäki and Sipilä

2009; Cariñanos et al. 2017; Vaz et al. 2017). In case of a mismatch between ES supply and ES demand, a different alternative can be picked, or the objectives refined.

5) Climate-proof the alternatives. After the alternatives are identified and designed, their climate resilience needs to be tested. This allows for allows for considering nature-based or traditional investments options in a medium to long-term perspective and with respect not only to the hazard they are designed to tackle. The effectiveness of a NBS designed at a certain point of time might dynamically change, as a result of climate change impacts on ecosystems' living components. For instance, a wetland might be designed as a water retention measure against flood, but its effectiveness in time might be altered by extreme temperatures.

It is therefore necessary to "climate-proof" the NBS alternative, as it is increasingly done with their grey counterparts (see for instance, DGCLIMA 2011). Yet, this is far from being a straightforward exercise. It implies understanding how climate change will impact ecosystem structure and processes and how this, in turn, will affect the actual supply of ES bundles. The response of different ES to the same driver can be complex, especially when ES are functionally interacting (see Bennet et. al (2009) for a discussion of the relationships among multiple ES). The bundle analysis undertaken in step 4 thus play a crucial role for appreciating if ES will either co-variate or show antagonistic behaviour in response to the same pressure. Again, the analysis should factor the way climate change could amplify possibly associated ecosystem disservices. As for the example on green spaces, rising temperatures could lead to longer allergy seasons, the proliferation of mosquitos or other pest animal (rats, arthropods and insects) acting as vector of diseases and lead to an increased use of pesticides (Lõhmus and Balbus 2015; WHO Regional Office for Europe 2016).

6) Map expected (in)direct effects of alternatives. As a preparatory step to the quantitative assessment, a mapping of the expected 'performance' of climate-proof alternatives should be carried out. In fact, NBS might prove to be competitive with traditional grey interventions only if their multifunctionality is accounted for. This means breaking-down the foreseen effects of each alternative in terms of (in)direct environmental, social and economic benefits and costs, so to provide a comprehensive basis on which alternatives can then be assessed and selected.

In general terms, the direct benefits of a NBS are those associated with the primary ecosystem service which is exploited to reach the objective (eg. flood regulation). Direct costs, as in the case of grey solutions, typically refer to construction and maintenance expenditures. In principle, it is possible to exclude other types of direct costs (eg, social and environmental direct costs) as a measure should not be designed and implemented with the stated objective of being detrimental. The co-benefits stem from the multifunctionality of a NBS. Along the same line, ecosystem disservices should be interpreted as co-costs.

Based on this qualitative screening, decision-makers can decide to go back to the definition of alternatives in order to refine them. Indeed, as climate change impacts enter into the picture, the effectiveness of an alternative in reaching the pre-defined objectives and sub-objectives might be compromised. The feedback-loop thus allow for designing more climate resilient options through an iterative and participatory process.

4.3 Quantifying and selecting

This last stage is devoted to a quantitative evaluation of the effectiveness of alternatives in responding to the main and sub-objectives and to the eventual selection of the preferred option.

7) Set the criteria to evaluate alternatives. Indicators are required to qualify and quantify the impacts of each alternative on the system. All the expected effects from a measure which are relevant to the objective should be identified, together with respective metrics. These indicators are selected on the basis of costs and benefits listed in the mapping phase. They provide comparable measures for the following assessment.

8) Analyse the alternative. Alternatives are evaluated through the indicators selected, usually using a model or models of the system (Walker 2000). This might not always be necessary for any analysis, but it is convenient to have models when dealing with complex problems entailing vast amounts of data (Shell and Stelzer 1971). Tools employed for the analysis can include hydrological models in the case of flood.

9) Evaluate the alternatives. This is the "putting-everything-together" step (Shell and Stelzer 1971), which can be carried out by employing several analytical tools *(eg. Cost-benefit analysis, MCA)*. The most common approach is to translate, through a variety of techniques, expected positive and negative impacts of a measure into monetary terms. This allows for having the same metric against which the choice of the preferred alternative can be made.

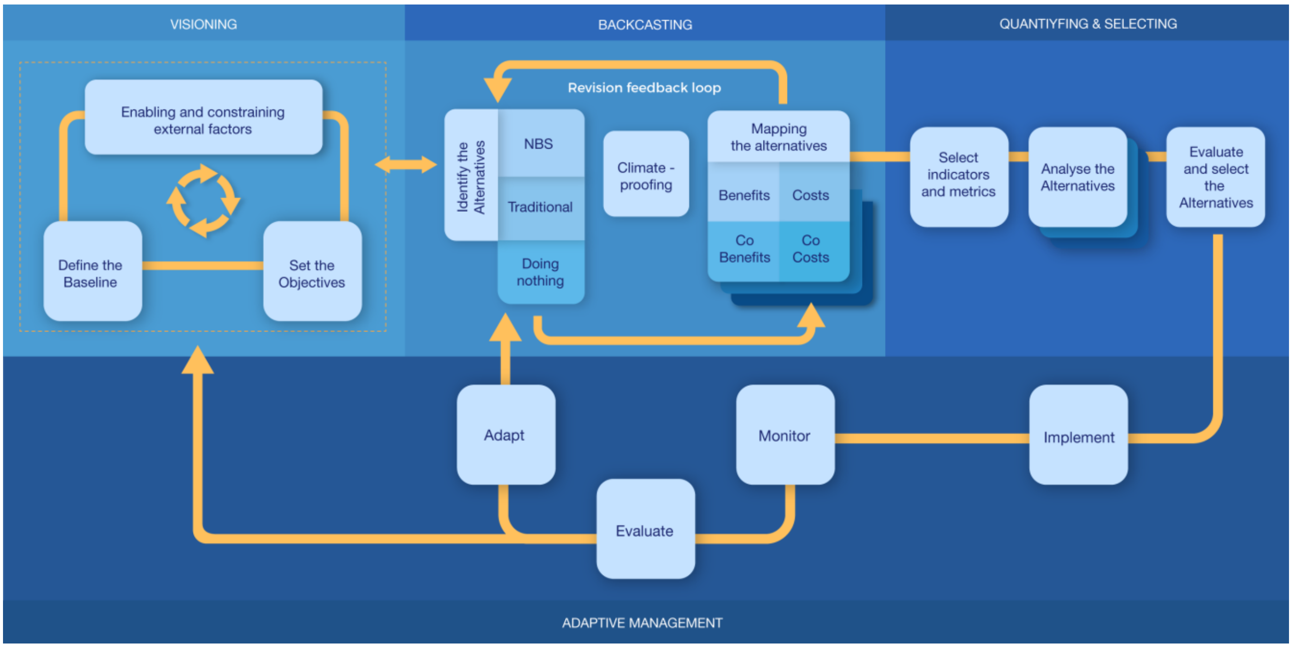


Figure 2 – Proposed assessment framework for climate-proof NBS. The framework supports the choice among NBS, hybrid or traditional solutions to societal challenges by considering their effectiveness, benefits and costs under future climate conditions. The framework builds on the integration between a system analytical and a visioning-backcasting approaches. The visioning phase aims to define a shared vision of the future by analysing the situation that should be transformed (baseline), by setting the main objective and sub-objectives to be reached, and by identifying associated external enabling and constraining factors. The backcasting stage establishes the concrete actions needed for achieving the vision. It is based on the identification and climate-proofing of possible alternatives, and the mapping of the (in)direct benefits and costs associated with each solution. This step is followed by a quantification and comparison of benefits and costs, eventually leading to the choice of the preferred alternative. Finally, the chosen solution is implemented and adaptively managed.

The proposed assessment framework is part of a wider approach for the implementation of NBS. As specified in the visioning stage, the time horizon considered for planning is of around 30 years. As NBS evolve over time, they must be continuously managed, and their effectiveness monitored. Adaptive management can prove to be useful to this aim (WB 2017). It features an iterative learning-by-doing process composed of three steps (monitoring, evaluation and adaptation). It makes it possible to revise and eventually refine actions to reach the desired/expected outcomes more effectively (Williams 2011). Monitoring observes system characteristics after the implementation and collects evidence on the way NBS measures perform in practice. The difference between expected and actual outcomes shed light on system’s response. The interventions should be reviewed and adjusted to respond to the challenge or to the potential new needs (evaluate and adapt). This could result in several feedback loops over the time. The evaluation phase can also lead to a corrective action (adapt) to safeguard the effectiveness of the measure in time. This could mean, for instance, integrating a NBS with a more traditional approach. Alternatively, the process could go back to the visioning stage and define new objectives for the system of interest. The adaptive management cycle is depicted in the lower section of Figure 2.

5. Discussion and conclusions

The growing attention paid to NBS, both in policy and research, has thrusted efforts to define guiding principles and design effective assessment frameworks that satisfy public policy requirements and demonstrate empirically the societal value of 'working with nature'. We propose a framework that reconciles and complements previous efforts, while introducing additional, complementary elements supporting a comprehensive assessment of the effectiveness of NBS.

Similarly to Raymond et al. (2017b) and Liquete et al. (2016), we build upon an integrated valuation method that simultaneously accounts for economic, social and environmental benefits. This approach informs the level of ambition and targets chosen within the visioning stage, and guides mapping of benefits and costs of alternative courses of actions in the backcasting stage. Our framework explicitly addresses the unintended consequences or disservices that NBS can produce. These have received limited (Raymond et al. 2017a, b) or no consideration (Reguero et al. 2014; Liquete et al. 2016; Narayan et al. 2017) in previous works. We account for the disservices as additional (co)-costs.

Building on Liquete et al. (2016), we frame the objectives and sub-objectives of interventions in terms of ecosystems services that should be strengthened to reach the desired future state. In doing so we encourage multifunctional design of proposed interventions and lay down common criteria against which the green, hybrid and conventional engineering solutions can be evaluated. In many situations NBS are proven to be viable alternatives to traditional engineering interventions when their simultaneous contributions to several environmental policy objectives is accounted for. If NBS were assessed in terms of costs only, incentives for their deployment could be eroded as the construction and maintenance costs may reach levels similar to that of traditional engineering options.

The previously proposed frameworks have not considered the impacts of future environmental changes on the performance of NBS solutions. However, NBS are 'living' solutions whose effectiveness is determined both by the magnitude of the threats which they help to respond to, as well as their genuine ability to endure the raising (climate and other) environmental and anthropogenic pressures to which they are exposed. The dynamic nature of NBS is explicitly accounted for in our framework within the 'climate-proofing' stage. We believe important to consider how climate change will affect the future flow of ecosystem services, and scrutinise to what extent the future flow of ecosystem service will satisfy the societal demand for which the green solutions were initially designed. Our extended framework responds to Raymond et al (2017) call for further research on how 'opportunities and threats (among others) are likely to constrain or promote different policy options'.

Our framework comprises and is informed by a combination of systems analytical and backcasting schools of thoughts. While backcasting has not yet been applied for NBS assessment and implementation, it is particularly suited to seize the innovative and transformative essence of NBS. Backcasting has been used in innovation and sustainability studies (Quist 2007) and is well positioned to support tackling societal challenges by innovating with nature. Visioning encourages transformative societal change rather than incremental improvements, by challenging assumptions about complex problems with a long-time horizon for decision making. Backcasting as a planning methodology goes beyond the traditional policy-making linear model (EC 2017), and favours continuous iterations and feedback loops that characterise the visioning and backcasting stages. In addition, the adaptive management framework situated in the implementation stage provides for continuous monitoring, evaluation and adaptation of the green solutions and preserves its effectiveness under future environmental and climate conditions.

We acknowledge that several factors can inhibit the full operationalization of the framework, among them data accessibility/availability and uncertainties permeating all aspects of the decision-making process. Effective involvement of experts and stakeholders in the knowledge co-production process on which the design, implementation and evaluation are based on, can prove challenging. The application of the framework requires trans-disciplinary and multi-sectoral knowledge and tools, and a close engagement of multiple stakeholders (Raymond et al. 2017b). Greater emphasis on knowledge co-production practices in different contexts allows for in-depth lessons learned and recommendations which can be usefully applied when dealing with nature-based interventions. These include enabling environment that draws on positive histories of collaboration (eg. social dialogue and cross-sector partnership), institutional support for social innovation; and support of intermediaries that bring together a diverse set of stakeholders' views and assist in shifting away from a directive to a collective form of leadership (EC 2018a).

The recently released evaluation of the EU Strategy on adaptation to climate change reaffirms the role of GI and NBS for CCA and DRR (EC 2018b). Ecosystems-based approaches are vital for climate adaptation, for mediation of flows and nuisances, or for maintenance of physical, chemical, biological conditions in the face of pressures. Our framework calls for a systematic, evidence-based account on how NBS perform under changing environmental/climate conditions and how decline of ecosystem services may amplify climate-related risks. The ecosystem services on which NBS rely are often 'taken for granted', but many changes to ecosystems may have the unintended consequence of reducing these functions, potentially leading to growing societal vulnerability and susceptibility to harm that is expensive and/or difficult to reverse. Our extended framework can contribute to a better-informed deployment of ecosystem-based approaches to CCA and DRR and meaningfully support related strategies and plans.

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