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A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas

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ABSTRACT

To address challenges associated with climate resilience, health and well-being in urban areas, current policy platforms are shifting their focus from ecosystem-based to nature-based solutions (NBS), broadly defined as solutions to societal challenges that are inspired and supported by nature. NBS result in the provision of co-benefits, such as the improvement of place attractiveness, of health and quality of life, and creation of green jobs. Few frameworks exist for acknowledging and assessing the value of such co-benefits of NBS and to guide cross-sectoral project and policy design and implementation. In this paper, we firstly developed a holistic framework for assessing co-benefits (and costs) of NBS across elements of socio-cultural and socio-economic systems, biodiversity, ecosystems and climate. The framework was guided by a review of over 1700 documents from science and practice within and across 10 societal challenges relevant to cities globally. We found that NBS can have environmental, social and economic co-benefits and/or costs both within and across these 10 societal challenges. On that base, we develop and propose a seven-stage process for situating co-benefit assessment within policy and project implementation. The seven stages include: 1) identify problem or opportunity; 2) select and assess NBS and related actions; 3) design NBS implementation processes; 4) implement NBS; 5) frequently engage stakeholders and communicate co-benefits; 6) transfer and upscale NBS; and 7) monitor and evaluate co-benefits across all stages. We conclude that the developed framework together with the seven-stage co-benefit assessment process represent a valuable tool for guiding thinking and identifying the multiple values of NBS implementation.

1. Introduction

The potential for introducing ecosystem-based approaches into urban planning and policy-making is increasingly gaining attention from both scientists and policy-makers as approaches that offer sustainable and cost-efficient solutions for water management (Armson et al., 2013; Young et al., 2014), air quality (Calfapietra et al., 2015; Wang et al., 2015) urban biodiversity (Connop et al., 2016), and for cross-cutting challenges like biodiversity conservation, public health and well-being (Bennett et al., 2015; Carrus et al., 2015). Researchers are now encouraged to move from ecosystem-based approaches to nature-based solutions (NBS) in order to work integratively with ecosystems to adapt to and mitigate the impacts from climate change, conserve biodiversity and improve human health and well-being (Cohen-Shacham et al., 2016). NBS can be 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” (European Commission, 2016, p. 1). NBS bring together established ecosystem-based approaches, such as ‘ecosystem services’, ‘green-blue infrastructure’, ‘ecological engineering’, ‘ecosystem-based management’ and ‘natural capital’ (Nesshöver et al., 2016; Nature Editorial 2017) with assessments of the social and

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economic benefits of resource-efficient and systemic solutions that combines technical, business, finance, governance, regulatory and social innovation (European Commission, 2015).

The need to protect natural capital and value ecosystem services is increasingly recognised as fundamental to progress towards sustainable development objectives. A prominent example is represented by the European Union (EU) actions towards smart, sustainable and inclusive growth for Europe 2020. The EU Biodiversity[1] and Green Infrastructure[2] strategies are significant contributions to this. Additionally, the EU Thematic Strategy on the Urban Environment[3] recognizes that it is in urban areas that the environmental, economic and social dimensions of the EU Sustainable Development Strategy come together most strongly. NBS, therefore, are directly relevant to several policy areas and through their systemic nature interact with many others, such as land use and spatial planning.

NBS are also seen as open innovations that require engagement with multiple actors, providing co-benefits that bridge social and economic interests and as thus, can stimulate new green economies and green jobs (Kabisch et al., 2017; Raymond et al., 2017). They are increasingly promoted across funding schemes and projects (e.g., European Commission, 2015).

Until now, most researchers have drawn upon the ecosystem services framework for assessing the biophysical or economic value of ecosystem-based approaches in cities (Baró et al., 2015; Green et al., 2016; Liquete et al., 2015), and for examining the potential for synergies and trade-offs between bundles of ecosystem services (Mouchet et al., 2017; Turner et al., 2014). While the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) is drawing upon a wider framework of nature's contributions to people, recognizing that different types of values need to be promoted in environmental decision-making, including concepts associated with other worldviews on human-nature relations and knowledge systems (Pascual et al., 2017). The European Commission is assisting its Member States in the process of mapping and assessing ecosystem services, including their economic value and in incorporating these values into EU and national accounting and reporting systems (Maes et al., 2016)

However, important questions remain about how to assess the impacts of NBS within and across different societal challenges. When fulfilling the functions of urban infrastructures using or mimicking natural processes, NBS may simultaneously provide co-benefits for biodiversity and human well-being (Cohen-Shacham et al., 2016), but existing frameworks do not cater for such complexity. Previous work has narrowly framed and assessed (co-)benefits mainly with reference to single indicators or challenge areas, such as ecosystem service values, synergies and trade-offs (Maes 2013; Mouchet et al., 2017), the co-benefits of climate interventions (Bain et al., 2015; Rao et al., 2016), the direct and indirect (including anthropogenic) drivers of environmental change (Díaz et al., 2015), cost-benefit approaches (Ürge-Vorsatz et al., 2014), and resilience frameworks (Adger et al., 2011; Kais and Islam, 2016; Leichenko, 2011).

Furthermore, there is a severe lack of practical, and targeted guidance for the processes that enable the consideration and assessment of co-benefits within and across the stages of implementation and decision-making (Ürge-Vorsatz et al., 2014). A recent review of EU policies found that while the ecosystem service concept is being gradually taken up by policy and planning, it remains confined to natural resource policies (Bouwma et al., 2017). The assessment of environmental impacts was in many cases restricted to single challenge areas (e.g., biodiversity, ecosystems) and rarely addressed cross-sectoral impacts (e.g., links between biodiversity, and the economy). Moving to solution implementation requires decision-making toolkits that simplify and systematize the monitoring and evaluation of co-benefits in decision-support (Ürge-Vorsatz et al., 2014); processes for reflecting, connecting and investigating, modelling and exploring, doing and suggesting solutions (Bell, 2012); and supporting multi-dimensional communication networks for delivering co-benefits in real-world contexts (Spencer et al., 2017). NBS implementation requires political, economic and scientific challenges to be addressed simultaneously by several actor groups (Maes and Jacobs, 2017). Practitioners need to consider elements of urban management, biodiversity, governance and social innovation within a socio-ecological system (Maes and Jacobs, 2017; McGinnis and Ostrom, 2014), and to integrate diverse types and systems of knowledge and values for NBS design and implementation so as to be socially comprehensible and acceptable to a range of stakeholders (Frantzeskaki and Kabisch, 2016; Maes and Jacobs, 2017; Raymond et al., 2017).

In response to these challenges, this paper provides a holistic framework that systematically identifies how NBS may provide both synergies across ecosystem services, but also co-benefits (or costs) in other different elements (socio-cultural, socio-economic system, environment, biodiversity, ecosystems, and climate) particularly in urban areas. The framework is intended to be used by professionals involved in multi-stakeholder and multi-disciplinary teams with expertise and interests in the design, implementation, monitoring and evaluation of NBS during the various stages of NBS action plans. It is a guiding framework that will require further operationalisation and tailoring to city-specific institutional circumstances for a successful implementation of NBS action plans. It provides, however, a holistic and globally applicable approach for multiple stakeholders that can lead and/or be used in the NBS action planning process. In most instances, comprehensive teams from many stakeholder groups such as researchers and academics, policy makers, planners and entrepreneurs from different parts of Europe will be established to design and implement NBS in cities (as in the case of NBS projects currently being funded by the European Commission). Research and academic institutions, corporate bodies and cities can all lead these NBS-oriented teams. City officials, however, will have a leadership role in ensuring that NBS actions align with existing and/or proposed urban planning strategies and governance processes including but not limited to climate change and urban regeneration strategies. We set out briefly the methodology which guided us to the definition of the framework, present the elements of it and then describe and justify a seven-stage process through which local governments and other key actors can assess, choose and implement NBS. We conclude with discussing the strengths and weaknesses of the framework and process, and identifying future research and policy directions for the implementation of NBS co-benefits.

2. A framework for the assessment of NBS co-benefits

Our framework includes four dimensions that may appear simultaneously when implementing NBS in urban areas (Fig. 1): 1) co-benefits for human health and well-being; 2) integrated environmental performance (e.g., the provision of ecosystem services); 3) trade-offs and synergies to biodiversity, health or economy; and 4) potential for citizen's involvement in governance and monitoring (Kabisch et al., 2016). The framework advances current knowledge by highlighting not only the benefits and costs of NBS derived from (existing) ecosystem services (Palomo et al., 2015; Plieninger et al., 2015), but also the benefits and costs of interactions across elements of socio-cultural, economic system, biodiversity, ecosystems, and climate.

We considered 10 key societal challenges faced by cities in the light of global environmental change (Fig. 1, bottom), and we identified for each challenge potential actions and expected impacts of specific NBS objectives; indicators of impact; and potential methods for assessing impact. A rapid evidence assessment methodology (Collins et al., 2015) was used for their identification. The assessment involved a structured search of papers from science and practice and the collection of

[1] EU Biodiversity Strategy to 2020 (COM(2011) 244).

[2] Green Infrastructure (COM(2013) 249 final).

[3] Thematic Strategy on the Urban Environment (COM(2005) 718 final).

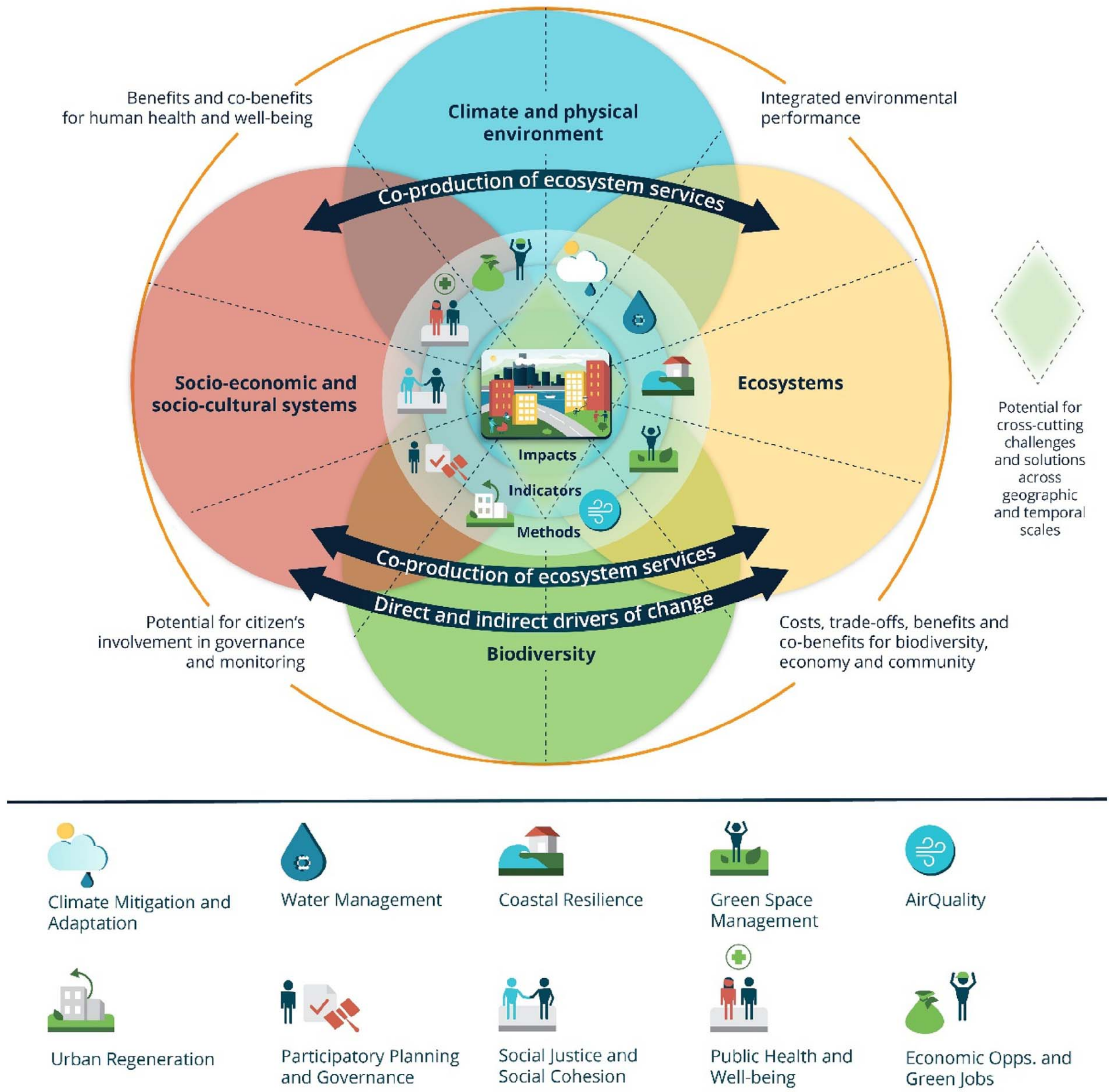

Fig. 1. The NBS assessment framework considering different elements of the system, the 10 challenge areas and indicators and methods for assessing NBS impacts within and across challenge areas.

additional literature from experts. This led to screening over 500 peer-reviewed journal articles and 1200 planning and policy documents. A narrative synthesis of selected literature was used to develop the framework (see Raymond et al., 2017 for further details).

Different types of indicators, representative of the interaction between specific NBS and the socio-ecological system were reviewed (Table 1). For a complete list of indicators see Raymond et al. (2017). The assessment of indicators within a given challenge area has a range of potential success and limiting factors. This range depends on the specific characteristics of the NBS and its way of interacting with the socio-ecological systems in cities, including the potential for trade-offs in benefits and costs within every given challenge. For example, urban trees contribute to carbon sequestration, to cooling of urban areas during heat waves and lower air pollution but at the same time can produce allergens and thus may negatively affect the health and well-being of citizens (Grote et al., 2016).

A NBS targeted towards a specific societal challenge is likely to produce co-benefits, costs and neutral effects in other challenges (Table 2). For example, flood peak reduction actions designed with nature in mind are likely to have co-benefits for not only coastal resilience, but also for quality of life by improving urban living conditions (Larson and Perrings, 2013). By improving environmental qualities and the related increase of property values (Mitchell Polinsky and Rubinfeld, 2013); however, such actions can adversely affect social justice and social cohesion by contributing to gentrification (Haase et al., 2017).

These multi-directional effects underline the importance of a holistic approach to NBS design, implementation and assessment in urban areas considering synergies and potential trade-offs. This holistic approach entails: 1) understanding the environmental and socio-ecological context of NBS design, implementation and evaluation, so that expected costs and benefits are identified, assessed and managed for different stakeholder groups prior to NBS design; 2) designing NBS in ways that address multiple interconnected challenges so as to take advantage of NBS co-benefits; 3) implementing NBS across multiple scales using a learning-by-doing approach so as to encourage ownership of NBS and adaptive management in response to emerging risks; and finally 4) managing, maintaining, monitoring and assessing NBS using

Table 1
Examples of different types of indicators for assessing the impacts of NBS across different challenge areas.

Challenge area	Example of indicators	Type of indicator	Unit of measurement
	Net carbon sequestration by urban forests (including GHG emissions from maintenance activities)	Environmental (chemical)	t C per ha/year
	Economic benefit of reduction of stormwater to be treated in public sewerage system	Economic (monetary)	Cost of sewerage treatment by volume (€/m^3)
	Area remaining for erosion protection	Environmental (physical)	km^2 or m^2
	Species richness of indigenous vegetation	Environmental (physical)	A count, magnitude or intensity score of indigenous species per unit area
	Annual amount of pollutants captured by vegetation	Environmental (chemical)	t pollutant per ha /year
	Index of ecological connectivity (integral index of connectivity	Environmental (physical)	Probability that two dispersers randomly located in a landscape can reach each other
	Quality of the participatory or governance processes	Social (process)	Perceived level of trust, legitimacy, transparency and accountability of process
	Accessibility to public green space	Social (justice)	% of people living within a given distance from accessible, public green space
	Level of involvement in frequent physical activity in urban green spaces	Social (physiological)	Number and % of people being physically active (min. 30 min 3 times per week) in urban green spaces
	Net additional jobs in the green sector enabled by NBS projects	Economic (productivity)	New jobs/specific green sector/year

multi-actor co-production processes over the long-term so as to track changes in NBS impacts and find ways to navigate trade-offs and capitalise on multiple co-benefits.

In the next section, we show how this holistic approach can be considered as part of the assessment and valuation of NBS co-benefits.

3. A seven-stage process to guide the assessment of NBS co-benefits

We present a process for implementing NBS (Fig. 2). On the left side of the scheme, we describe how successful NBS projects could be implemented and on the right side we show how the solutions generated through these projects could be innovated. The seven-stage process situates NBS co-benefit assessment within policy and project implementation. It is founded on the concept of participatory process involving the various stakeholders but also includes the idea of alternatives routes and/or possible feedbacks between one stage and the previous one. Monitoring and evaluation of co-benefits is considered transversal in that it needs to be considered by urban professionals with expertise in impact assessment in each of the stages of the

Table 2
Examples of the co-benefits, costs and neutral effects of NSB across challenge areas.

Challenge	Indicators										
	Carbon sequestration		+	O	+	+	+	O	O	O	
	Flood peak reduction			+	+		O	O	O	+	+
	Daily mean temperature or daily temp. variation				+		O	O	O		+
	Accessibility to public green space		O			+	O	O	+	+	+
	Amount of pollutants captured by vegetation		+		+			O	O	+/-	+
	Ecological connectivity		O		+			O	O	+	+
	Quality of the participatory or governance processes			+	+	+				O	O
	Being able to move freely and safely from place to place				+		O	O		O	O
	Number and amount of people being physically active				O		O	O	O		O
	Net additional jobs				+				+	+	

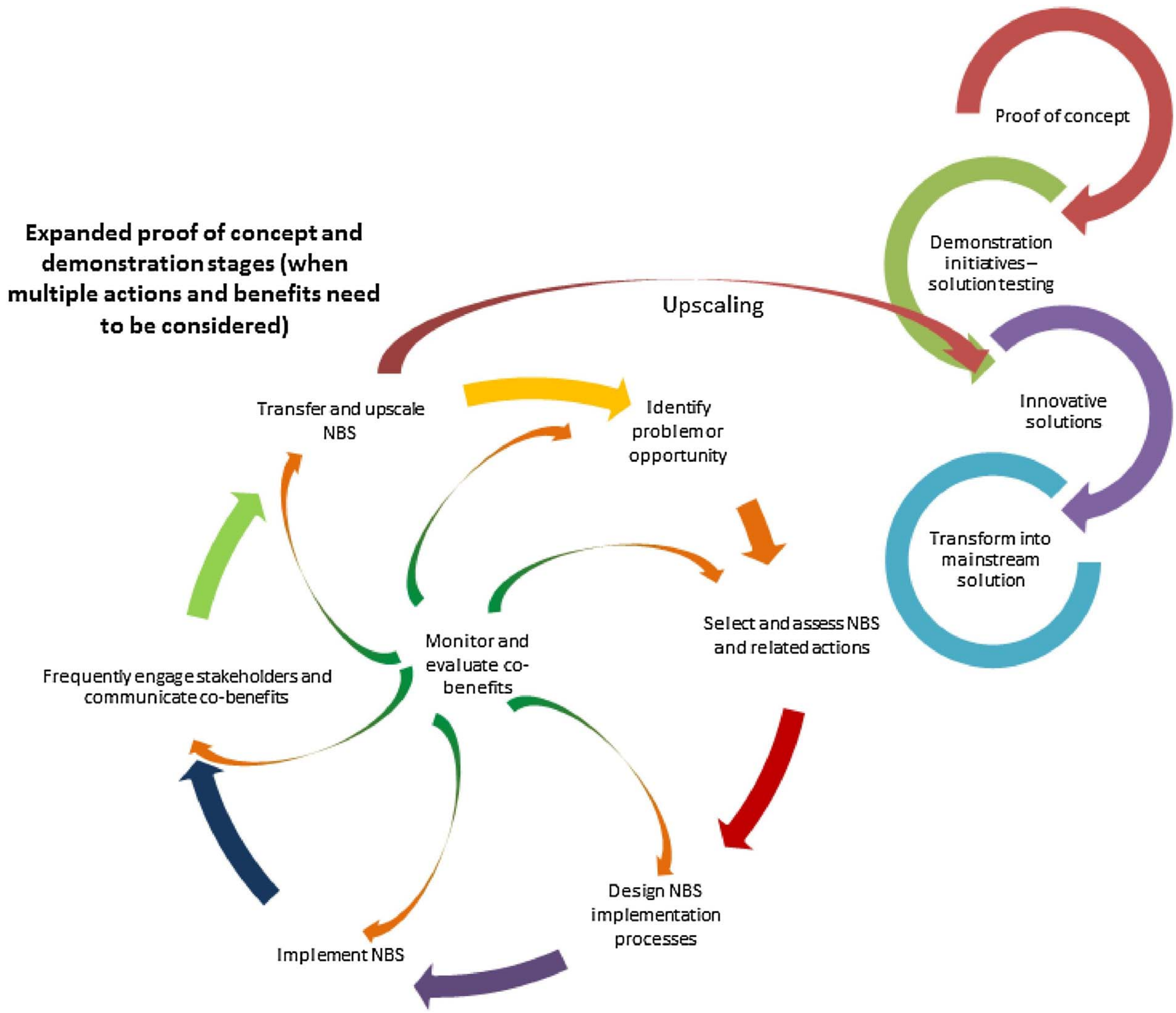

Fig. 2. NBS implementation process including phases of social innovations adapted from the European Commission (2013) on the right and the circular sequence of demonstration phases and related interactions on the left based on the assessment framework recently developed by the EKLIPSE Expert Working Group (Fig. 1 and Raymond et al., 2017).

implementation process.

This idea of a circular and flexible scheme is making each stage not totally independent from the others and not necessarily in the same sequence. The seven stages are: 1) identify problem or opportunity; 2) select NBS and related actions; 3) design NBS implementation processes; 4) implement NBS; 5) frequently engage stakeholders and communicate co-benefits; 6) transfer and upscale NBS, and the transversal stage of 7) monitor and evaluate co-benefits. Multiple types of engagement and communication are required to reach stakeholders of different power, expertise and interest at each stage. Below we describe each stage in some detail with the assistance of pertinent questions.

3.1. Identify problem or an opportunity

3.1.1. What are the identified needs and challenge areas to be addressed in the project and which criteria will be employed to understand problem dynamics?

In many situations, the problems to be addressed by NBS are multi-dimensional and complex. Participatory modelling (Angelstam et al., 2013) and solution-led sustainability assessments (Zijp et al., 2016) can support a holistic mapping of the problem and the possible feedback loops across social, economic, ecological and governance dimensions. Having identified the problem areas, criteria need to be established for assessing the relationships between problem dimensions and the potential blind spots, or, missed opportunities. Assessment of gaps in ecosystem services delivery/supply and/or trade-offs between ecosystem services can complement the problem analysis. For example, NBS have been employed for greening and retrofitting vacant spaces in cities (these are often under-utilised places, but with great potential in supplying multiple ecosystem services), and result in producing co-benefits for community cohesion and inclusivity (Frantzeskaki et al., 2017).

3.1.2. What NBS are proposed to address these problems? Which alternative grey solutions are at stake?

Having identified the problems, the next important step is to identify what NBS and alternative grey/hybrid solutions can address them. The multiple benefits to be provided by NBS need to be identified and compared with the benefits from the alternative green or grey/hybrid solutions. Cost-benefit analyses alone may not adequately capture the multiple benefits over time of NBS, thus new methods are required for ex-ante assessments such as participatory assessments, group modelling and integrated sustainability assessment (Raymond et al., 2017). The mapping of multiple benefits and how they change over time is also required (Xing et al., 2017).

3.2. Select and assess NBS and related actions

3.2.1. How are the objectives of the plan identified?

The selection and assessment of NBS objectives will depend on the types of problems and NBS that have been identified. Given the potential for multiple (and sometimes perverse outcomes) from any given solution, objectives need to be suitably flexible to cater for costs, benefits, trade-offs and neutral effects, in addition to being specific, measurable, assessable, realistic and time-bound.

3.2.2. How are the actions relevant to NBS identified?

An action plan then needs to be established for linking project objectives to specific actions, and to indicators for measuring the effectiveness of each action (Raymond et al., 2017). When prioritising actions, planners need to minimise the use of 'hard adaptation measures' that are often associated with high costs, inflexibility and conflicting interests (Brink et al., 2016). The type of data available for monitoring and assessing actions may influence the types of actions to be considered for NBS design and implementation.

Diverse types and systems of knowledge need to be engaged in action planning so as to ensure activities are socially acceptable and defensible to a range of stakeholders (Frantzeskaki and Kabisch, 2016; Maes and Jacobs, 2017; Raymond et al., 2017). Tools, such as the Adaptation Planning Support Toolbox (van de Ven et al., 2016) and public participation GIS (Raymond et al., 2016) provide a systematic way of engaging local policy-makers, planners, designers, practitioners and citizens in defining actions. Both monetary and non-monetary values need to be considered in this process given that economic valuation alone misses nuances in socio-cultural valuation (Derkzen et al., 2017). In this way, tools and public participation GIS, but also focus group discussions, aim at including and valuing diverse stakeholder knowledge. This knowledge may come from policy officers, urban planners, and practitioners and is an important addition to, and may even be a precondition for, scientific knowledge (Kabisch, 2015). This interwoven process can lead to mutual learning and the establishment of relationships as a process of knowledge co-creation particularly relevant for urban environmental governance processes, as shown in the cases of Berlin, Germany and Rotterdam, the Netherlands (Frantzeskaki and Kabisch, 2016).

3.3. Design NBS implementation processes

3.3.1. How are processes established for the engagement of multi-disciplinary teams?

In urban planning attention needs to be given to processes that bridge different knowledges on urban systems (Colding and Barthel, 2013; Frantzeskaki and Kabisch, 2016). Implementation processes need to support openness, transparency in governance processes and legitimacy of knowledge from citizens, practitioners and policy stakeholders (Crowe et al., 2016; Frantzeskaki and Kabisch, 2016; Specht et al., 2016). They also need to create different institutional spaces for cross-sectoral dialogues amongst different stakeholders for fostering adaptive co-management and knowledge sharing about urban ecosystems (Crowe et al., 2016; Dennis and James, 2016; Fors et al., 2015; Frantzeskaki and Tilie, 2014; Ugolini et al., 2015) and enable cross-sectoral partnerships (Krasny et al., 2014; Specht et al., 2016; Ugolini et al., 2015).

Barking Riverside, London, UK provides a good example of how some of these issues have been addressed in practice. Barking Riverside is a brownfield development site, where planning consent recognised the importance of the brownfield habitat, as well as its multifunctional ecosystem service values, including stormwater storage, recreation access and biodiversity (Connop et al., 2016). To address these sustainability objectives, a knowledge transfer partnership (KTP) of key stakeholders, including academics, statutory and development agencies, local authority and local SMEs was set up and community engagement undertaken. Subsequently, a Community of Interest Company, which includes residents, was established to eventually take over the management of the public space from the Greater London Authority and the developer.

3.4. Implement NBS

3.4.1. How are the actions relevant to the NBS implemented?

Having identified and agreed on the NBS actions and the processes through which to engage multi-disciplinary teams, the actions then need to be implemented. Implementation should consider the relative costs and benefits of a given action, as well as manage the difficulties relating to uncertainty. For example, in a densely built urban context like Berlin, the urban greening strategy points to potential co-benefits from roof-greening in terms of additional attractive usable spaces for recreation of employees, the transformation of private roof spaces into roof top cafés (City of Berlin, 2014).

3.4.2. How are NBS implemented alongside grey solutions?

Green solutions can be distinguished from grey solutions based on their visual and functional qualities (Davies et al., 2006), although how to distinguish them based upon the new definition of NBS remains an important research gap. Green solutions can be implemented alongside grey solutions in various ways, depending on the socio-ecological characteristics of the city, such as the level of existing greenery, availability of land, the physical characteristics of the area and key environmental threats (Mell, 2013). It is therefore important for practitioners to clearly define their spectrum of green to grey solutions and how they will be implemented in the light of various contextual constraints.

3.4.3. How are the negative perceptions of some stakeholders managed?

There are several stakeholder perception challenges that need to be managed during NBS implementation, including the perceived cost of new solutions relative to short-term and long-term benefits, the impact of new solutions on mobility, visual amenity, social cohesion and equity in access (Raymond et al., 2017). Ways of overcoming barriers include ensuring transdisciplinary working methods, co-production of knowledge and adaptive management (Ahern et al., 2014), the co-creation and design of the NBS (Collier et al., 2016), as well as education and greater effort on monitoring and assessing the multiple benefits of the NBS (Connop et al., 2016).

3.5. Frequently engage stakeholders and communicate co-benefits

3.5.1. How are different types of stakeholders engaged in the project, and what forms of communication are used?

Traditionally, implementation of large projects has had discrete stakeholder engagement and communication phases (Bragança et al., 2014), but we propose that these elements need to occur across all project activities (Frantzeskaki and Kabisch, 2016). This means communicating the co-benefits to different levels of decision-makers and citizens becomes a transversal activity throughout the entire lifespan of the project (Raymond et al., 2017). Communication is most effective when realized through a series of parallel and overlapping top-down and bottom-up processes. New means of collaboration, such as private-public partnerships, social innovation, or, dialogue platforms for different stakeholders are already used as methods to innovate the communication process. Collaborative and imaginative approaches of communication not only increase the support for NBS, but have been found through the received feedback to also optimize the potential of attaining the co-benefits (Jones and Somper, 2014).

For example, the City of Vienna adopted a multi-level communication process as part of its recent development of its Green and Open Space Strategy (2016). Residents in each district in Vienna were asked about their values for green spaces (including activity preferences) and how they would like to see their green spaces managed into the future. In parallel, senior politicians within the city, were frequently briefed about the benefits and purpose of the green and open space strategy, and they were invited to participate in strategy development.

3.6. Transfer and upscale NBS

3.6.1. Why upscale NBS and how can it be done?

The upscaling of NBS can occur during the demonstration phase, as well as during the mainstreaming phase when teams learn from the project demonstrations. During the demonstration phase, upscaling can contribute to strengthening government, stakeholders and investors' confidence (Cohen-Shacham et al., 2016) and increase the number of NBS implementation projects and consequently the provided co-benefits. Upscaling NBS requires multi-actor partnerships (Frantzeskaki et al., 2017). Scientists can provide the evidence base to predict the benefits of NBS across scales (e.g., Demuzere et al., 2014 multi-scale assessment of the performance of green urban infrastructure). Societal stakeholders can be instrumental in informing key implementation issues; for example, finding suitable locations for NBS (Connop et al., 2016). Planners can contribute to developing innovative ways to systematically incorporate NBS into governance instruments and regulations. Examples include guidance documents for including sustainable urban drainage systems in developments, such as those produced by the city of Treviso in Italy (CdT, 2013) and the borough of Tower Hamlets in the U.K. (LBTH, 2015). Public authorities can provide direction for implementing NBS across planning tiers and policy sectors. A case in point is the mix of policies and actions undertaken by the city of Ljubljana to increase green surfaces to mitigate the heat island effect (Nastran and Regina, 2015). A more commercial example relates to a private venture at BOKU, Vienna involving the establishment of outdoor courtyards that combine solar roofs, urban food gardens, water reticulation systems and picnicking facilities for social interaction.

During the mainstreaming phase, project teams can upscale NBS in various ways, including through the development of open innovation business models and market strategies required to introduce these innovations into the market, capture market share and to establish dominant market positions. While an overview of detailed business models and marketing strategies is beyond the scope of this paper, it is important that the learnings generated during the NBS demonstration phase feed into the mainstreaming process. Project teams therefore need to be committed to a process of continuous learning so as to continually develop and improve one's skills and knowledge of NBS (based on experiments, trial and error) and to apply new or integrated knowledge to mainstreaming problems. During the mainstreaming process, it is also important to facilitate policy learning so as to find new ways to integrate the lessons learnt from NBS demonstration phase to urban planning and policy development processes and in this way, embed NBS innovations into urban planning and governance.

3.6.2. What are the characteristics of NBS that are more prominent or promising for up-scaling?

Some NBS produce additional co-benefits when up-scaled. This characteristic can be used to promote upscaling interventions and demonstrate their contribution to broader and multiple policy goals (Geneletti and Zardo, 2016). For example, although green roofs may be locally incentivised for their thermal benefits, when up-scaled to a catchment area, they can create additional benefits in terms of habitat for wildlife or water regulation (Bates et al., 2009; Raymond et al., 2017). However, broader-scale NBS might not yield the desired benefits and further research is still needed in some areas. Empirical evidence suggests that natural water retention measures can be effective in small catchments, but may not have the same effectiveness when up-scaled to larger areas (Collentine and Futter, 2016).

Paris's Climate Protection Plan demonstrates how NBS can be progressively up-scaled from the site to the city scale (Maire de Paris, 2007). After a first core set of interventions, a multi-year programme has been undertaken to plant all possible areas and promote green roofs, green walls and community gardens on city administration land, as well as privately owned land. During the programme, the administration identified priority sites for interventions, approached owners, and shared the decisions with them.

3.7. Monitor and evaluate co-benefits across all stages

3.7.1. What is the aim of monitoring and evaluation?

Monitoring is considered a transversal process in that it needs to occur in each of the other six stages in the NBS implementation process (Fig. 2). Monitoring in this way can be seen as building up to long-term plans and goals for NBS rather than looking only at short-term effects within a given stage (Kabisch et al., 2016). Long-term monitoring should lead to new insights into NBS functioning and active learning – even from failure – which can help improving future NBS implementation (Connop et al., 2016). Evaluation relates to the numerous ways of assessing the direct and co-benefits (and costs) of NBS within and across challenge areas (Fig. 1), and within different stages of NBS implementation (Fig. 2).

3.7.2. What standard indicators and methods are used to measure and monitor the direct and co-benefits of the NBS actions?

There is a need to monitor the NBS implementation process, including the final benefits of the NBS, how it is perceived and most important, how the NBS responds to the challenge for which it was implemented. To do so, targeted indicators are needed (both new and existing). Indicators of NBS effectiveness can cover a range of aspects, including integrated environmental performance, health and well-being benefits, civil participation and transferability of NBS actions (for a comprehensive overview see Kabisch et al., 2016 and Raymond et al., 2017). Indicators may also relate to the administrative budget of the city and can include percentage of budget and or number of staff allocated to the monitoring of implementation projects and strategies. Financial indicators relate to resources, in terms of investment, return on investment and 'profit' margins assessed. Indicators that quantify the cost-benefit in addition to the involvement of stakeholders can enable a cost-added-value quantification as done in the "Barking Riverside brownfield landscaping project" (Connop et al., 2016).

Assessment of direct benefits or costs of actions relevant to the NBS can be undertaken using a range of qualitative, quantitative and mixed-methods (Raymond et al., 2017). For example, ecosystem service stocks and flows associated with NBS can be assessed through the quantitative modelling of ecosystem services and ecological networks (Liquete et al., 2015; Maes et al., 2012) and air pollution can be modelled using iTree (Nowak et al., 2008). Direct social impacts can be assessed using: Q method (Buchel and Frantzeskaki, 2015); narrative analysis (Gerstenberg and Hofmann, 2016), fuzzy cognitive mapping (Gray et al., 2015), actor-network analyses and interpretative methods (Frantzeskaki and Tilie, 2014; Hansen et al., 2015). Direct economic benefits can be assessed using: cost effectiveness assessments (CEA), performance assessments (non-monetary, single outcome) of the measures against their costs (Pearce et al., 2002); multi-criteria analysis (MCA), or; social costs and benefits approach (SCBA), analysing the monetised costs and benefits from the effects of the measures discounted over time (Pearce et al., 2002; Romijn and Renes, 2013).

For example, the city of Rotterdam, the Netherlands is very active in developing approaches and tools as a response to the challenges of climate change and urbanisation (Tillie and van der Heijden, 2016). This also includes the monitoring and evaluation of the current state of biodiversity and the resulting development of nature conservation measures. Regular monitoring includes city wide mapping of ecological state, monitoring of species number and habitat types in the city. Rotterdam tries to include several other monitoring systems that relate to potential co-benefits e.g. from health and safety to the assessment of green infrastructure projects in an integrative approach.

Methods for assessing the co-benefits of NBS will need to take into account the changing dynamics of the system at a variety of geographic and temporal scales (Gari et al., 2015; Menz et al., 2013; Raymond et al., 2017; Svarstad et al., 2008; Tscherning et al., 2012), and the potential disconnections between short-term environmental actions and the long-term outcomes of NBS (Kabisch et al., 2016).

3.7.3. What are potential barriers to successful monitoring and evaluation?

In some cases, there is uncertainty about the values and benefits a NBS can bring, particularly among certain urban stakeholders, such as urban planners and decision-makers (Kaczorowska et al., 2016). In addition, there are constraints related to timing and financial aspects (Baur et al., 2013; Hansen et al., 2015; Kabisch, 2015). Sometimes monitoring is not encouraged (e.g., monitoring of a strategy's implementation) when considering multiple geographic scales (Tillie and van der Heijden, 2016) and, if indeed included, there may be no clarity about for how long monitoring should be undertaken.

4. Discussion

Our framework has implications for the future development and implementation of strategies related to biodiversity conservation, green infrastructures and urban development, including the Green Infrastructure and Biodiversity Strategies of the EU. It highlights the need to consider not only elements of biodiversity, ecosystems and climate but also the multi-directional pathways between these systems and elements of the socio-cultural and economic system (Fig. 1). These pathways can be addressed in policy by showing how strategies for conserving or enhancing biodiversity or green infrastructure may have co-benefits or costs for other challenge areas like health, economic development or social justice and social cohesion. We recognise that broadening the policy agenda to consider co-benefits (and costs) in this way comes with some risks (e.g., Nature Editorial, 2017), and, therefore, a rigorous approach to problem identification, NBS selection, monitoring and evaluation and upscaling is required. This can be informed by the 7-stage process illustrated in Fig. 2.

In practice, the framework presented in this paper may result in a shift in focus from the design and implementation of green infrastructure and biodiversity management strategies to multi-sector solutions-oriented policies and strategies that address specific environmental, social and economic problems deemed important to key stakeholders in cities (e.g., supporting social cohesion and well-being using green infrastructure). From a governance arrangement perspective, this may require agencies to reduce the amount of effort directed towards the development of permanent management structures and increase focus on temporary systems to achieve a limited solutions-oriented agenda across multiple sectors, agencies and interests. Individuals from different policy units (within and across departments) could come together to identify specific problems and then review, design, implement and evaluate NBS to address them in solution-oriented teams. Important steps have already been taken in this direction through setting up guides that foster cross-sectoral co-ordination and collaboration between policy-makers, businesses and scientists interested in the mainstreaming and upscaling of social innovations (European Commission, 2013). However, we build upon these processes by showing that much greater attention needs to be paid to the design, implementation and evaluation of NBS demonstration projects in partnership with multiple stakeholders and citizens prior to any upscaling and commercialization of those solutions.

Multiple knowledge gaps inhibit delivery of this holistic approach to policy development. The involvement of various stakeholders along a truly participatory and multidisciplinary process is still rarely adopted; mainly resulting from the general perception that multi-stakeholder initiatives slow down urban planning and policy development processes due to lack of consensus and different sectoral interests. There are even fewer examples of where multi-stakeholder initiatives have been systematically monitored and evaluated. Future research would benefit from applying the framework presented here within established projects and initiatives that attempt to coordinate across projects.

We present a guiding framework and as such more work is needed to assess the different elements of NBS effectiveness across temporal and spatial scales (Kabisch et al., 2017). We encourage teams to look beyond cost-benefit analysis. Cost-benefit analysis is insufficient at evaluating NBS effectiveness given the potential for multiple forms of co-benefits spanning different elements of the socio-ecological system (Fig. 1), and considering co-benefits vary across spatial and temporal scales. For example, the monetary valuation of ecosystem services provided by NBS is only mainly possible for limited time scales and/or limited areas. Reliable upscaling of NBS requires new tools models that consider different spatial and temporal distribution of benefits based on different land-use scenarios and different socio-economic contexts. Future research therefore needs to invest in co-benefit analyses across scales and co-evaluation across multiple challenge areas (Table 2), and across multiple stages of NBS implementation (Fig. 2).

Our framework does not specify how policy, or policy based on the evidence gathered throughout the NBS implementation stages, can be adapted based on new opportunities such as the availability of new forms of NBS through technological development, and threats such as increasing urban temperatures due to climate change. In the future, researchers could consider how such opportunities or threats (among others) are likely to constrain or promote different policy options in urban areas. Policy options also need to be socially acceptable to citizens and diverse stakeholder groups, highlighting the importance of embedding policy development in participatory processes that weave together multiple forms and systems of knowledge across institutions and governance processes (Kabisch et al., 2017; Tengö et al., 2017).

5. Conclusions

In this paper, we presented a framework for the assessment of NBS co-benefits across various challenge areas considering relevant indicators and methods. We translated the framework from theoretical support to practical importance by presenting a seven-stage process which can guide NBS implementation. Problems to be addressed by NBS are multi-dimensional and complex, therefore the selection and assessment of NBS and related actions requires the participation of a wide range of stakeholders, multi-disciplinary teams and policy and decision-makers. For each stage of the process we presented a set of questions for consideration by policy makers and multi-disciplinary project teams. However, these stages are not linear as even a NBS targeted to a specific societal challenge can produce dynamic interactions between stages; interactions which are fundamental in assessing the overall co-benefits of a specific NBS process. A set of principles were presented to ensure holistic co-benefit assessments. Any NBS policy or implementation process not only needs to consider how to monitor and evaluate the effectiveness of interventions, but also consider how such assessments are embedded within a holistic process of option selection, NBS design implementation, monitoring and evaluation and upscaling.

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