Planning, Designing, and Monitoring of Nature-based Solutions

Guidelines to urban transformations

Johannes Langemeyer, Sara Maestre Andrés, Isabel Melo, Nicolas Salmon

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Contents

Case Studies

Featured information

Executive Summary

Urban planning today is confronted with a myriad of challenges. These challenges include rapid biodiversity loss; air, water and soil pollution; climate-change imposed heatwaves, droughts, and extreme precipitation events; and increasing social and environmental inequalities for which vulnerable human communities and ecosystems are disproportionately burdened by environmental hazards. In this context, nature-based solutions (NBS) are increasingly recognized for their potential to address the urgency and complexity of associated planning issues.

In order to support cities in fostering a sustainable urban transition that benefits people and nature, this guide outlines comprehensive strategies for the planning, designing, and monitoring of NBS aimed at addressing urban environmental and societal challenges. The guide features a stepwise, modular and hierarchical approach that is highly adaptable to various urban settings. It also introduces a dynamic, Agile framework specifically developed to create tailored assessment systems that respect local urban contexts and planning cycles.

Each module within the framework addresses distinct aspects of urban NBS planning—from decision framing and policy context, through co-creation and spatial vulnerability assessment, to NBS design, comparison, and post-implementation monitoring. This modular approach facilitates the integration of specific urban needs and stakeholder perspectives at every stage and across the single stages, ensuring that NBS align with urban ecological and social priorities while fostering participatory governance, knowledge co-creation, and empowerment of stakeholders.

This guide provides cities with a clear methodology to harness the potential of natural processes and ecosystems, effectively tackling pressing challenges such as climate change adaptation, habitat restoration, and improving human well-being. As the culmination of the development, application, and lessons learned from the INTERLACE project and its six partner cities in Europe and Latin America, this guide encapsulates the essence of collaborative, cross-continental efforts, emphasizing the potential of NBS in urban transformations. Ultimately, this document is designed as a resource for urban planners, policymakers, and practitioners worldwide, advocating for the transformative potential of NBS to create more resilient, sustainable, and liveable cities.

Introduction

In the current era marked by rapid, global changes, cities worldwide are faced with a number of escalating challenges such as the impacts of climate change and degradation of habitats and ecosystems. Nature-based solutions (NBS) are uniquely positioned to address these and other societal and environmental challenges. NBS are defined as actions to protect, conserve, restore, sustainably use, and manage natural or modified [...] ecosystems (United Nations, 2022). Within academic and practical realms alike, NBS are championed for harnessing the power of nature to address multiple social and ecological challenges in urban settings in parallel, for their ability to combat climate change and conserve biodiversity, but also for their pivotal role in contributing to human health and well-being.

This comprehensive scientific-technical guide aims to provide cities with a comprehensive framework for collaboratively producing city-tailored, multi-objective, and multi-criteria assessment systems that supports leveraging the potential of NBS addressing city needs. Developed within the EU-funded INTERLACE project, it outlines comprehensive strategies for the planning, designing, and monitoring of NBS and enables cities to act according to their unique local environmental, social, and economic contexts.

At its core, the framework is distinguished by its scientifically robust but practical approach, avoiding complex, theory-driven models and rigid method-driven frameworks. Instead, it focuses on meeting stakeholder needs through three core principles: adaptability and transformative change, justice and social inclusivity, and transparency and legitimacy. These principles guide its application in different stages, such as vulnerability assessments and designing, implementing, and monitoring NBS.

The framework and this guide were developed in an Agile way together with the project's six diverse urban and metropolitan partners in Latin America and Europe: the Metropolitan Area of Krakow, Poland; the interurban ecological corridor of Maria Aguilar, Costa Rica; Chemnitz, Germany; Granollers, Spain; Envigado, Colombia; and Portoviejo, Ecuador. By presenting a systematic procedure that has been tested and validated in these six urban settings, the guide aims to set a benchmark for the effective development of NBS and to serve as a valuable resource for urban planners, policymakers, and practitioners.

Guiding principles

This guide is designed to address the dynamic, uncertain, and complex nature of social-ecological systems through NBS. It promotes a flexible yet structured approach to guide decision framing and co-creation of knowledge, all while integrating diverse stakeholder perspectives. Emphasizing an Agile methodology, the framework supports continuous reflection and self-improvement aimed at **adaptability and transformative change**. This transformative aim is centered on fundamentally altering the dominant processes and structures within social-ecological systems to sustain Earth's biophysical systems while also meeting human needs. Through the assessment of multilayered vulnerabilities, the comparison of NBS design alternatives, as well as post-implementation monitoring, this document aims at facilitating adaptive responses to changing conditions, thereby achieving multifunctionality in addressing urban environmental and social challenges by NBS.

Recognizing the uneven distribution of benefits (and eventual burdens) associated with NBS, the framework prioritizes **justice and social inclusivity** across its planning, design, and implementation. It encompasses distributional, procedural, and recognitional justice to ensure equitable access to green amenities and inclusive participation in decision-making. This principle is operationalized by recognizing the unequal spatial distribution of vulnerabilities, engaging diverse stakeholder groups, and valuing their varied perceptions and values of nature. These methods aim to prevent social exclusions and empower local communities through active deliberation and engagement.

Transparency and legitimacy are paramount in the assessment framework, ensuring that stakeholders have a clear understanding of the process, thereby fostering effective participation and fair outcomes. The framework challenges traditional notions of planning and decision-making by embracing a communicative and deliberative approach while also acknowledging the constructed nature of knowledge and the power dynamics involved. This critical perspective facilitates an ethically reflexive approach to NBS planning and evaluation, enhancing the legitimacy and ethical grounding of the decision-making process.

Methodological foundations

A crucial aspect of our methodology involved a thorough review of existing NBS assessment frameworks developed under the EC Horizon 2020 programme, where twenty-four previous projects have offered groundbreaking insights. Among these, seven frameworks were identified as particularly relevant due to their innovative approaches to evaluating the impact of NBS on urban resilience, environmental sustainability, and socio-economic development. Frameworks like Nature4Cities provide diagnostic tools for cities to assess NBS impacts through comprehensive questionnaire. Meanwhile, the Reflexive Monitoring tool, developed under the Connecting Nature project, introduces a real-time monitoring method to adaptively manage projects with stakeholder input. The CLEVERCities Impact Assessment Framework and NAIAD emphasize the importance of decision support and stakeholder-driven incentives, respectively. Quantitative approaches, such as those found in the ThinkNature and PHUSICOS frameworks, apply numerical grading and Multi-Criteria Decision Analysis (MCDA) to evaluate various design scenarios of NBS, highlighting their effectiveness, feasibility, co-benefits, and resilience. Moreover, the Green Cities Framework by the GrowGreen project stands out as a comprehensive guide, promoting a modular and co-design approach to NBS strategy development and implementation across city, district, and site levels. These frameworks collectively advocate a tailored, stakeholder-inclusive assessment and monitoring approach, underlining the diversity of methodologies from descriptive analyses to quantitative evaluations.

Incorporating insights from these projects, this guide introduces a step-wise, hierarchical and replicable approach that builds on interdisciplinary, locally available scientific data, while suggesting a participatory multi-criteria analysis approach that enables stakeholder engagement and accounts for diverse social and ecological interests and needs. Central to the INTERLACE evaluation methodology is a participatory approach, intricately designed to accommodate the dynamics of urban municipalities and engage a broad spectrum of stakeholders.

This guide advocates co-creation as a means of collaborative governance, fostering cooperation and learning among stakeholders to collectively design, implement, and monitor NBS. This involves a diverse array of stakeholders from the outset, ensuring that the assessment framework is informed by a wide range of perspectives and knowledge. The adoption of an Agile approach underscores this commitment to inclusivity and flexibility, allowing for iterative feedback and adaptations that ensure the framework remains relevant and responsive to stakeholder needs. The deliberative approach suggested by this guide is particularly apt for consensus building regarding NBS priorities between diverse stakeholders, while it is less appropriate to examine individual and likely conflicting perspectives.

Rooted in operational research, Multi-Criteria Decision Analysis (MCDA) provides a structured framework to support complex decision-making, breaking down complexity into manageable steps and criteria. This approach enables a systematic assessment of alternatives, incorporating diverse ecosystem services and stakeholders' values into the decision process. By employing a combination of unweighted and weighted summation, pairwise comparison, and ideal point approaches, the framework accommodates various methodological preferences and application contexts, enhancing its applicability across different social-ecological systems. By adopting a modular structure, the assessment framework affords cities the flexibility to devise custom assessment systems attuned to their unique needs while adhering to a unified theoretical foundation. These systems, inherently versatile, are designed to identify spatial priorities for NBS implementation, guide the design of NBS, and facilitate the monitoring of existing NBS projects.

By detailing each module and presenting their application within the INTERLACE cities, this guide aims to pave the way for a nuanced understanding and implementation of NBS. It serves as a testament to the collaborative effort undertaken by stakeholders across multiple scales, striving to integrate restorative NBS within urban ecosystems.

Integrated modular approach

This guide is structured in a stepwise sequential, modular and hierarchical fashion (Figure 1). The selection and implementation of one or more modules can be adapted to the NBS implementation cycle. However, ideal integration of all five modules would be achieved in a sequential manner. This section presents a brief description of each module, i.e. decision framing, co-creation, planning, design and monitoring. Each module is then described in its hierarchical sub-steps in the following sections.

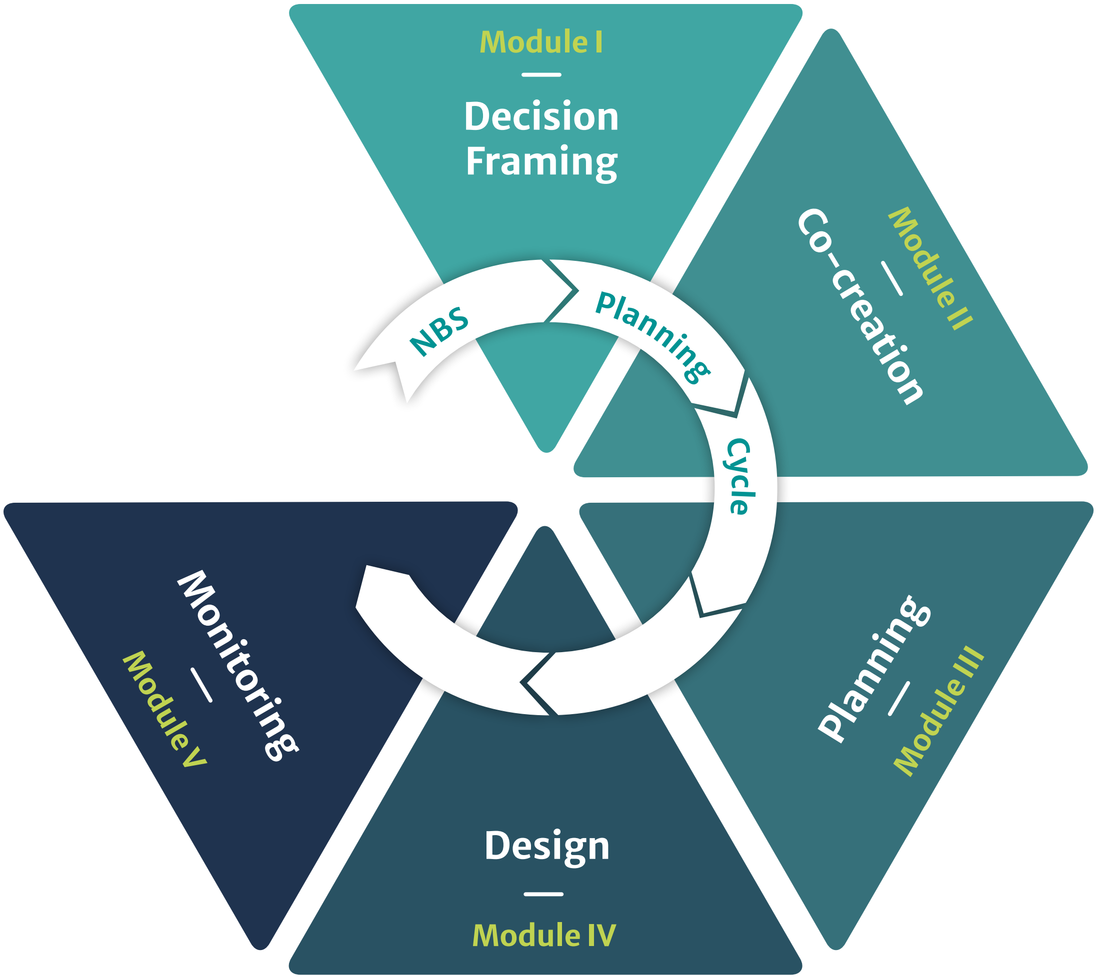


Figure 1.
Overview of the INTERLACE Nature-based Solutions Evaluation Framework.

Module I elaborates on the evaluation of the **Decision Framing** and policy context. This module supports the coherent integration of restorative NBS within existing and new strategies and policies and appropriate governance approaches across multiple scales. We suggest dividing the decision framing into the sub-steps of policy context, predefinition of challenges, selection of scale including considering cross-scale implications, and scope and potential constraints. A proper decision framing is foundational for all consecutive steps of the framework; its implementation is thus strongly recommended for the successful implementation of this guide.

Module II describes the design of a deliberative **Co-creation** process. This module supports an inclusive stakeholder engagement process. Although specific planning contexts might constrain the level of stakeholder engagement, co-created NBS assessment frameworks are more meaningful and add legitimacy to the evaluation. We thus recommend applying this module in all cases, even if the depth of the engagement might differ from case to case.

Module III addresses the NBS **Planning** through a spatial vulnerability assessment. This module is generally addressing a wider scale (e.g., city or metropolitan area) and supports the definition of geographical priorities in the implementation of restorative NBS. As such, it may be used to develop NBS and green-blue infrastructure strategies; it may also help to identify socio-spatial inequalities, such as areas of stronger social-environmental risks or areas with lower access to ecosystem services. This module is structured into five steps, including: selection of criteria, establishing spatial indicators, mapping vulnerabilities, weighting vulnerabilities, and spatial prioritization and reflection with considerations of feasibility for NBS implementation. Decision Framing and Co-creation are recommended presteps to the implementation of the Planning Module, while the Planning Module is designed to inform the NBS Design and Monitoring modules.

Module IV elaborates on the NBS **Design** and comparison of alternatives. This module builds on existing resources to provide examples of NBS. Design is characterised by using technical modelling, visualisation and simulation tools that facilitate the understanding of problems, feed the co-creation process, and enable the potential impacts and feasibility of the solutions studied to be assessed a priori. It further provides a rigorous framework for the evaluation of different restorative NBS design alternatives/scenarios. This module is structured into a sequence of seven consecutive steps, including: a site diagnosis, design strategies, inspiration for design, space design and modelling, comparison of alternatives, and final design. It is recommended to employ the Design module in combination with the Decision Framing, Co-cocreation and Planning modules in order to unfold its full potential to address relevant urban challenges.

Module V provides a framework for **Monitoring** of NBS after the intervention. This module is structured into four steps, including: selection of thematic indicators, action plan design, evaluation of the co-formulation process, and action plan implementation and evaluation. The monitoring module builds on the Decision Framing and Co-creation modules. It is strongly recommended as a follow-up of the Design Module, but it can also be used to develop a comprehensive monitoring approach for already existing NBS interventions.

In the following section we describe in detail each of the modules of the assessment framework.

01

Decision Framing Module

Figure 2. Decision Framing Module of The INTERLACE Nature-based Solutions Evaluation Framework.

Decision framing plays a crucial role in the planning, design, and monitoring of NBS. Although stakeholder participation has been endorsed for its ability to lend legitimacy to decision-making processes and to acknowledge a diversity of values (Hauck et al., 2014), the significance of decision framing in inclusive urban planning is often underestimated. In this context, it is essential to scrutinize the existence of equitable engagement spaces (Martin et al., 2016). Such spaces are pivotal in determining who participates in shaping the social, built, and ecological dynamics of the city, as well as the nature of this participation. This approach highlights the challenge of recognizing diverse priorities, knowledge bases, and practical needs across different interest groups. It facilitates the negotiation of conflicting and incommensurable values while balancing professional practices and political strategies with the desires and priorities of local stakeholders. This module integrates aspects related to decision framing, the identification of relevant policy tools, and governance structures (Figure 2).

1.1 Policy context

Understanding and analysing the policy context of NBS interventions requires examining several aspects of NBS governance. These include ongoing policy processes, relevant policy strategies, instruments that may influence the intervention (e.g., local norms, laws, and master plans), and existing governance structures like multi-stakeholder collaborations. It is also important to specify the dimension(s) of governance to be examined, whether within a particular policy field or sector (e.g., water management), at a specific governance level (e.g., city or regional), within a certain geographical area (e.g., a neighbourhood or along a river), or during a specific period (e.g., past or future). Accurately defining the policy context in which this guide is applied is essential for the effective adoption and impact of its results.

1.2 Predefinition of challenges

This guide recommends beginning the evaluation of NBS projects—whether in the planning, design, or monitoring phases—with an initial definition of the challenges that NBS aim to address. Clearly articulating these initial challenges and objectives is crucial as they play a pivotal role in framing the decision-making process. A narrowly focused framing on a specific challenge may cause the assessment process to mirror this limitation, potentially leading to an incomplete understanding of restorative NBS and their multifunctionality. Conversely, broadly formulated initial objectives will likely result in a more comprehensive, holistic, and inclusive assessment, considering a wider range of potential stakeholder preferences. A broader set of objectives aligns with the concept of multifunctional NBS, which may enhance adaptive capacities and ultimately improve the resilience of urban environments. The INTERLACE urban project partner cities defined fifteen main challenges (Knoblauch et al., 2021) to be addressed by NBS:

1. Heat stress & heat island effect
2. Soil quality
3. Watershed restoration
4. Water management
5. Drought & fire
6. Landslide risk
7. Ecologic connectivity
8. Green space management
9. Flood risk
10. Social cohesion
11. Social equity
12. Air quality and noise
13. Nature mainstreaming and stewardship
14. Reconnection education
15. Human health and well-being

1.3 Scale

A crucial component of decision framing is defining the principal scale at which to operate. This scale can range from an entire metropolitan region to a single site. In addition, it is important to consider both smaller and larger scales (n-1, n+1, n+2, etc.) that may influence or interact with the main scale. Acknowledging these multi-scale interactions can enhance the potential for NBS success, particularly if planning objectives are aligned across these different scales.

1.4 Scope and potential constraints

Defining the scope of the assessment system involves determining the extent of the area or subject matter that the assessment system addresses or is relevant to, as well as identifying opportunities for action in the ecological restoration of urban spaces. Another related sub-step is the identification of potential constraints in implementing the assessment framework in specific case studies, such as those arising from subordinate planning frameworks or data availability. This sub-step is crucial for formulating strategies to overcome these constraints whenever possible.

Case Study 1. Decision framing in Granollers, Spain

Granollers, a city in the Metropolitan Region of Barcelona, Spain, has a population of 61,983 inhabitants. It actively pursues a green transformation through the Connecta Congost Natura 2025 project (CoCoNat25). This initiative, funded by the European Union, focuses on renaturalizing the Congost River and enhancing the city's green infrastructure through NBS.

Predefinition of challenges. The CoCoNat25 project is geared toward addressing crucial needs in Granollers for biodiversity conservation and resilience against climate change effects. It includes a variety of actions aimed at improving connectivity between the city and nature.

Objective of the assessment framework. The primary goal is to collaboratively design the restoration of the Congost River, using the CoCoNat25 actions as a framework for envisioning a greener urban transformation in Granollers.

Scale. The assessment framework is implemented on two levels: 1) A focused intervention on the Congost River, serving as a pilot for broader naturalization efforts in Granollers; 2) A city-wide participatory process to design the overall renaturalization strategy for the city.

Scope and potential constraints. While the restoration activities for the Congost River are designed collaboratively, their scope is limited by the predefined parameters of the CoCoNat25 project. Furthermore, the participatory design process for the Granollers urban green transformation may face challenges in integrating results due to regulatory constraints from the Catalan Water Agency.

This streamlined approach exemplifies how the Decision Framing and Policy Context Module is applied in practice, guiding the strategic implementation of NBS within an urban setting while managing systemic constraints.

Figure 3. Congost River in Granollers, Spain. Source: Grace Yépez.

02

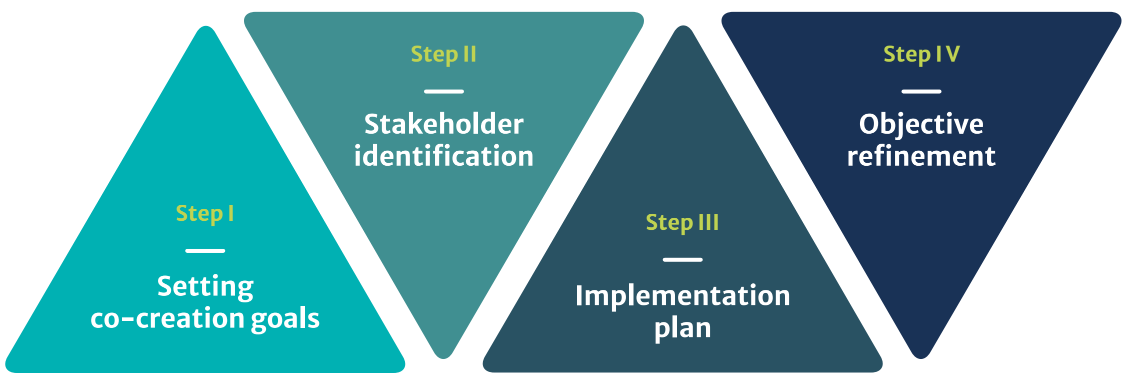
Co-creation Module

This module outlines the methodological process for implementing the assessment framework, which is based on two core approaches: co-creation and Multi-Criteria Decision Analysis (MCDA). Co-creation is a form of collaborative governance that fosters cooperation and facilitates learning among different stakeholders to design, implement, evaluate, and monitor NBS. This approach is particularly relevant where NBS planning, design, or monitoring involves multiple stakeholders, as is often the case in public-domain projects. Stakeholders are defined as any group or individual who might have a direct or indirect interest in, be affected by, or influence a project (Reed, 2008). In the context of NBS, these stakeholders include those who can provide essential knowledge and expertise resources, those affected by the city's challenges, those who influence the planned NBS interventions to address them, and even those more distant from but interested in restorative NBS (Leone et al., 2021).

The breadth and depth of the co-creation process are adaptable and should be aligned with the scale and scope of the NBS decision framing and policy context (see Chapter 1). Stakeholders are typically selected to represent a plurality of values and knowledge. Engaging stakeholders allows for the exploration of issues, concerns, expectations, interests, and opportunities related to NBS from various perspectives. Incorporating a broad and diverse range of knowledge and viewpoints ensures the creation of tailored, locally adapted, and more equitable NBS, while also enhancing stakeholders' acceptance and the sustainability of the solutions. Engaging a diverse array of public institutions, formal and informal community organizations, and private entities, with special consideration for non-traditionally engaged or marginalized groups, may enhance the representation of diverse values. The predefinition of challenges (1.2) offers useful guidance on the necessary knowledge domains that different stakeholders should cover, such as hydrology, green space planning, and community management.

It is advisable to involve stakeholders as early as possible, typically after defining the decision framing and policy context (Chapter 1). This

Figure 4. Co-creation Module of the INTERLACE Nature-based Solutions Evaluation Framework.



approach integrates the co-creation process closely with the MCDA, particularly in steps such as the selection and weighting of criteria, ensuring continuous stakeholder engagement. The following roadmap (Figure 4) guides the development and implementation of a tailored, deliberative co-creation process. It was initially developed to create an evaluation system to support the planning, design, and monitoring of NBS. Once this system is designed and tested, it may be standardized for scaled rollout, at which point the co-creation process may also become more standardized.

2.1 Setting co-creation goals

Once the decision framing and policy context have been defined, the initial step in the co-creation approach is to establish goals. This step focuses on clarifying the reasons for involving specific stakeholders and defining their roles in the NBS planning, design, or monitoring processes. It is important to recognize that stakeholders perform diverse functions throughout the NBS planning cycle, influenced by their roles and specific calls to action. Establishing clear collaboration objectives is crucial, as it considers the values that stakeholders contribute through their participation. To effectively define the goals of stakeholder engagement, we recommend first determining which stakeholder roles (Table 1) and *calls to action* are most pertinent.

2.2 Stakeholder identification

The second step, stakeholder identification, is done through a charting exercise to understand stakeholders' roles, interests, and knowledge within the NBS planning, design, and monitoring context. Stakeholders are categorized based on their roles or functions in the process (Table 1) and grouped according to their profession, knowledge, expertise, needs, or interests (Table 2). Initially, five key stakeholder roles are considered. A single stakeholder may assume one or more of these roles, which can change throughout the assessment framework.

Calls to action

Calls to action refer to specific tasks assigned to stakeholders at a particular moment of the NBS evaluation process, based on their roles. These tasks may include, among others, developing, organizing, leading, reviewing, deciding, and enabling. As a second step, it is crucial to define the added value each call to action brings. The following formulation can be used to help establish specific co-creation goals:

For [objective of the NBS planning module], the [stakeholder and stakeholder role] will [call to action] in order to [added value(s) of engagement].

Example:
To adapt the Spatial Vulnerability Assessment to the NBS strategic planning of the Interurban Ecological Corridor of María Aguilar, municipal representatives from the metropolitan cities will be involved as shapers to make sure the vulnerability mapping meets their expectations and needs as end-users.

Table 1. Stakeholder roles in the NBS planning cycle.

Stakeholder role	Definition
Developers	Those who are part of the development team. They develop project products and activities (usually as project partners).
Shapers	Those who provide input and feedback on project outputs.
End-users	Those who use the outputs of the INTERLACE project (products) for real-world applications outside the project.
Enablers	Those who can help the project reach and engage a diversity of other audiences, or achieve other desirable impacts (e.g., promoting and disseminating project outputs). They have significant social capital and standing in a community.
Interested public	Those who can generate bottom-up support for NBS and help translate the work of INTERLACE to other stakeholders (improved understanding, increased relevance).

Table 2. Stakeholder groups in the NBS planning cycle.

Stakeholder group	Definition	Examples
Political representatives	Those who are elected to public office and make political decisions within governmental settings.	» Mayors » Ministers » Elected officials
Governmental authorities	Those who develop, control, or maintain laws, strategies, or plans.	» National government » Regional administration » Municipal urban planners
Civil society	Those who hold the space for collective action around shared interests, purposes, and values. This group is generally distinct from government and commercial for-profit actors.	» Community-based organisation/ neighbourhood association » NGO » Environmental and social movements
Beneficiaries	Those who use NBS and benefit from them in diverse forms, including provisioning, regulating, and cultural ecosystem services.	» Neighbouring residents » Environmental stewards
Negatively impacted communities	Those who might experience adverse outcomes (encompassing both social and environmental impacts) from the implementation of NBS.	» Neighbouring residents » Vulnerable groups
Academia, research, and education	Those doing research and wanting to advance knowledge and/or share knowledge with students and interested parties.	» Research institutes » Universities » Highschool or primary schools » Environmental education projects

Stakeholder group	Definition	Examples
Private sector	Those who make part of a country's economic system and run individual and company businesses to make a profit.	» Finance sector and funders » Private company / consultancy » Design and/or architecture office » Cooperatives / foundations » Landowners and land managers » Farmers
Media & networks	Those who produce and spread news and stories.	» Press representatives » Online influencers » Professional associations » National and regional associations of municipalities

2.3 Developing an implementation plan

The implementation plan is a logical order of planned engagement activities, their objectives, who to engage with and through which format and tools. Planning should consider realistic sequences and timing, allowing updates based on new insights. Several engagement activities need to be considered in the implementation plan, such as the objective refinement (2.4) and the selection and weighting of criteria (3.1 and 3.4).

2.4 Objective refinement

During the objective refinement step, the objectives of the assessment framework are shared with and discussed among stakeholders. This ensures their relevance and facilitates the establishment of common goals. It is important to recognize general objectives while also giving due consideration to the specific objectives of minority groups, ensuring that all stakeholder perspectives are adequately represented and addressed. Based on the Agile development process, the creation of *user stories* can support this step.

User stories

User stories offer a structured way to capture the goals of stakeholders. Each stakeholder articulates their expectations from the NBS planning in this format:

As a [role], I want [goal] so that [benefit].

Examples:

(1) As a neighbor, I want the design of the urban park to help minimize the occasional flooding events.

(2) As a technician of the city council, I want to identify which areas of my municipality are most vulnerable to climate change, so I can prioritize them when allocating NBS.

Case Study 2. Co-creation in the metropolitan area of San José, Costa Rica

The Corredor Biológico Interurbano María Aguilar (CBIMA) serves as a crucial ecological and urban link in the metropolitan area of San José, Costa Rica. Since its establishment in 2009, CBIMA, which covers 39 km^2 and houses approximately 400,000 residents, has focused on integrating modified and natural habitats to address socio-ecological vulnerabilities through NBS.

Setting co-creation goals. The CBIMA project was initiated with clear goals to foster collaborative efforts centered on common interests, goals, and principles. It aimed to facilitate information sharing among civil society for NBS development, ensure governmental authorities shape outcomes to meet public needs, and leverage academic and research contributions for data-driven decision-making.

Stakeholder identification. A thorough identification and categorization of stakeholders based on their roles, interests, and potential impact were conducted. This process involved compiling a comprehensive list of stakeholders from the six municipalities of CBIMA, totaling 58 stakeholders. This foundational work was crucial for effective engagement throughout the project.

Figure 5. Co-creation workshop in San José, Costa Rica. Source: Johannes Langemeyer.

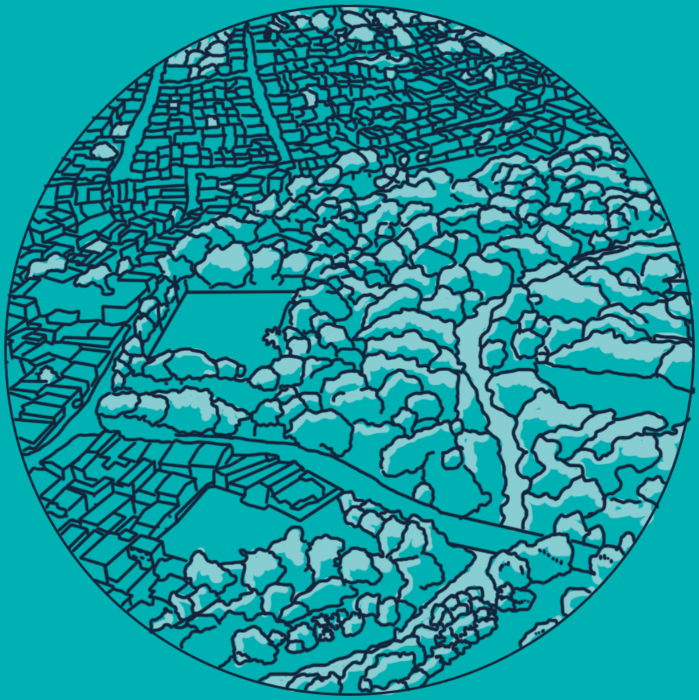
Developing an implementation plan. Following stakeholder identification, an implementation plan was developed, outlining the co-design and co-creation phases. The plan included schedules for online and in-person meetings and workshops aimed at defining challenges and finalizing participation strategies.

Objective refinement. The project's objectives were refined during online co-design meetings, where stakeholders discussed and aligned on urban vulnerability criteria and the broader project goals. This phase ensured a mutual understanding of objectives, setting a solid foundation for subsequent activities.

Selection of criteria. Initial criteria were identified to represent the specific vulnerabilities within the urban context of CBIMA. These criteria were discussed and preliminarily agreed upon during the first phase of online meetings, setting the stage for deeper engagement and refinement in subsequent workshops.

Weighting of criteria. The co-creation and weighting of criteria were conducted through a series of six participatory workshops, including one metropolitan and five municipal sessions. The Participatory Weighting Workshop utilized the Pebble Distribution Method, allowing stakeholders to physically prioritize urban vulnerability criteria. This approach facilitated comprehensive discussions and consensus-building on the relative importance of each criterion.

Through continuous stakeholder engagement, collaborative decision-making, and iterative refinements, the CBIMA project successfully aligned its outcomes with the diverse needs and preferences of the community. This structured approach to co-creation was the starting point for the application of the spatial vulnerability assessment module.



03

Planning Module

NBS offer a substantial avenue for fostering just and efficient urban transformations. As NBS become increasingly mainstream in addressing urban challenges, systematic planning is vital to unfold their full potential and avoid eventual undesired outcomes. However, NBS planning often lacks spatial and sectoral integration, which hinders their ability to provide multifunctional ecosystem services. A cornerstone of strategic NBS planning is the identification and spatial localization of urban vulnerabilities, which allows for targeted prioritization of NBS interventions, sensitive to the unique challenges of local contexts. This is essential not only for the systematic and efficient implementation of NBS but also for a just distribution of ecosystem services adapted to local needs (Langemeyer & Connolly, 2020).

The complexity of urban vulnerabilities makes seeking new approaches in NBS planning that promote justice and efficiency within urban environments highly compelling. Such approaches must integrate social and ecological considerations into NBS planning processes, ensuring that the benefits and impacts are equitably distributed among communities whilst requiring a comprehensive understanding of the social dynamics, cultural contexts, and ecological sensitivities of urban areas. This is why, on the one hand, the spatial vulnerability assessment proposed here provides a guideline to spatially assess both natural and anthropogenic vulnerabilities that can be addressed through the strategic planning of NBS (e.g., excess urban heat, lack of recreational space, or lack of habitat for species). On the other hand, the methodology presented builds on the assumption that tailored, context-specific approaches are necessary to assess urban vulnerabilities and recognizes that each city has a unique set of vulnerabilities and priorities that require customized strategies for effectively planning NBS. The spatial vulnerability assessment provides a structured approach to support NBS planning in an early strategic stage, enabling cities to address environmental and social concerns with precision and foresight.

The outcome of the assessment—vulnerability maps at various levels of aggregation—provides a spatially explicit representation of vulnerabilities, empowering urban planners and decision-makers to prioritize resources, allocate interventions, and enhance the equity of urban areas. The combination of comprehensive data analysis, stakeholder engagement, and visualization techniques enables a robust and informative vulnerability mapping process. Following the MCDA framework, this process unfolds in five distinct, yet interconnected, sequential steps: 1) criteria selection, 2) indicator definition, 3) mapping of indicators, 4) weighting, and 5) final integration (Figure 6).

3.1 Selection of criteria

The spatial vulnerability assessment starts with the determination of evaluation criteria. These criteria are understood as vulnerabilities that are relevant in the local and regional context and that are meant to be targeted through NBS. The initial proposal of criteria should align with—but

Figure 6. Planning Module of The INTERLACE Nature-based Solution Evaluation Framework.

not be limited to—the predefinition of challenges (1.2). The objective of this activity is to understand, validate, and refine the criteria while also incorporating any relevant criteria missing from the initial list. This may include anthropogenic vulnerabilities, such as the lack of recreational space, and ecological vulnerabilities, such as the lack of habitats for species, but also those that affect both humans and non-human species, such as vulnerability to excess heat.

The criteria selection process should bring together a diversity of stakeholders (local communities, NGOs, government representatives, and urban planners) relevant to the scale of the assessment. This initial convergence is important for identifying the specific vulnerabilities. The engagement process establishes the foundation for collective action and further fosters a shared understanding for its implementation. During this phase, stakeholders share their knowledge and perspectives, ensuring that the assessment of vulnerabilities is comprehensive and inclusive of different viewpoints. The stakeholder selection follows the approach outlined in Chapter 2.

Critical insights for the selection of criteria

Various participatory methods are available for selecting criteria. A recommended approach, tested in the INTERLACE partner cities, involves conducting an in-person workshop with stakeholders. During the workshop, participants are divided into small groups of 5–7 people. Each participant selects a criterion from a pre-prepared list that they find most relevant, providing a brief justification for their choice, which is then discussed by the group. This process is repeated until all pre-prepared criteria have been reviewed. Subsequently, the group discusses whether any criteria should be removed, merged, or if new ones should be added. Insights from the MCDA literature and practical applications in the INTERLACE partner cities offer valuable guidance for the criteria selection process.

Lessons learned:
(1) Consider the criteria breadth and aim for similar aggregation levels between the criteria to avoid biased results.

Good practice example: ***Criterion A: Opportunity for Recreation; Criterion B: Air pollution reduction***

Bad practice example: ***Criterion A: Opportunity for Recreation; Criterion B: Sulphur dioxide reduction; Criterion C: Nitrogen dioxide reduction; Criterion D: Carbon monoxide reduction***

(2) Reach a consensus regarding the list of evaluation criteria among all stakeholders. In case there are minority stakeholder opinions, keep them in so that everybody can agree on the final list. The weighting of criteria (3.4) will allow for adjusting the relative importance of the criteria.

3.2 Establishing spatial indicators

After identifying relevant vulnerabilities—the evaluation criteria to be addressed—, the next step is to establish spatial indicators to map these vulnerability criteria. Urban vulnerabilities are spatially heterogeneous, encompassing the two dimensions of exposure and sensitivity (Figure 7). Exposure relates to proximity to a hazard, while sensitivity describes how significantly someone or something is impacted by a hazard (Camacho-Caballero et al., 2024). The establishment of indicators requires identifying both the hazards (like flooding or extreme temperatures) and descriptors of ecological and social sensitivity to these hazards (e.g., areas with high concentrations of vulnerable populations such as the elderly). This step is critical for translating qualitative assessments into quantifiable metrics that can be mapped and analysed.

Figure 7.
Exemplary list of vulnerability criteria and corresponding exposure (green) and sensitivity (blue) indicators.

Criteria/ Challenges	Indicators										
Lack of recreational opportunities	Walkability to green spaces above 0.5 ha	Walkability to green spaces below 0.5 ha	Visibility of green	Visibility of blue	Density of non-green recreation	% of population below 14 years	% of population receiving social assistance	% of unemployed population in the working age	Population density		
Air pollution	Average concentration of PM10	Average concentration PM2.5	Average concentration NO2	% of population above 65 years	Distance to health & care facilities	% of population below 14 years	Distance to elementary schools	Distance to playgrounds	% of population receiving social assistance	% of unemployed population in the working age	Population density
Noise pollution	Traffic noise level	Land-use sensitivity	Population density								
Heat	Heat islands	% of population above 65 years	Distance to health + care facilities	% of population receiving social assistance	% of unemployed population in the working age	Population density					
River flooding and runoff	Fluvial flood risk	Runoff coefficient	Critical infrastructure	Population density							
Landslides	Landslide risk	Critical infrastructure	Population density								
Wildfire	Wildfire risk	Areas under nature conservation	Critical infrastructure	Population density							
Drought	Soil moisture content	Areas under nature conservation	Areas of food production								
Habitat fragmentation	Cost distance for pollinators	Main ecological corridors									
Biodiversity loss	Biodiversity intactness	Areas under nature conservation									

The process often begins with a theoretical list of indicators, which is then refined based on data availability and the local context. Unlike the vulnerability criteria, these indicators are often not easily understood by lay stakeholders. Therefore, we suggest developing an indicator list based on a scientific literature review and discussions among an interdisciplinary team of experts. In cases where data limitations exist, it may be necessary to develop proxy indicators that accurately represent the vulnerabilities.

Non-linearity and vulnerability thresholds

Vulnerabilities can be characterized by nonlinearities and thresholds, which should be considered during the normalization process (Camacho-Caballero et al., 2024).

Example:
The exposure to heat during the day might involve identifying a specific temperature below which heat poses no significant hazard to humans and ecosystems. A practical threshold could be 32 ºC. Below this threshold, no hazard is considered; the hazard value equals zero.

3.3 Mapping vulnerabilities

Using the indicators identified in the previous step, experts in Geographical Information Systems (GIS) help to determine and map the spatial distribution of vulnerabilities. This involves a detailed process where exposure to hazards and social and ecological sensitivities are spatially represented. After the initial preparation of single indicator maps, all vector data is converted into raster format. This conversion facilitates the spatial comparison and integration of different resolutions. For strategic NBS planning at the city or municipal scale, a cell size of 10m x 10m strikes a good balance between data accuracy and computing capacity. Raster data with coarser resolution must be resampled.

When preparing vulnerability indicators for comparison, each indicator's value is adjusted to a 0–1 scale through min-max normalization. Here, a value of 0 indicates no exposure or sensitivity, while a value of 1 represents the highest observed exposure or sensitivity. Additionally, the normalization process should account for nonlinearities and thresholds relevant to the context to accurately map and understand different levels of vulnerability (Camacho-Caballero et al., 2024).

For each type of vulnerability, aggregated exposure and sensitivity maps are produced by summing the respective indicators, which are weighted according to their relevance. The process of determining the relative weights of the indicators is typically guided by expert input, contrasting with the method used for weighting evaluation criteria (3.4). In cases where specific weights for indicators cannot be justified, an equal weighting approach is advisable. This method involves grouping all indicators related to the same phenomenon and then applying equal weight to each group collectively. Considering that vulnerabilities emerge at the intersection of exposure to hazards and sensitivity, the aggregated exposure and sensitivity maps are finally multiplied to obtain a single map for each vulnerability.

3.4 Weighting of vulnerabilities

In the next step, stakeholders' preferences are considered through a method known as "weighting of criteria". Criteria weights are defined as the relative importance of one criterion in the context of all others considered. This step revisits the stakeholder group to debate and determine the relative significance of each vulnerability criterion. Known as "weighting" in multi-criteria decision analysis, this phase can employ various methods to ascertain stakeholder weights. We recommend conducting a workshop to collaboratively prioritize these criteria. The objective of collective weighting is to achieve a consensus on the relative importance of each criterion, but also to exchange different expert and stakeholder perspectives. The collective weighting can thereby play an important role in integrating plural knowledge into the strategic planning process.

The specific technique proposed for allocating relative weights during the workshop is the Pebble Distribution Method—a deliberative group valuation approach based on trade-off assumptions. In this method, stakeholders use pebbles or similar items to denote the relative importance of each vulnerability, reaching a consensus through discussion and adjustment. This method is particularly valuable as it physically and didactically engages participants, helping them articulate their preferences and priorities regarding the criteria in a group exercise that leverages diverse expertise (Langemeyer & Baró, 2021).

3.5 Spatial prioritization map

The final step is to combine the individual vulnerability layers into a comprehensive map using a GIS environment. This is typically achieved through a weighted summation approach, employing the weights assigned during the stakeholder weighting exercise for each of the vulnerability criteria. To evaluate the robustness of the results to different preferences, weighting profiles of different stakeholders or uniform weights can also be applied for comparison. For large areas, this weighting process may be repeated for smaller regions to reflect localized priority variations (see Case Study 2).

This methodology provides a robust foundation for prioritizing NBS in a spatially focused manner. It allows for a detailed assessment of numerous spatial vulnerabilities while aligning with local priorities and contexts. This process not only aids in developing more equitable and efficient NBS strategies but also ensures that resources are directed where they are most needed. This strategic planning approach underscores the importance of a vulnerability-centric perspective in the development of NBS, enhancing the justice and sustainability of urban environments.

Pebble Distribution Method

For the practical application of the Pebble Distribution Method as a weighting approach, it is useful to divide participants into heterogeneous break-out groups of 5–7 individuals, each led by a facilitator. The facilitator guides the discussion, explains the methodological steps, and ensures that all opinions are expressed and represented. The previously established evaluation criteria are provided in written form, for example, printed on large sheets of paper, as illustrated in Figure 8. Each break-out group receives 100 points, represented by pebbles, beans, or any other suitable/local material, which reflect the importance of the criteria.

In the first round of the exercise, each participant selects one criterion and discusses its relevance. This round continues until each criterion has been initially addressed, laying the groundwork for a common understanding of the criteria.

In the second round, participants begin distributing all pebble-points across the criteria. This distribution should be completed promptly.

In the third round, participants debate the initial distribution and adjust the placement of pebbles based on the discussion about the relative importance of each criterion. This process is repeated until a consensus on the final distribution of weights is reached.

Figure 8. Weighting criteria or vulnerabilities using the Pebble Distribution Method.

Case Study 3. Spatial vulnerability assessment of the Krakow Metropolitan Area, Poland

The spatial vulnerability assessment framework was applied to the Krakow Metropolitan Area (Metropolia Krakówska) in Poland to address a variety of urban challenges through NBS. This application showcases the process from the identification of urban vulnerabilities to detailed mapping and prioritization.

The assessment began with an extensive stakeholder engagement process involving local government representatives, environmental NGOs, urban planners, and community members. Through facilitated workshops, a range of ten urban vulnerabilities, including lack of recreational green spaces, noise pollution, heat islands, and urban flooding, were identified. These workshops helped pinpoint the issues most relevant to the local and regional context of Krakow and its surrounding areas.

The vulnerability assessment benefited from a data-rich environment, with a total of 47 spatial indicators selected for the analysis. For each vulnerability criterion, both exposure and sensitivity indicators were defined. For example, in addressing the challenge of flooding, exposure indicators included proximity to the Vistula River and its tributaries, areas historically affected by floods categorized under the domain of fluvial flood exposure, and surface runoff. As direct information about runoff was unavailable, land-use data was employed as a proxy indicator. This land-use data is critical in urban settings like Krakow, where detailed data on the exact nature and distribution of impermeable surfaces may be lacking, but the understanding of general land use is well-documented and readily accessible for analysis.

For assessing sensitivity, factors such as the distribution of critical infrastructure and population density were analysed to determine how susceptible different areas are to the impacts of flooding. These sensitivity metrics were then layered with the exposure data to produce a comprehensive vulnerability map. This map effectively highlights the zones where high flood exposure intersects with high sensitivity, pinpointing areas most at risk of urban flooding.

The detailed vulnerability maps produced from this framework offer significant advantages for urban planning in the Krakow Metropolitan Area (Metropolia Krakówska). The maps enable planners to identify where NBS can be most effectively implemented to mitigate specific vulnerabilities. For flooding, potential interventions might include creating or restoring wetlands along the Vistula River to enhance natural flood mitigation or designing green roofs in urban areas to reduce surface runoff. By identifying the most critical areas, resources can be allocated more efficiently, ensuring that investments in NBS yield the greatest benefit in terms of risk reduction and enhanced urban resilience. Focusing on the sensitivity of particularly vulnerable communities also allows for more equitable NBS planning. Moreover, the participatory approach ensures that the solutions developed are more widely supported and address the actual needs of affected communities.

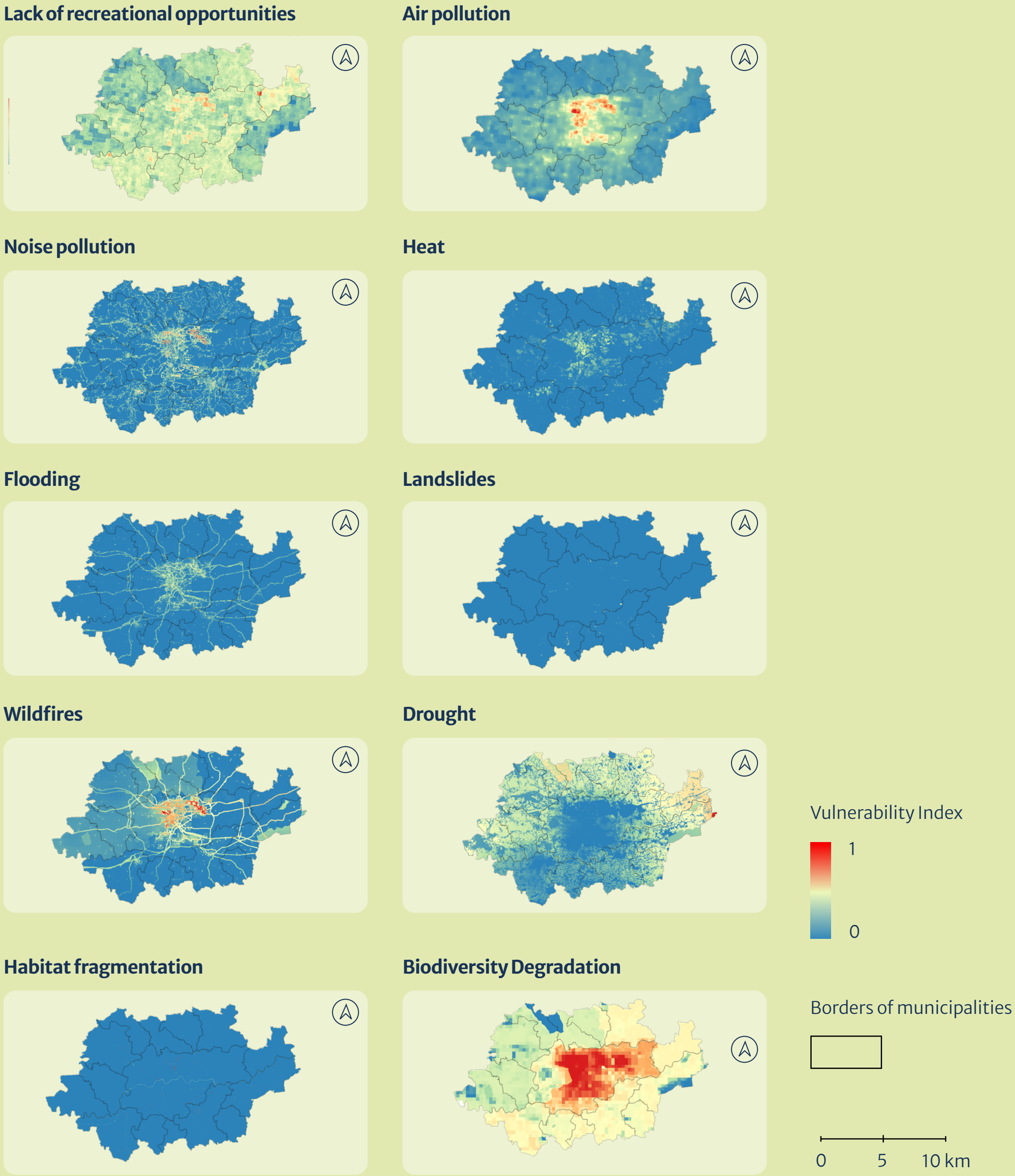


Figure 9.
Vulnerability maps from Krakow Metropolitan Area
Source: Johannes Langemeyer.

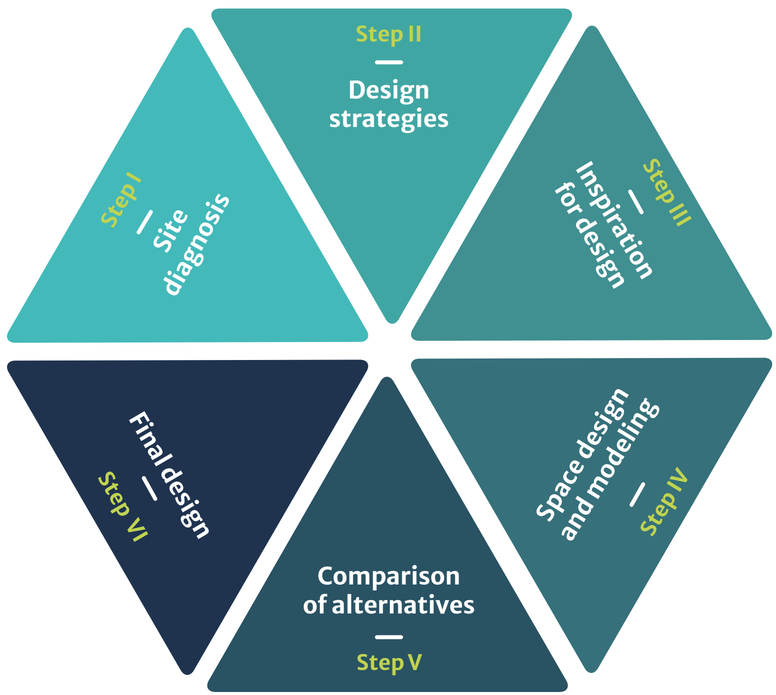
04

Design module

This module is designed for urban designers tasked with transforming project ideas into concrete interventions and integrating NBS into urban proposals. It combines urban design practices with ecosystem restoration processes and is applied at the scale of the urban intervention project. The site selection is informed by the results of the spatial vulnerability analysis, which also helps define part of the programmatic specifications for the project, specifically the ecosystem services NBS should provide. Additionally, this module considers the local context, which includes the natural and urban features of the site, as well as programmatic demands or constraints influenced by political or technical decisions driving the project.

There are various ways to design an NBS intervention, and it is advisable to use a formal design-centered methodology to facilitate the process and ensure the quality of its outcome. Traditional waterfall planning methods are less recommended in favour of more advanced methodologies such as Design Thinking or Agile, which are user-oriented and impact-focused, allowing for flexibility and experimentation. INTERLACE has successfully tested an Agile approach to NBS design (Mortelmans et al., 2021), involving short, iterative development loops that culminate in an exchange with the user. This Agile approach is reflected in the structuring of the steps of the design module.

Figure 10. Design Module of The INTERLACE Nature-based Solution Evaluation Framework.



The design module comprises six essential steps to be applied in a defined order, with repetition loops (co-creation) for defining strategies and designing solutions (Figure 10). It builds on the previous co-creation module to justify, fuel, and open the design process by establishing a constructive exchange between urban design experts (town planners, architects, landscape architects, biologists, engineers) and stakeholders familiar with the project area (local councillors, municipal technicians, residents). The six essential stages will enable the successful completion of a design project incorporating NBS. We recommend following the process step-by-step and documenting each stage. The essential steps are listed below, with key elements of each step defined in terms of process, supporting tools, criteria to be included, outcomes, and links between steps.

4.1 Site diagnosis

This first step, the site diagnosis, is the most important in the NBS design process. It establishes the foundations of the project based on the programmatic information already defined, the conditions of the site, and the conditions of the existing or sought ecosystem. This stage generates design requirements, including climate conditions, key parameters about the local ecosystem, current landscape design and users' perceptions, functionality of the place, and risks related to the area. Site diagnosis is based on data collection, site visits, meetings, and workshops. It is important to be able to call on different areas of expertise for this stage, as multiple viewpoints will help to capture the complexity of the site, which is essential for the design.

Decision framing in the context of NBS design

Decision framing is part of all NBS assessments (for the generic approach, see Chapter 1). However, in the NBS design module, there are specificities as the decision framing closely determines and guides the design decisions and the way the design steps are implemented. This enables the design team to know whether a decision has been validated or whether it can still be called into question. Moreover, the design team may better understand which determinants are rigid, and which aspects allow for more flexibility.

(1) The political and technical decisions for an NBS intervention need to be scrutinized. Guiding questions can be: What are the objectives? How is the decision-making mandate formalised? What is the process for validating a decision? How does the project fit in with the local political agenda?

(2) Design decisions must be based on tangible information that corresponds to the political and technical objectives of the stakeholders involved, as well as on the specific urban and environmental requirements of the site.

The assessment criteria include:

- **Natural context:** existing natural ecosystems, topography, corridors, relevant natural fluxes (e.g., water, wind, sun, fauna), risks, climate change scenarios.
- **Ecosystem to be restored:** description (composition, structure, function), level of degradation, restoration potential.
- **Places:** public plots, local land-use regulation, urban dynamics, private and public green spaces, public infrastructures (e.g., water, transport, buildings), accessibility to green areas, specific urban challenges (e.g., safety, memory, heritage).
- **People:** social composition and homogeneity, perception of nature, relationship with urban green, uses of public areas (type of user, schedules, activities, expectations/added value of the green area), inclusion.

4.2 Design strategies

Based on the project's technical and programmatic specifications, the design team can initiate the proposal work by defining intervention strategies. These strategies must address both the environmental and ecosystem restoration challenges and the urban challenges, such as accessibility, relationship with mobility, relationship with urban facilities, urban landscape, and the inclusive character of the public space. Strategies should be defined primarily in terms of functions and ecosystem services to be provided (e.g., retaining runoff water at this location), not techniques (e.g., implementing rain gardens).

The proposed functions as part of the design strategy must respond to the specific vulnerabilities (as detailed in Chapter 3) and opportunities of a site. Their definitions must be sufficiently precise and meet the design criteria defined for the project. Generally, not all functions can be maximized; therefore, we suggest weighting the NBS functions to determine which ones are to be prioritized at the site scale. A proven approach for the participatory weighting of criteria is the Pebble Distribution Method. Similar to its application in the strategic planning phase, this method can be applied in the design phase (see page 32 for further details on the execution of the Pebble Distribution Method).

The functions need to be aligned with the project's capacity to meet them. Working with the strategies in this way allows a certain amount of design freedom, so that the process is not locked into technical details, and essential functions that the project must incorporate are not overlooked. It also enables vague requirements to be reformulated into technical parameters for the design. This work can take the form of a functional plan, using the site map as a basis.

At this stage, it is important to discuss the choice of strategies with the stakeholders, as this introduces them to the spatial dimension of the project and the choices to be made to prioritize the design options (See Figure 11 for an example). A feasibility check should also be conducted with the local authorities, to confirm whether there are technical impediments for the strategies to be implemented as defined.

Figure 11.
Example of design strategies including NBS for the Mamey Park in Portoviejo, 2024.
Source: YES Innovation.

Blue cycle as back bone

—

Treatment demo, floodability, blue landscape

Biodiversity on the scene

—

Vegetable islands, protection, visibilisation

New user hotspots

—

Circuit and places to see, to enjoy, to empower

Welcome facade

—

Connection to the city, easy access, safety everywhere

Co-creation in the context of NBS design

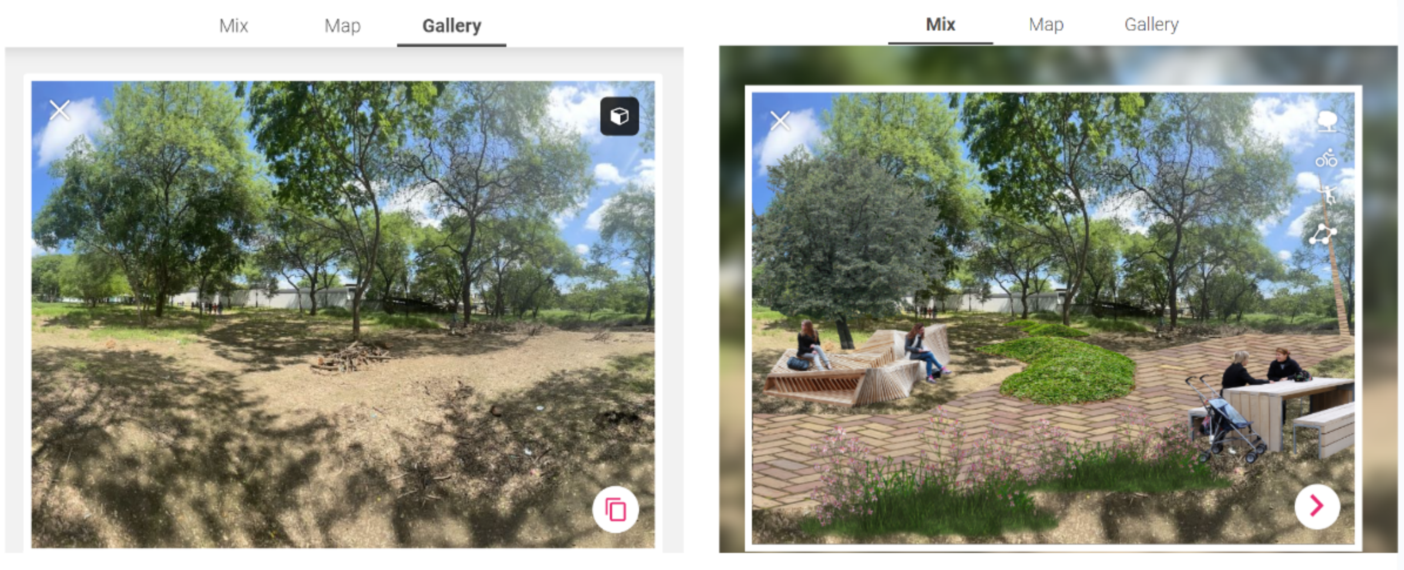
The co-creation process is particularly important for steps 2 (the development of design strategies) and 4 (space design and modelling), and as a cycle between them.

Lesson learned:
For the design module, it is essential to be able to transmit qualitative and explicit information to the parties involved. For the design with NBS, this means balancing the information provided between urban and environmental criteria.

Advice 1: Start with the environmental criteria, which are generally not as well-known and less considered by local stakeholders.

Advice 2: To facilitate the participatory process and strengthen the sharing of information between experts and users, it is worth using dynamic and fun digital tools. For instance, the use of survey solutions such as Mentimeter or working on dynamic maps with Miro offers initial advantages. The Unlimited Cities tool takes this a step further by facilitating dialogue with users of public space, whether in a workshop or directly in the street, through a quick and intuitive co-design platform (Salmon et al., 2021). INTERLACE has worked on the development of a new version of this tool incorporating qualified information on NBS.

Figure 12. Example of a mix generated onsite with Unlimited Cities DIY for the Mamey Park in Portoviejo, Ecuador. Source: YES Innovation.



4.3 Inspiration for design

Designers often seek inspiration from existing projects or past examples, whether for establishing overarching design principles or for the details of specific techniques. While this step is not mandatory, it is a common practice. Beyond providing inspiration, this stage also aids in communicating ideas to stakeholders by showcasing examples of what can be achieved. Introducing the aesthetic aspects of the proposal facilitates dialogue, frees up ideas, and helps to structure the landscaping proposal. Resources include project libraries on Pinterest or Archdaily; design and landscape magazines like *Dezeen;* and local and international examples from conferences and social media can support the creative process and facilitate co-design.

4.4 Space design and modelling

Step 4 is the heart of the design module. It consists of transforming the strategies defined previously into a detailed and coherent public space design. This is a classic design stage, where the use of 3D tools makes it easier to take account of topography and dialogue with stakeholders. Traditional tools do not incorporate much information specific to NBS—a barrier that INTERLACE is trying to overcome through a set of thirty NBS objects available freely in the SketchUp 3D Warehouse since April 2024 (see Additional Resources). It is advisable to refer to existing technical documentation and standards to be able to incorporate them as effectively as possible. It is also important to be able to draw on the advice of environmental experts when sizing solutions and choosing which vegetation species to include.

4.5 Comparison of alternatives

While some of the functions and ecosystem services that NBS can provide can be analysed using the implementation plan alone, others require the support of specialised tools to measure their impacts more accurately and thus be able to define whether the proposed solutions are appropriate and sufficient. There are various tools—of varying degrees of complexity—available for this purpose, the choice of which will depend on the objectives and size of the project. These solutions provide scientific support, which is a real added value for integrating NBS into a project. Criteria to be considered for the comparison include:

- **Viability check:** land tenancy, infrastructures, planned projects, public policy, budget.
- **Urban integration:** functionalities, accessibility, landscape.
- **Ecosystem restoration:** reducing vulnerabilities, repairing ecosystem functions, supporting recovery of ecosystem services.
- **Social acceptance:** inclusion, co-design, social value.
- **Risk mitigation:** thermal comfort and urban heat island, runoff management, slopes control.

4.6 Final design

This final stage consists of formalizing the plans for the urban intervention, which prefigure the implementation. It is a straightforward technical step in this module, as it is not advisable to modify the design at this stage; everything should have been discussed and validated previously with the project stakeholders.

Studying thermal comfort to build more resilient cities

Thermal comfort simulations are valuable tools for designers, urbanists and planners, utilised to predict comfort levels and, in some cases, to evaluate the impact of nature-based solutions (NBS) in reducing thermal stress in urban areas.

Practical application in Envigado and Granollers

- Five modelled areas, one in Granollers and four in Envigado, totalling 990.000 m^2.
- Future climate projections indicate an increase in thermal stress across both study areas. ranging from 1 °C to 3 °C in Physiological Equivalent Temperature (PET).
- The trees in both projects serve to mitigate the increase in thermal discomfort.

In **Granollers**, the urban tree canopy will be crucial for maintaining thermal comfort in the future. Temperature differences of up to 9 °C can be observed between shaded areas under trees and exposed asphalt surfaces. This demonstrates significant variations in thermal comfort indicators when comparing the current urban design with the projected design that incorporates NBS under future climate conditions. 93 % of the neighbourhood will be under risk conditions in the future, which makes it necessary to design whilst considering the positive effect of natural solutions.

Figure 13. Urban overheating in current and future climate scenarios, in Sant Miquel, Granollers. Source: Fundación Tecnalia R&I.

In **Envigado**, four areas were identified for modelling to locate opportunity spaces where nature-based solutions improvements could be implemented. This provided a spatially explicit representation of areas where NBS implementation could significantly improve thermal comfort in public spaces. The proposed indicators are based on percentages of surface area exposed to different ranges of thermal comfort, which allows for comparison between design alternatives and scenarios.

Figure 14.
PET degree differences in current and future urban overheating in central Envigado, Surface Index (SI) values calculated at the hottest hour of the day in four neighbourhoods of Envigado (table).

Neigbourhood	Current SI*	Future SI
Mesa	180	184
Flores	174	178
Centro	178	180
Alcalá	172	175

* The SI can range between 100 (highest comfort) and 200 (lowest comfort).
Source: Fundación Tecnalia R&I.

Case Study 4. Designing the ecological rehabilitation of the Mamey Park in Portoviejo, Ecuador

The Mamey Park is located in a central area of Portoviejo, Ecuador, very close to the historic centre, but suffers from partial abandonment, safety problems, and a poor connection with the Portoviejo River, which runs through it. The river is not very visible or accessible, which is why people have lost interest in it. To reverse this trend and recover the connection with its river, the municipality of Portoviejo began defining a specific plan for the urban restoration of the Portoviejo River corridor in 2020. The design process aimed at making the park an example of the ecological integration of urban ecosystems (in this case, the river), by involving the neighbouring populations that use this public space. Mamey Park interventions aim to tell the story of the relationship between the city and the river and recreate a synergy between nature and urban space.

The initial diagnosis covered both the urban aspects and the state of nature in the park. The co-creation process enabled the definition of users' priorities and the construction of park proposals through participative workshops. The rehabilitation proposal included a central role for existing nature, which became crucial in structuring the uses, discovery, and ecosystem functions offered by this new public area in the heart of the city.

Figure 15. Mamey Park in Portoviejo, Ecuador. Source: YES Innovation.

Figure 16. Design insights for the Mamey Park. Source: YES Innovation.

05

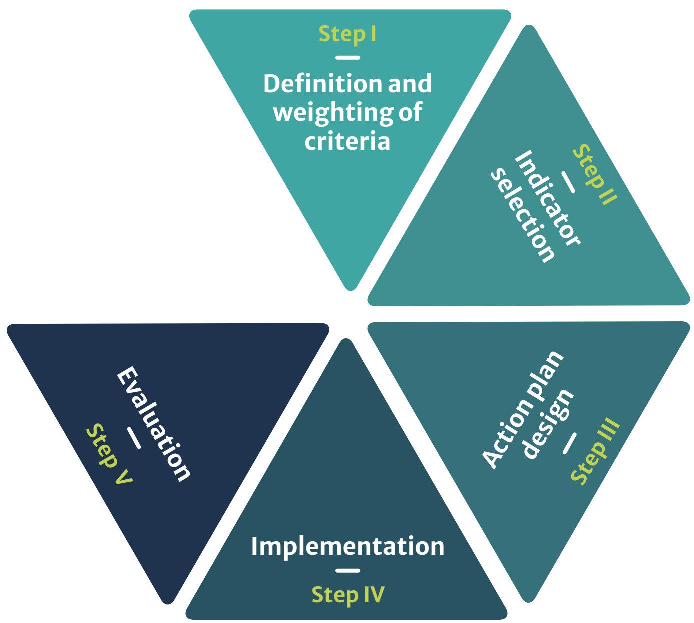
Monitoring Module

The monitoring module is designed to measure the effectiveness of NBS post-implementation and with changes over time. Effectiveness is understood as the capacity for NBS to address specific challenges, including the mitigation of locally relevant vulnerabilities and enhancement of ecosystem services. It is adapted from the "methodological approach for biodiversity monitoring in the context of territorial transitions" developed by the Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, which includes the processes of planning, implementation, and evaluation of (biodiversity) monitoring strategies (Sánchez-Clavijo et al., 2019).

The monitoring module integrates the co-creation and multi-criteria approaches outlined in previous modules with an adaptive management approach. Co-creation is understood as a form of collaborative work that promotes cooperation and stimulates learning between actors who are directly affected or have influence over the challenges or interventions in the city. The multi-criteria approach is based on the theory of multi-criteria decision analysis and provides a decision-supporting framework that can help to make complex decisions. Adaptive management includes all processes of planning, implementation, and evaluation of monitoring strategies, and allows changes to be incorporated based on lessons learned.

The monitoring module guides the formulation and implementation of a monitoring strategy for the NBS, and then evaluates its impacts against urban challenges and vulnerabilities. It consists of five steps (Figure 17).

Figure 17. Monitoring Module of The INTERLACE Nature-Based Solution Evaluation Framework.



5.1 Definition and weighting of criteria

The definition and weighting of criteria is a critical first step for the monitoring of NBS, as those criteria are understood as descriptors of the NBS effectiveness. However, this step does not necessarily have to be repeated for the monitoring module, specifically if the criteria selection and weighting were already conducted in a previous application of the planning or design module. Practical guidelines for the definition of criteria and the weighting of criteria are given in pages 17, 26, and 31. The same procedure applies.

5.2 Indicator selection

Indicators are variables used to represent a system's characteristic of interest (Tate, 2012). To monitor NBS effectiveness, it is key to define a set of indicators that allows for appropriate and robust measurement of its impact. Sparks et al. (2011) proposed a framework of Response-Pressure-State-Benefit (RPSB) indicators to emphasize the guidance of policy and other practical actions related to biodiversity loss. In this guideline, this approach was adapted to the NBS context. *State indicators* are understood as those indicators that have been used to analyse the baseline condition and status of vulnerabilities and ecosystem services needs during the planning and design phases. Corresponding indicators will be selected to measure the impact of an NBS regarding biodiversity and ecosystem service management (*response*) and reduction of social and ecological vulnerabilities (*benefits*). Contrary to the definition and weighting of criteria step, which deeply engages with stakeholders, the selection of monitoring indicators is a task for experts. It should be conducted in a small group with diverse expertise (such as biodiversity, cultural ecosystem services, regulating ecosystem services, etc.) and supported by a scientific literature review. The elaboration of monitoring questions can support this step.

Monitoring questions

Defining indicators is not an easy task. For this reason, it is advisable to define monitoring questions that include thinking about why monitoring is needed in relation to each action implemented. Guiding monitoring questions will be formulated for each of the criteria in relation to the NBS capacity to improve the current conditions.

The suggested structure of questions is:

» *To which extend does the NBS intervention improve / decrease criterion A?*

For each question, an initial set of possible indicators is defined. Indicators are then discussed and validated with the extended group of stakeholders or with those involved in the NBS management team.

In order to select and validate the indicators, these questions should be answered:

» *Is the indicator relevant to measure the effectiveness of the action?*
» *Is the indicator measurable in terms of data availability?*
» *Are the resources (financial, technical and personnel) available to measure the indicator over time?*
» *Is the indicator compatible with the expected response time? That is, is there sufficient time for the system to reflect the change to be measured?*

Case Study 5. Formulation of a monitoring strategy for an urban NBS in Envigado, Colombia

Envigado, a medium-sized city with approximately 250.000 inhabitants, is located in the Colombian Andes, adjacent to Medellín. The city faces urban challenges, such as heat islands, biodiversity loss, and impacts on the quality of life. To address these, the Envigado Florece program was developed under the guidance of a specifically tailored monitoring strategy. This initiative aims to enhance urban

Figure 18. Plant nursery in Envigado, Colombia. Source: Johana Tabares.

livability by reducing hard surfaces, planting native species, and offering educational programs.

The design of the monitoring strategy involved three stages: contextualization, co-creation, and formulation. In the first two stages, the scope, objectives, participants, and criteria were established. Then, indicators and protocols were defined following the steps of the monitoring module. The process was led by researchers from the Instituto Humboldt and professionals from the Ecosystems and Biodiversity office of the Envigado Environment Secretariat, as part of the INTERLACE project. A working group was formed, including officials from various departments related to the Envigado Florece program, community members, academics, and other researchers from the Instituto Humboldt and Tecnalia, another INTERLACE partner. Envigado municipality officials will implement this strategy in a pilot area in 2024.

Guiding questions and indicators:

Social component

Q1. How does the Envigado Florece program contribute to the increase in urban green areas?

Indicators: square meters intervened by number of inhabitants of the neighbourhood and the area of influence of the program.

Methods: spatial analyses (once per year).

Q2. How do the participatory activities of the Envigado Florece Program contribute to social cohesion, social participation and mainstreaming, and human well-being?

Indicators: participation of different social groups, generation of ties between actors, perception of security, perception of the connection with nature, etc.

Methods: surveys to activity participants applied after each activity.

Biodiversity component

Q3. Are the trees and plants planted by the program associated with the increase in the diversity of birds and insects in the municipality of Envigado?

Indicators: change in the diversity of bird species associated with green areas, and change in insect diversity associated with green areas created or improved by the program.

Methods: data collection carried out by the municipality team and through citizen science (twice a year).

Climate component

Q4. Does the change from hard to soft flooring and new green areas has an effect on the climatic comfort?

Indicators: Universal Thermal Climate Index.

Methods: data collection (twice a year).

5.3 Action plan design

The third step is the design of an action plan based on the indicators previously defined. The plan includes protocols for measuring the indicators and mentions the sampling design, which includes frequency, storage, and data analysis (Table 3). This step summarizes the actions needed for implementation and data collection related to the individual indicators. As it involves the distribution of responsibilities, it requires close collaboration with the NBS management team charged with the execution of the monitoring. The process of co-formulation of the monitoring strategy ensures that the plan is grounded and consistent with the capabilities and knowledge of stakeholders in the implementation process. The action plan should be presented in a space (workshop) open for dialogue and reflection on the formulation process. In this workshop, agreements are reviewed and reinforced, and the action plan may be adjusted as necessary.

5.4 Implementation and evaluation

The fourth step is the implementation of the monitoring strategy, which is divided into monitoring cycles. Each cycle consists of the collection, storage, and analysis of data related to the indicators within a specific time frame. Once all

Table 3. Example of a template for one indicator of the monitoring action plan.

Indicator name	Definition
Challenge(s)	Selected criteria/challenges that the NBS is addressing.
Description	It includes the following information: indicator definition, sampling design, and methods of analysis.
Information needed	All the variables needed to measure the indicator.
Action(s)	The specific action or actions that NBS is addressing, to be measured with this specific indicator.
Guiding question	The question that was previously defined to identify this specific indicator.
Baseline date	Date for the measurement of the baseline. If the NBS is already in place, it should be indicated that there is no baseline available, and the first monitoring measure will serve as the baseline.
Indicator frequency	The frequency in which the sampling will take place, during one monitoring cycle (for example, monthly, once a year, biannual, etc.).
Responsible for data collection	The name and affiliation of the person responsible of data collection to measure the indicator.
Data storage	The place, ideally with a link, where data for measuring the indicator will be stored.
Responsible for data analysis	The name and affiliation of the person responsible for analysing the data related to the indicator.
Useful references or additional comments	Any reference to useful documents related to the indicator, if relevant, and additional comments.

Case Study 6. Monitoring strategy for The Old River Bath in Chemnitz, Germany

The Old River Bath in Altchemnitz, located in Chemnitz, Germany, is one of the intervention areas of the European Capital of Culture Chemnitz 2025. The project is part of the City on the River initiative, aimed at revitalizing the various flowing waters throughout the city. This includes enhancing the leisure and recreational potential of the floodplain along both sides of the river and improving the accessibility of the area with a new bridge. City officials utilized a monitoring module to formulate the monitoring strategy for the project.

The project offered several benefits in terms of:

Biodiversity: improved fluvial biodiversity and water quality, and an increase in species populations on land or in the river.

Ecological connectivity: through the planting of new trees and shrubs, and ecological restoration.

Human health & well-being: through the creation of recreational areas in the Stadtpark.

Green space management: through the development of the area, its maintenance improves.

Social cohesion: the area of intervention lies between two socially and economically challenged neighbourhoods. The development of this area aims to improve cohesion and exchange between them and other neighbourhoods.

The defined indicators to measure the impact of the intervention were:

- Abundance of land and air species (bats, dragonflies, birds)
- Water quality – measurement of total dissolved solids (TDS)
- Abundance of aquatic species (fish otter)
- Perceived nature experience
- Numbers of visits
- Perceived increase of landscape aesthetics

Figure 19. **Old River Bath in Altchemnitz.** Source: Max Lukas Krombholz.

indicators are measured, a report should be prepared with the results. When creating this document, it is important to consider and reflect on the level of importance that was assigned in the weighting of criteria.

Once each cycle has completed, the impact of the NBS is evaluated through a workshop in which the results of the measurement of the indicators are presented. If the NBS is about to start, the first cycle will be the baseline (which will include measurements without any implementation). After the NBS is in place, the second monitoring cycle will occur. The cycle follows the following order: data collection, data storage, and data analysis.

After each monitoring cycle, evaluation and reflection on the results are conducted to jointly evaluate the monitoring process and the effectiveness of the intervention or necessary actions to improve the NBS outcomes. This evaluation should ideally involve the initial group of stakeholders defined in the co-creation module. Expert advisors can also be invited to participate.

Additional resources
Acknowledgements
Bibliography

Additional resources

For further information regarding the INTERLACE products referenced in this guide, please consult Oppla at: https://oppla.eu

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