



Integrating Social Impact Assessment and Ecosystem Services toward Adaptive Urban Planning for Biodiversity

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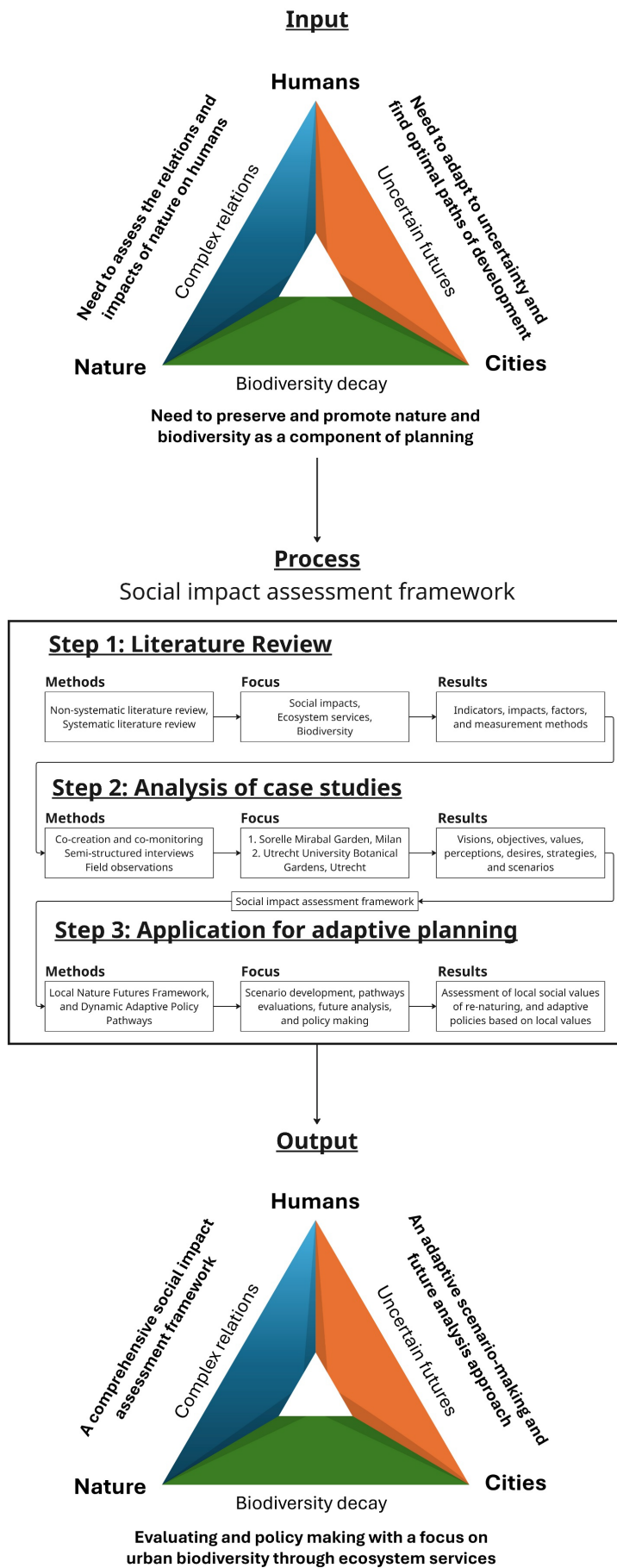
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Abstract

To improve and preserve urban biodiversity, re-naturing measures that enhance human-nature interactions are essential. However, urban re-naturing faces three primary challenges: rapid biodiversity loss, complex human-nature relationships, and deep uncertainty regarding the future. To address these, this thesis proposes an adaptive planning framework structured as a cycle of monitoring, assessment, scenario-making, implementation, and learning. This research introduces a three-step social impact assessment (SIA) methodology for evaluating the co-benefits of re-naturing by analyzing ecosystem services (ES) at the local scale. The methodology is built on direct interaction with citizens and stakeholders through collaborative sessions to gather perceptions, narratives, and social values related to nature. First, a systematic literature review established a new typology of social impact indicators and factors to aid planners in selecting context-specific metrics. Second, this typology was applied in two case studies: the Sorelle Mirabal Garden (Milan, Italy) and the Botanical Gardens (Utrecht University, Netherlands). Through collaborative sessions using ES cards and surveys, this step identified the social values and the impact of nature on human lives, as well as community desires for the future, alongside social-ecological dynamics. Finally, this data was integrated into the Local Nature's Future Framework (LNFF) and Dynamic Adaptive Policy Pathways (DAPP) to develop 25-year future scenarios. This process mapped potential social-ecological interactions and identified optimal decision-making pathways under deep uncertainty. The resulting SIA package is a replicable, cost-effective tool that uses ES to optimize urban re-naturing policies. This research demonstrates that SIA must be a continuous, inclusive, engaging, and evidence-based process that can uncover the social values of re-naturing, interpret social-ecological dynamics using ES and biodiversity values, support scenario-based planning for future studies, and guide decision-makers in conditions of deep uncertainty. By recasting the process of SIA at the conceptual, methodological, and practical levels, and bridging theory and practice within a practical, replicable SIA framework, this study ultimately lays the groundwork for orienting planners and policymakers toward the inclusion of social values in the policy-making process for urban green areas through continuous monitoring and evaluation.

Graphical abstract



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*“I traveled far and wide across the world,
I spent my days with many people;
I found enjoyment in every corner,
From every harvest I gathered a grain.”*

Saadi Shirazi

در اقصای عالم بگشتم بسی
به سر بردم ایام با هر کسی
تمتع به هر گوشه‌ای یافتم
ز هر خرمنی خوشه‌ای یافتم
سعدی

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List of abbreviations

ATP: Adaptation Tipping Point

BD: Biodiversity

DAPP: Dynamic Adaptive Policy Pathways

DF: Desired Future

EC: European Commission

ES: Ecosystem Services

LNFF: Local Nature Futures Framework

NFF: Nature Futures Framework

NC: Nature as Culture

NN: Nature for Nature

NS: Nature for Society

NbS: Nature-based Solutions

OTP: Opportunity Tipping Point

PF: Plausible Future

SES: Social-ecological Systems

SESF: Social-ecological Systems Framework

SF: Strategic Future

SI: Social Impact

SIA: Social Impact Assessment

SMG: Sorelle Mirabal Garden (case study 1)

UB: Urban Biodiversity

UES: Urban Ecosystem Services

UGI: Urban Green Infrastructure

UUBG: Utrecht University Botanical Gardens (case study 2)

Glossary

Co-benefits: Secondary or complementary (in some instances, side effects) positive outcomes of intended re-naturing measures in urban areas and beyond (Ommer et al., 2022). These benefits may manifest at social, ecological, and economic levels, contributing to the overall improvement of human well-being (C. M. Raymond et al., 2017). For example, wind protection ES, besides its primary objective for reducing discomfort, may also reduce airborne particles and dust in urban areas, leading to co-benefits of disease reduction and an increase in public health. This research, in addition to co-benefits, also considers the primary benefits that directly impact society in its general framework of assessment.

Ecosystem Services: Benefits people obtain through ecosystems and natural processes that contribute directly or indirectly to sustaining their health and well-being (Liquete et al., 2016; Santos-Martín et al., 2013). The Ecosystem Services in this research, based on the classification of the European Environmental Agency are viewed in categories of provisioning (like Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes), regulating (like Noise attenuation), and cultural (like Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions).

Re-naturing: The process of reconnecting and bringing nature back to cities with the general objective of preservation of biodiversity and an approach toward sustainability (EC, 2015; Lemes de Oliveira, 2019). This process can vary in its actions, ranging from small-scale interventions, such as pocket gardens or individual plantings in streets, to large-scale interventions, including bio-remediation and the regeneration of abandoned industrial sites. These activities primarily include NbS, rewilding, UGI development, UB enhancement, and planned greening interventions, all of which involve local actors in the process.

Social-ecological Systems: Complex, multifaceted, and interconnected systems in urban areas (in this research), resulting from interactions between humans, nature, and social-ecological variables that provide the context for the living and well-being of users (Ostrom, 2007, 2009). These systems exhibit nonlinear behavior in response to contextual variables. The variables of social-ecological systems are defined by bidirectional causal linkages and feedback loops between biodiversity, ecosystem services, and the biophysical environment, generating measurable outputs that affect human well-being and ecological integrity, which in turn may impact governance systems, economic systems, and users, which are all embedded within the broader socio-economic, cultural, and political context of urban areas.

Social Impact Assessment: Although the definition of social impact encompasses a wide range of definitions, scales, and parameters, this research primarily focuses on the impact and effects of re-naturing measures in urban areas, primarily through ecosystem services channels (Imperiale & Vanclay, 2024; Vanclay, 2003, 2024). The research considers both the positive and negative impacts resulting from direct and indirect effects. For the sake of comprehensiveness, the study

does not consider specific limits for the identification of social impact, though these impacts may take place under these categories: human health and well-being, change in monetary and financial terms (e.g., income, welfare, expenses, replacement costs), perceptions and feelings (mainly non-use values like aesthetics of a scene or observation of a particular animal and change in feelings) mainly gathered through questionnaires, models (obtained impacts through secondary ES functions or sequences of calculation methods), the indirect impact which observed through proxies that might not be directly related to ES but their analyzed results can for assessing the social impact.

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Chapter I.

Introduction

I.1. Introduction and problem statement

The increasing complexity of urban environmental challenges, the rapid exacerbation of climate change effects, and the decline in biodiversity, particularly in urban areas, necessitate immediate support measures and policies worldwide (Elmqvist et al., 2015; Frantzeskaki et al., 2024; Hobbie & Grimm, 2020; Kowarik et al., 2025). Several framework policies and programs focusing on cities, as prominent inhabited places of humans, have been developed at international, European, and national (Italian) scales to answer these growing concerns. On the global level, the Sustainable Development Goals (SDGs), defined by the 2030 Agenda of the United Nations, focus on goals 11, 13, and 15, which give special attention to climate change, biodiversity loss, and the sustainability of cities. Within this given framework, at the European Union scale, several policy frameworks and initiatives have been developed to support the implementation, mapping, and assessment of Ecosystem Services (ES) and Nature-Based Solutions (NbS) (see: European Commission (EC), 2021; Hermoso et al., 2022; EC, 2020). At the national level in Italy, the National Recovery and Resilience Plan (PNRR) (established in 2021), in its second mission, provided space for a “green revolution and ecological transition”. Within this plan, the National Biodiversity Future Center (NBFC) - 2022/2025, under Spoke Five, aims to sustain Italian biodiversity and develop a research space for observing, monitoring, and assessing urban biodiversity. In the Netherlands (as the second case study), National Framework: The Dutch Recovery and Resilience Plan and National Biodiversity Strategy & Action Plan (NBSAP) (2025 – 2030) by the Netherlands Environmental Assessment Agency have specific focus on nature restoration and balance between human well-being and biodiversity throughout the country, with nature-inclusive design and in many municipalities under the 3-30-300 rule (Konijnendijk, 2023).

Biodiversity, as defined by McNeely (1988), is an umbrella term for the degree of nature's variety, including both the number and frequency of ecosystems, species or genes in a given assemblage. In cities, urban biodiversity values are defined as plural, multiscale, context-dependent ways of ascribing importance to the biodiversity which spans from intrinsic value of non-human life, instrumental (e.g., economic) contributions to human well-being via ecosystem functions and services, relational meanings (e.g., cultural values) embedded in human-nature interactions, to recognized ecosystem disservices (e.g., pests in green areas) (Connop et al., 2016; Dearborn & Kark, 2010; Kowarik, 2023; Leventon et al., 2021; Rega-Brodsky et al., 2022). In this context, urban biodiversity refers to the degree of variation within and among living systems, along with their associated values. Nature, on the other hand, represents a broader and more relational concept, encompassing both the biophysical environment and the meanings, values,

and experiences that humans associate with it. In other words, in this thesis, biodiversity is viewed as a measurable dimension of nature, primarily concerned with the structural and functional diversity of species and ecosystem levels, which it values in relation to society in urban areas, and is measured through social impact assessment. Nature, on the other hand, extends beyond biological parameters to include cultural, emotional, and symbolic dimensions that shape how people perceive, relate to, and interact with the living world. Nature in cities is not limited to its biological components and diversity but is socially constructed through human-nature interactions, governance frameworks, and everyday practices. Having established the definitions of urban biodiversity and nature for this thesis, the following paragraphs examine how re-naturing engages these elements in urban settings and how this poses challenges for evaluating and assessing their social values and impacts.

On the urban scale, the implementation of re-naturing measures in cities is being studied and supported internationally and locally to tackle local environmental challenges and the effects of biodiversity loss (Nilon et al., 2017a; Wilkinson et al., 2013). Re-naturing is defined as attempts to create nature-positive cities by reconnecting human-nature relations, where nature is deliberately reintegrated into built environments to address social-ecological challenges (EC, 2015; Frantzeskaki, 2019; Sarabi et al., 2023). In the context of re-naturing, due to the surge of biodiversity loss in cities, conservation, promotion, and valuation of biodiversity gained attention in recent years, as they provide essential context for nature's functionality (I. Mahmoud et al., 2025; Rega-Brodsky et al., 2022; Schwarz et al., 2017).

As Lemes de Oliveira (2019) states, contemporary literature groups re-naturing measures in four thematic areas of human needs to connect with nature, health, and well-being, climate change and resilience, and ecology. The concept of re-naturing measures encompasses a broad range of activities and benefits that can also coincide. The social and ecological benefits and impacts of re-naturing measures in urban areas have been studied and reviewed in the literature and practice (EC, 2015; Pinto et al., 2022). Despite a long history of research on re-naturing measures, relatively few studies and frameworks in literature and practice have systematically conducted comprehensive social impact assessments of re-naturing interventions in urban areas (Aledo et al., 2021; Imperiale & Vanclay, 2024; Karrasch, 2016; Mahmoud et al., 2021).

A Social Impact Assessment (SIA) is an interdisciplinary process that monitors and analyzes the intended and unintended positive and negative social consequences of interventions over time (Vanclay, 2003, 2024). SIA was initially considered as part of environmental impact assessment in the production of an environmental impact statement (Arce-Gomez et al., 2015; Esteves et al., 2012; Larsen et al., 2018), which later evolved into a stand-alone process necessary for regeneration and development projects in urban areas. SIA is traditionally a standard top-down process, mainly elaborated by an expert within technocratic paradigms (Aledo-Tur & Domínguez-Gómez, 2017). While the essence of the SIA of re-naturing measures in cities is observable in the literature and theoretical frameworks (Boskma, 1986; Carley & Bustelo, 2019; Toomey et al., 2025; Vanclay, 2003, 2024), it still faces challenges for implementation at the local

urban and community scales, especially in engaging citizens and stakeholders to uncover social values. Primarily, the lack of a coherent multidimensional assessment framework within the contextual parameters is a considerable gap in the literature on SIA in urban areas (Queiroz et al., 2017; Shoemaker et al., 2019). In the local urban context, quantifying the co-benefits of re-naturing measures is challenging, as most measurements (especially those related to health and well-being) involve qualitative data, and each context relies on different methods and indicators (Guerry et al., 2023; Haase et al., 2014). Moreover, a lack of defining common ground on indexing methods and establishing a general framework for assessment tools and methods to achieve comparable results are additional challenges (H. A. Becker & Vanclay, 2003; Glasson & Therivel, 2019). Ultimately, few studies have established a connection between SIA theory and practice that comprehends the complexities of the local urban context.

A major challenge in SIA, particularly in the context of urban planning, is defining social impacts and determining what needs to be measured during the assessment process (Vanclay, 2024). In literature, social impacts are primarily socially constructed based on social values, meaning they are perceived differently by different people through socially mediated understandings shaped by their experiences, perceptions, and backgrounds (C. M. Raymond et al., 2014; Sairinen, 2004). In other words, social impacts are perceived as intended or unintended consequences of interventions (in the case of the thesis, re-naturing), which societies perceive and interpret based on a series of social values. To understand the social impacts, it is essential to define the social values. While in SIA literature there is no universal definition of what social values are, Kenter et al. (2015, p. 88) introduce social values as *“the term ‘social values’ has also been used in diverse ways. It can refer to the values of a particular community or the cultural values and norms of society at large, but can also be used to refer to the public interest, values for public goods, ‘altruistic’ values and feigned altruistic values, the values that people hold in social situations, contribution to welfare or well-being, the willingness-to-pay (WTP) of a group, the aggregated WTP of individuals, or values derived through a social process”* (for willingness to pay examples see also: Balzan et al., 2020; Bernués et al., 2022; Y. Wang et al., 2014) and Kenter et al. (2015, p. 88) specifically define shared social values as *“the outcome of processes of effective social interaction, open dialogue and social learning. From this perspective, shared social values were closely allied to shared meanings, and effective policy for a society depends on the creation of these among cultural groups, as they do not exist a priori”*. Kenter elaborates on (shared) social values through a non-monetary place-based lens and subsequently highlights the importance of non-monetary valuation and assessment methods. Similarly, this research views social values and impacts through a non-monetary place-based lens and follows the shared and social values framework introduced by Kenter et al. (2015) to establish what social values are considered to define social impacts. This approach focuses on shortcomings in non-monetary methods of SIA and social values that are not quantifiable (such as cultural values) to offer a new perspective on evaluating human-nature relations in urban areas.

To address these challenges, and in contrast to classic approaches, the constructivist paradigm in SIA views this process as a bottom-up, socially constructed, and multi-value system,

which is oriented around deliberating local values (Aledo-Tur & Domínguez-Gómez, 2017; Carley & Bustelo, 2019; Esteves et al., 2012). In this perspective, information is provided by actors and stakeholders, analyzed with them, and finally elaborated upon in collaboration with them to enhance sustainable life quality, raise awareness, and improve the transformational capacities of citizens. In an overview as Esteves et al. (2012, p. 40) states “*There is consensus on what ‘good’ SIA practice is – it is participatory; it supports affected peoples, proponents and regulatory agencies; it increases understanding of change and capacities to respond to change; it seeks to avoid and mitigate negative impacts and to enhance positive benefits across the life cycle of developments; and it emphasizes enhancing the lives of vulnerable and disadvantaged people*”. While the constructivist paradigm is becoming more dominant in the field of SIA, its implications and practices for use in the field of urban planning are still evolving, and there is limited knowledge on the best practice of implementing such an approach in (local) urban scales (Mottee et al., 2020; Vanclay, 2024; Wan et al., 2024).

The constructivist paradigm in SIA is defined as a multiple-value system that adopts a transdisciplinary combination of qualitative and quantitative methods to recognize the socially constructed nature of impacts and the diversity of perspectives through which they are experienced and interpreted through social values (Aledo-Tur & Domínguez-Gómez, 2017; Kenter & O’Connor, 2022; C. M. Raymond et al., 2014). Within this paradigm, social impacts are understood as context-specific outcomes that emerge based on human perception and experiences, which are perceived by the social actors involved in the interactions (Aledo-Tur & Domínguez-Gómez, 2017; Arce-Gomez et al., 2015; Carley & Bustelo, 2019). In this paradigm, SIA is a socially negotiated process (among participants in assessment), where knowledge, values, and experiences are co-produced by diverse actors involved in or affected by a project within uncertain conditions (ibid). The constructivist paradigm promotes the use of participatory and deliberative techniques, fostering an extended peer community that integrates lay knowledge, expert judgment, and stakeholder experience into the assessment process. Moreover, it acknowledges the political dimensions of SIA, emphasizing reflexivity, transparency, and the social management of impacts as integral components of the project lifecycle (Aledo-Tur & Domínguez-Gómez, 2017). The constructivist paradigm aligns SIA with a bottom-up, collaborative process that seeks to understand and address social change as experienced by affected communities rather than as externally defined variables or proxies (ibid).

Within this context, to address the challenge regarding the definition of social values and social impacts, it is essential to establish clear boundaries for the analyzed social values. For this purpose, this research follows the shared and social values framework established by Kenter et al. (2015) and C. M. Raymond et al. (2014) and its later developments and refinements (Kenter et al., 2019; Kenter & O’Connor, 2022; C. M. Raymond et al., 2023; C. M. Raymond & Kenter, 2016) to clarify boundaries of explored social values. This framework is relatively the most developed and comprehensive structure that covers social values in comparison to other existing frameworks. In this framework, shared and social values are explored in five dimensions of the

value concept: value provider, value elicitation process, value scale, and value intention. Initially, similar to the framework, this research recognizes three concepts of value as transcendental (normative) values, contextual values, and value indicators. Transcendental or normative values are viewed as “*concepts or beliefs, about desirable end states or behaviours, that transcend specific situations, guide selection or evaluation of behavior and events, and are ordered by relative importance* (p.241)” (C. M. Raymond & Kenter, 2016). Within the context of this research, transcendental values are considered part of the abstract and guiding principles that communities and society hold regarding urban greenery and nature (C. M. Raymond et al., 2023). These values are formed based on people's overall perceptions and beliefs and are specific to each context of the study. Contextual values in this case are more object-specific and are more attitudinal, which makes them more detailed than transcendental values (Kenter et al., 2015; Kenter & O'Connor, 2022; C. M. Raymond et al., 2014). For example, while this research explores transcendental values related to re-naturing in general, it also examines social contextual values regarding the importance of local biodiversity or the local significance of specific flora and fauna species. Lastly, as value indicators, the social values and importance of re-naturing are mainly measured through non-monetary value terms within collaborative activities.

Regarding the values provider dimension, this research focuses on societal and cultural values in general, investigating communal and group values, while excluding individual values from the assessment. Individuals are excluded as value providers, as their opinions and contributions are mainly elaborated through collective activities (Kenter et al., 2019). Another reason behind such a selection is the scale of SIA. As the scale of the SIA in this research is at the local urban scale (encompassing several urban blocks within a neighborhood), communities and local groups are key participants in collaborative sessions. At the same time, individual opinions are primarily dedicated to assessments at lower scales, such as SIA at the building or block level. The social values in this research are elicited through a deliberative process in collaboration with communities and social groups, facilitated by workshops and collective activities. The elicitation process mainly focuses on the social deliberative process of non-monetary values (Kenter et al., 2019). The last two dimensions of the values scale and values intention align with the general framework of the thesis, which focuses on following social collective values. As a result, this research focuses on the scale of value to society and other-regarding values in relation to value intentions. In contrast, individual scales that emphasize self-regarding values are excluded from evaluation and consideration in analyzing social impacts, as they do not reflect collective values in the process (Kenter et al., 2015, 2019).

It is worth mentioning the latest developments and refinements in the shared and social values framework, which introduced two new dimensions of value layers (living from, living in, living with, and living as nature) (C. M. Raymond et al., 2023) and meta-lenses (epistemic and procedural lenses)(Kenter et al., 2019). On value layers, this research explores social values and tracks their outcomes as social impacts across all layers without any prior division. This approach enables the collection of comprehensive information without prior division between layers,

which can later be utilized for analysis as part of the Nature Futures Framework (see Section 1.3 and Chapter Five). Regarding the meta-lenses, this research approaches social values through value deliberation from communities and groups in a step-by-step procedure, utilizing a procedural meta-lens to address matters of social values.

By establishing the boundaries of what is considered a social value in this research, the next step is to construct social impacts from these values. In this research (as presented in Figure 1), the social impacts of nature and re-naturing are viewed as both intended and unintended effects of human-nature relations that create social values (within the above-mentioned boundaries) within communities and groups in society. These effects can be direct or indirect in human lives, having both short-term and long-term positive or negative consequences for human well-being. The social values that create social impacts are based on the experiences of actors and stakeholders, which shape their perception and evaluation of nature and re-naturing. In other words, social impacts refer to the meaningful effects of human-nature relations on human lives, which are shaped by social values and norms. In this context, it is noteworthy to mention that not all social values translate to social impacts. In this research, individual or self-regarding values, worldviews, and knowledge systems do not lead to the creation of social impacts for analysis. The process of establishing social impacts from social values is illustrated in Figure 1. Ultimately, one of the significant differences between SIA and environmental impact assessment is how social impacts are viewed. In the broader literature of SIA, social impacts are viewed both as positive and negative consequences (Carley & Bustelo, 2019; Parsons, 2020; Vanclay, 2024), while in environmental impact assessment, impacts are mainly evaluated to assess the negative effects of interventions or changes (Glasson & Therivel, 2019; Larsen et al., 2018). In this research, similar to the general SIA approach, social impacts are viewed as both positive and negative consequences, with a special emphasis on positive consequences, as the research focuses on nature's contribution to human lives that improve well-being and quality of life. In this research, both positive and negative consequences are considered within the value elicitation process based on the input from participating actors and stakeholders.

Additionally, it is important to mention that this research is fundamentally based on the assessment of social values related to biodiversity and nature, with a clear focus on qualitative values and stakeholder perceptions. The thesis methodology prioritizes qualitative approaches, such as semi-structured interviews, collaborative activities, and co-monitoring, to capture complex, non-quantifiable social dimensions, including cultural meanings, emotional responses, and community experiences, which are underrepresented in the existing literature. At the same time, the thesis includes quantitative indicators or measurement methods (as described in Chapter Two, such as the willingness-to-pay of local residents and tourists, production function and replacement cost approaches for economic valuation, and the richness of bee and butterfly species) that provide contextual and structural support for the SIA. These quantitative data can be derived from spatial analysis, field observations, and official statistics; however, their primary role is to inform and frame the qualitative inquiry rather than serve as the core focus. The SIA

framework developed here explicitly aims to use qualitative information based on social values that are less suitable for quantification. While quantitative indicators help identify and monitor context conditions and ecosystem status, the emphasis remains on eliciting the less tangible but equally important social values through direct stakeholder engagement. By prioritizing qualitative social values, this thesis addresses gaps in the literature and advances a people-centered approach to SIA and evaluation of urban biodiversity impacts. This framing is crucial as many significant social dimensions of biodiversity cannot be adequately expressed through quantitative measures alone. Thus, methodology and presentation underscore that while quantitative data provide essential background and comparisons, the core contribution of this research lies in highlighting qualitative social value, perceptions, and experiences of biodiversity and nature.

Ultimately, before introducing the research approach, it is essential to note that the SIA process is traditionally heavily dependent on the assessor and the study context, which, in both cases, can lead to biases in the assessment process. In this thesis, to handle personal biases, the research follows general protocols set by previous studies (Vanclay, 2003, 2006) for data interpretation, and additionally mainly rely on public input (in both cases, participants in sessions and stakeholders) to provide information and analysis. Despite these considerations, when analysis is based solely on the expert's (the researcher's) opinion, the information is handled without any specific bias and are later validated with field experts and literature to ensure the integrity of the analysis. Such limitations and challenges are discussed in detail in the dedicated sections 3.5, 4.4, 5.5, and 6.5 of the following Chapters.

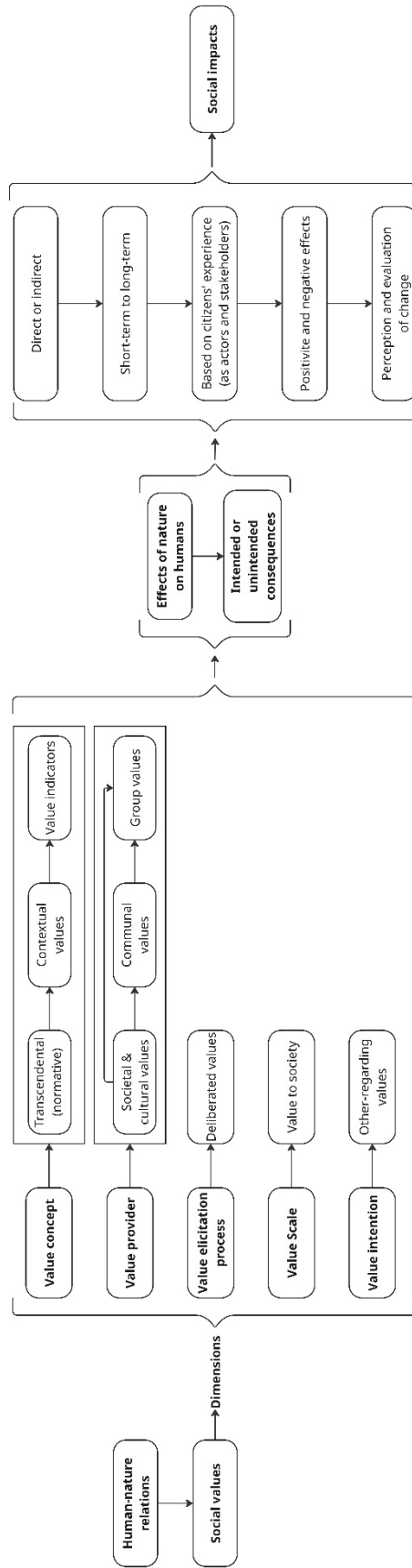


Figure 1: Process of establishing social impacts from social values, adapted from Kenter et al. (2015).

This research proposes an SIA approach based on the constructivist paradigm for evaluating the social impact of re-naturing measures in cities, supporting adaptive planning for biodiversity promotion. The process approaches social impacts by analyzing and evaluating local social values within social-ecological systems with a focus on prioritizing biodiversity values. Through this approach, the SIA process is revised at the conceptual, methodological, and practical levels to establish a replicable process that collaboratively incorporates social-ecological values directly into the assessment process. Within this research, the concept of ecosystem services (ES) will be a helpful lens for evaluation. ES are defined as the benefits people obtain through ecosystems and natural processes that contribute directly or indirectly to sustaining their health and well-being (Liquete et al., 2016; Santos-Martín et al., 2013). The integration of the ES concept in SIA can enhance the pace of social impact tracing and lead to a more efficient decision-making process (Landsberg et al., 2013; Rosa & Sánchez, 2015). Bridging between main ES categories (provisioning, regulating, and cultural) and re-naturing measures benefits can facilitate assessment procedures. Ultimately, the results of the SIA serve as the basis for developing scenarios for the adaptive planning process. This process provides suggested policies, actions, and interventions based on SIA results to improve the well-being of humans in cities and preserve and promote the status of nature in cities. An overview of the conceptual flow of this research, from social values to the social impact of nature, to SIA, and its use in adaptive planning, is presented in Figure 2.

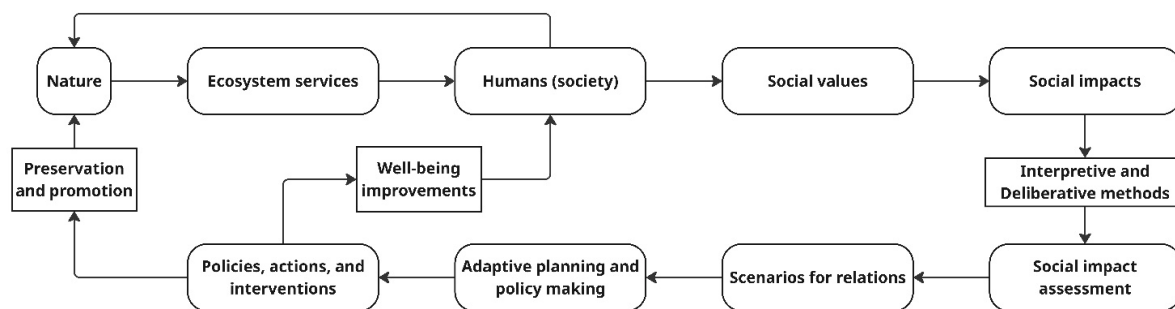


Figure 2: Research conceptual flow depicting the pathway from nature to social values, impacts, and SIA, to the adaptive urban planning process for humans and nature.

1.2. Research approach

This thesis is formed as a monograph and presents a three-step process (literature review, application to case studies, and analysis) for integrating SIA and ES toward adaptive urban planning for biodiversity. Despite this format, each chapter can act as a standalone manuscript. In contrast, the collection of manuscripts presents a process of establishing an SIA structure using ES, which aids the process of adaptive urban planning for biodiversity. The scope of this research is to support the adaptive planning and decision-making process

at the local scale in cities. In this scope, this research provides an SIA package of re-naturing measures in urban areas, which utilizes ES and gives special attention to urban biodiversity as an overarching approach. Within this context, this research aims to uncover social values regarding nature and biodiversity by utilizing ES in a collaborative process at the local urban scale, providing contextual input for planning processes. This research seeks to answer the question of how ES and biodiversity values benefit the SIA of re-naturing measures to support the process of adaptive decision-making in cities. What are the connections? To answer this question, three objectives and three sub-questions are established, which this research aims to cover sequentially through a three-step procedure: reviewing the current literature (Chapter Two), exploring the case studies for SIA (Chapters Three and Four), and analyzing the results for decision-aiding and adaptive planning (Chapters Five, Six, and Seven) alongside a policy outline in Chapter Eight.

In the first step (reviewing the literature), the objective is to integrate the use of ES in SIA and monitor by using and analyzing their indicators, factors, impacts, and measurement methods (Objective 1). In this step, the research aims to answer the question of which ES leading indicators and factors are relevant to SIA in urban areas, and subsequently, what are their value metrics, and to what extent are these issues related to urban biodiversity (Q1). The second step (exploring the case studies and SIA implementation) follows the objective of assessing the social impact of re-naturing measures through participatory processes for uncovering social values in local social-ecological systems (Objective 2). This step aims to answer: How can ES indicators be measured and localized in an urban context through participatory processes? What are the contextual influencing factors in the process of participatory SIA (Q2)? Ultimately, in the third step (analysis of information for adaptive decision-making at the local scale), the research explores how the SIA of re-naturing measures, by analyzing local social-ecological systems, aids the process of adaptive decision-making and policy-making in cities (Q3). The objective of the third step is to utilize local social inputs on re-naturing measures to support adaptive scenarios and policy-making processes at the local scale, both in the short- and long-term horizons (Objective 3). Table 1 presents the synthesis of the research questions and objectives, along with their corresponding steps and chapters.

Table 1: Relation between research questions, objectives, and the chapter of this thesis.

Research Question	Sub-questions	Objectives	Ch.
How do ES and biodiversity values benefit the SIA of re-	Which are the ES leading indicators and factors for SIA in urban areas?	Integrating the use of ES in SIA and monitoring by using and analyzing their indicators,	2

naturing measures to support the process of adaptive decision-making in cities?		factors, impacts, and measurement methods.	
	How can ES indicators be measured and localized in an urban context through participatory processes?	Assessing the social impact of re-naturing measures through participatory processes to uncover social values in local social-ecological systems.	3 & 4
	How does the SIA of re-naturing measures, by analyzing local social-ecological systems, aid the process of adaptive decision-making and policy-making in cities?	Utilizing local social inputs to inform re-naturing measures that support adaptive scenario and policy-making processes, both in the short and long term, at the local scale.	5 & 6 & 7

This research aims to address the primary research question throughout the study by examining the process of SIA in various dimensions and levels. Each of the following chapters is organized as a standalone scientific manuscript. In this structure, each chapter, following one of the defined objectives, aims to answer one of the three sub-research questions. Such a structure allows flexibility in exploring different dimensions of SIA while providing an in-depth overall picture of using ES in SIA for adaptive planning at the local scale. To facilitate navigation of the research steps, each chapter includes an introduction, methodology, results, discussion, and conclusions, which reflect on critical findings and their elaborations. In the first step of the research, the aim is to review the literature and reach Objective 1. In Chapter Two, a systematic literature review on ES is implemented, exploring the indicators, factors, impacts, and measurement methods that can be applied to SIA in urban areas. This chapter primarily aims to answer Q1 by establishing a connection between SIA, ES, and urban biodiversity through a state-of-the-art literature review.

In the second step of the research, by considering Objective 2 and to answer Q2, the acquired knowledge on using ES in SIA is tested and implemented in two distinct case studies (Chapters Three and Four). The reasoning for the selection of each case study is elaborated in Section Four of this Chapter. In Chapter Three, the process of collaborative SIA by using ES and with special focus on urban biodiversity and its impacts is explored in the local urban garden (Giardino Sorelle Mirabal) in Milan, Italy. The chapter, using the conceptual framework of social-ecological systems, explores the social perception of urban greenery and re-naturing measures through a collaborative process. This chapter, by

utilizing qualitative information that is often overlooked in mainstream SIA approaches, reveals practical insights to aid decision-makers in the policy-making and evaluation process. In Chapter Four, to validate the methodology used in Chapter Three, a distinct case study of the Utrecht University Botanical Gardens is considered for evaluation. In this chapter, to gain a deeper understanding of the case study, social information is interpreted through the lens of urban biodiversity narratives. Then, it is analyzed in relation to ES benefits to provide suggestions for improving the Botanical Gardens through policy. These two chapters collectively explore a co-evaluation of re-naturing and biodiversity values framework and methodology by utilizing ES and interpreting social values at the local scale to aid the decision-making process. The results additionally provide a foundation for future analysis in the third step of the research. In both case studies, the preservation and promotion of biodiversity, as well as the assessment of its values, are central to the evaluation process, which aims to take a step forward in integrating biodiversity values into the SIA process. This leads to more inclusive policies and pathways for sustainable human-nature interactions in cities.

In the third step, following Objective 3 and Q3, Chapters Five and Six explore how SIA information can be used to explore future development pathways, and SIA can aid the process of adaptive planning at the local scale. In Chapter Five, the results from both case studies are interpreted through integration with the Nature Futures Framework (Díaz et al., 2015; Pereira et al., 2020). In both case studies, the framework translates qualitative social values and priorities into an evaluation model that provides a vision of future development scenarios in each case study. This application helps decision-makers align their approach with local values and uncover the most efficient development pathways based on defined visions and objectives. In Chapter Six, the research builds upon the previous input, focusing explicitly on the Sorelle Mirabal Garden to envision local future scenarios for adaptive planning and policy-making. In the process of adapting the Dynamic Adaptive Policy Pathways methodology—an adaptive decision-making approach that includes multiple decision choices over time (Haasnoot et al., 2013, 2019)—the study explores potential development pathways for the Mirabal Garden over a 25-year time horizon. The results indicate which local policies are most critical to achieving the defined objective for the case study (Chapter Three) while maintaining the ES's functionality.

An overview of the three steps of this research suggests a collaborative SIA procedure at the local urban scale that, by using ES and urban biodiversity values, not only monitors impacts of re-naturing measures, but also puts a step forward in evaluating future scenarios through time and suggests development pathways that are established based on dialogue with citizens and stakeholders. This process integrated SIA with the adaptive planning process to aid decision-makers in policy-making for local green areas. The methodologies, conceptual frameworks, results, and limitations of each step are elaborated in detail in their dedicated chapters. A summary of results and advancements for the SIA

procedure, along with conclusions, is presented in Chapter Seven, along with an analysis of the objectives and research questions. The implications for policies are presented in a policy outline in Chapter Eight for use by urban planners. Figure 3 illustrates the research roadmap.

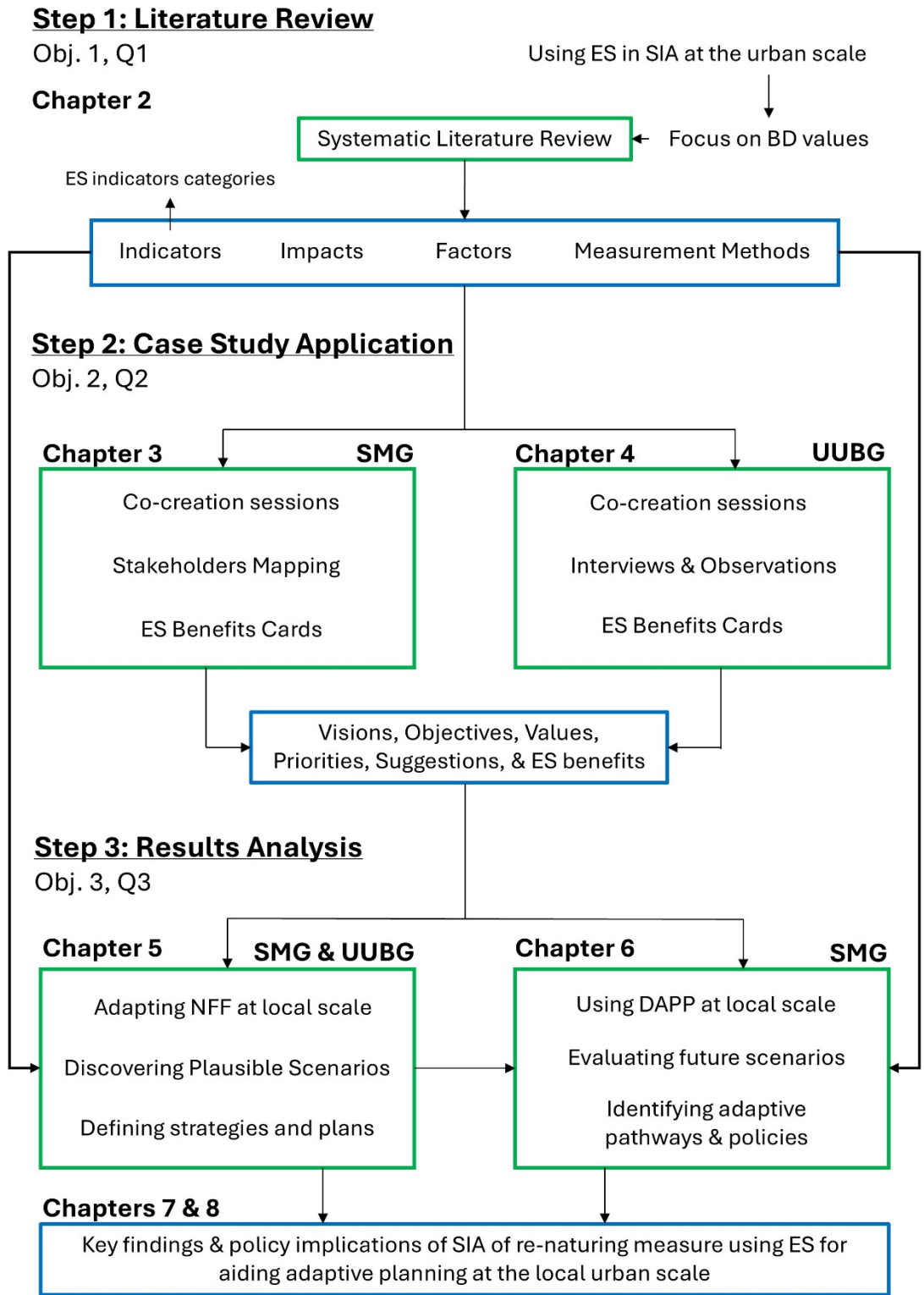


Figure 3: Roadmap and the structure of the thesis. Green boxes indicate methods; blue boxes indicate results. ES: Ecosystem Services, SIA: Social Impact Assessment, BD: Biodiversity, SMG: Sorelle Mirabal Garden, UUBG: Utrecht University Botanical Gardens, NFF: Nature Futures Framework, DAPP: Dynamic Adaptive Policy Pathways.

1.3. Methodological approach

This research employs a mixed-methodology approach, utilizing a systematic literature review in the first step, co-creation, gamification, and narrative making in the second step, and adapting the Nature Futures Framework (Díaz et al., 2015; Pereira et al., 2020) to integrate a Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013) in the third step. Despite the diversity of methodologies in each chapter, the underlying approach is to engage citizens and stakeholders in the process of data collection and analysis for SIA. To achieve this purpose in the first step of the research (Chapter Two), a systematic literature review prioritizes indicators and measurement methodologies that focus on social engagement. In the second step (Chapters Three and Four), methodologies focus on engaging citizens through direct interviews and face-to-face conversations in co-creation sessions, collective activities based on ES benefits selection, and defining collective biodiversity narratives. In the analysis step (Chapters Five and Six), the information gathered in the previous step serves as the basis for analysis in defining scenarios and developing pathways. An overview of methodologies used through this research is provided in this section, while a detailed description of methods used for each chapter is available in the conceptual framework and methodologies section of each chapter. It is necessary to note that each of the core chapters of this thesis includes a separate literature review and methodology section, providing clarity and an in-depth perspective on the topics discussed.

This research advances methodological practice not through the adaptation or use of novel methods, but by introducing a general, integrative framework for SIA in urban contexts. The key innovation is a compositional structure that links and adapts conventional methods (literature review, participatory engagement (through co-creation or co-monitoring), scenario making, and future analysis) into a robust, context-responsive circular process. The framework's adaptive logic allows these tools to interact dynamically. For instance literature review is not an end results, but it informs the context by establishing tailored information for collaborative activities by providing indicators impacts, and factors for exploration and understand the context's dynamics and measurement methods for evaluations; co-creation and narrative tools are positioned to elicit both mainly qualitative and also quantitative dimensions of social values and impacts; and outcomes from these steps feed directly into scenario development anchored in stakeholder priorities and the local context for future analysis. Conventional SIA often relies on broad-scale indicators or economic proxies, undermining place-based, experiential, and culturally situated dimensions of value. Here, participatory processes capture context-dependent narratives, prioritize value-driven impacts, and ensure human-nature relations are captured and embedded within the decision-making pathways. The framework operationalizes social values into impact through tools designed for narrative-

making, collaborative mapping, and the integration of non-monetary valuation techniques.

The methodological steps—systematic literature review, collaborative application in case studies, and scenario making for future analysis—do not stand alone but are deliberately connected by the framework. Literature review supplies foundational knowledge and informs the selection of impact and value indicators. These are tailored and deepened through participatory co-creation, integrating stakeholder perspectives and refining the typology of values and impacts. Finally, the results from participatory processes are utilized in adaptive scenario-making, which features a responsive analysis of contextual changes and stakeholder priorities. By designing the methodology as a relational and iterative process, the framework transforms the classic SIA into a flexible, interdisciplinary guide for adaptive urban decision-making. This approach enables the capturing of direct and indirect social impacts, strengthens integration of ES within SIA, and supports more holistic, policy-relevant insights for adaptive planning with a focus on nature and biodiversity. This research builds its methodological foundation not on the novelty of individual tools but on the design and integration of a general framework for SIA that is adaptive and responsive to the complexities and changes of urban social-ecological systems. The framework is purposefully structured to connect established methods—such as literature review, collaborative co-creation or co-monitoring, and adaptive scenario making for future analysis—into an iterative cycle that foregrounds context specificity and stakeholder engagement throughout the research process. The originality of this approach lies in its ability to relate and compose these methods in a way that each informs and enhances the next. What, therefore, distinguishes this SIA framework is its focus on operationalizing social values as central analytic constructs, rather than peripheral or supplementary aspects. By explicitly configuring the process to identify, analyze, and translate diverse social valuations at each stage, the methodology moves beyond classic indicator-based approaches. This dynamic enables the capture of indirect and multi-layered values (and consequently their impacts) that conventional, linear SIA approaches often overlook.

Within the first research step in Chapter Two (to answer Q1), after conducting a non-systematic literature review on gray literature and reports at the global European scales on the relation between ES and SIA, a systematic literature review is conducted to identify the general state-of-the-art landscape, pinpoint gaps, and determine the extent to which each ES category is discussed in SIA literature. Furthermore, to extend the focus, the research also examines the connection between SIA of ES and biodiversity in urban areas for more specific investigations. The ES referencing system used in the study is the latest version (version 5.1, as of 2023; later versions are not considered, as the literature review was conducted in 2023) of the Common International Classification of Ecosystem Services (CICES), which was developed from the work on environmental accounting undertaken

by the European Environment Agency (EEA) (European Environmental Agency, 2018). Compared to other classification methods implemented (e.g., the Economics of Ecosystems and Biodiversity), this classification is more detailed and comprehensive in ES categories. While CICES encompasses classifications from other frameworks and provides equivalents for them, it also proposes a series of ES-based group divisions within each ES section, which has not been previously considered for discussion. As this research mainly deals with biodiversity in urban areas, from six defined divisions of ES, three biotic divisions of provision, regulation, maintenance, and cultural are selected, and the same abiotic divisions are excluded from consideration.

The systematic literature review follows the PRISMA framework procedure and is repeated for each ES category, while the search queries vary according to ES classification specifications. For search execution, the Scopus search engine, provided by Elsevier, is utilized. By extracting social impact indicators, factors, impacts, and measurement methods from the selected literature for each ES, the results are then categorized based on their attribute and methodologies for measuring the social impacts. Specifically, indicators are categorized as direct or indirect, qualitative or quantitative, linked or separate from urban biodiversity and urban areas, and if there is any connection with other ES. This categorization framework is later utilized in Chapters Three and Four for developing ES benefit cards for collaborative activities. A complete description of methodologies is available in Chapter Two.

In the second step of the research, as outlined in Chapters Three and Four (to answer Q2), the focus of the methodologies in both case studies is on collaborative activities. In Chapter Three, a case study of Sorelle Mirabal Garden¹, a local urban garden, is selected. This Garden, with an area of 17,900 square meters, is located in the Lambrate and Ortica neighborhoods, east of Milan. The Garden was closed during the COVID-19 pandemic, and the local Municipality aimed to reopen it to conserve and promote biodiversity while engaging with citizens. Within this scope, Mirabal Garden was selected as a suitable case study to examine SIA approaches using ES and to investigate the role of biodiversity values in social perceptions of greenery. The motivation for selecting this case lies in its unique status as an urban garden, due to its previous closure period, which has given it a distinct biodiversity status. At the same time, residents and the municipality want

¹ The data collection and processing for this case study were conducted in strict accordance with the Information Notice on the collection and processing of personal data pursuant to Art. 13 of EU Regulation No. 679/2016 (GDPR) of 27 April 2016. All participants provided informed consent regarding the protection of such data. Specifically, this research pertains to the 'Urban Biodiversity Laboratory: A co-creation path to promote biodiversity at the Giardino Sorelle Mirabal "Las Mariposas" in via San Faustino 50, Milan'. This activity was carried out within the framework of the PNRR project 'CN-NBFC National Biodiversity Future Center' (Activity 7.3.3. - Spoke 5), with confirmation of Politecnico di Milano's (DAStU) privacy office, ensuring all ethical and privacy standards required by the funding body and European legislation were met.

to reopen the garden for social and cultural activities. This context presents an opportunity for conducting an SIA, where both ecological and social values are of equal importance, and the social impact of re-naturing can be assessed throughout a complete cycle, from the pre-intervention to the post-intervention phase. The process of information collection was embedded in a series of four co-creation sessions with citizens, stakeholders, and experts (local municipality councilors in environment and green areas, consultants on botany and biology, and representative of previous active cooperative in managing the case study) conducted between May and September 2024, as well as a session with local authorities in May 2024 (for further details, see Chapter Three and Morello et al., 2024). Beyond using information gathered through the co-creation process, the research also focuses on a collective activity that presents ES benefits as a set of cards. In this activity, participants were invited to select their desired benefits from a set of given cards and explain their choices. The information on the cards is elaborated from the literature review on ES indicators, benefits, impacts, and measurement methods. The details of the cards' development and their usage are available in Chapter Three.

In Chapter Four, the case of Utrecht University Botanical Gardens (UUBG)² is selected. This case study is selected for its special location around academic institutions, its accessibility to the public as an educational place, its appeal to academics and students as a recreational area, and, most importantly, its status as one of the main refuges for biodiversity in Utrecht, with a focus on preserving a wide variety of floral species. The Botanical Gardens cover 100,000 square meters and comprise nine thematic gardens that focus on immersive storytelling and the discovery of diverse species. They feature free walking paths and open spaces equipped with benches and sitting areas. UUBG is located in the Science Park at the east of Utrecht, the Netherlands. Beyond its scientific purposes, UUBG also serves as a city-level Garden mainly used by nearby residents and daily users of Science Park. The motivations for selecting such a case study have two dimensions. Firstly, the UUBG serves as both a scientific and recreational Garden, with high standards in biodiversity preservation and facility provision for users. As UUBG has fundamental differences with the first case study, it makes it an attractive choice to explore and examine the same methodologies on a larger scale with a new set of users and objectives. Secondly, UUBG, unlike Mirabal Garden, serves as a functional and active space. While in Mirabal Garden, the process of monitoring and assessment is *ex ante*, in UUBG, the methodology is tested in *ex post* conditions. This difference in condition offers new insights into how re-naturing measures can alter social perceptions and values over time. It is essential to note

² The research project titled 'Onderzoeksproject van het Urban Biodiversity Laboratory (LABU) bij Botanische Tuinen Universiteit Utrecht' received formal ethical approval from the Science-Geosciences Ethics Review Board (SG ERB) on 15 October 2024 (Reference: ERB Review Geo S-24.007). The committee determined that the study did not fall under the scope of the Dutch Medical Research involving Human Subjects Act (WMO) and raised no objections to the research activities as described in the submitted proposal.

that, as both case studies have significant differences, the results cannot be compared at every stage of the research. In the analytical chapter, particularly in Chapter Five, the results are analyzed to reflect on the importance of contextual parameters in the SIA process. The methodology used in Chapter Four is similar to that in Chapter Three (co-creation session and use of ES benefits cards), and it also includes semi-structured interviews and field observations. To better embed the research in this case study, the details of the co-creation boards differ from those of the Mirabal Garden, which are elaborated upon in Chapter Four.

In the third step, for the analysis of the results (to answer Q3), the research adapts and expands the Nature Futures Framework (NFF) to interpret the information gained from both case-study investigations (Chapter Five) for scenario-making at the local scale. Also, in Chapter Six, the research utilizes the Dynamic Adaptive Policy Pathway (DAPP) methodology as a methodological adaptive planning framework, which envisions multiple plausible futures and evaluates potential scenarios (pathways) of development. Specifically, in Chapter Five, NFF is adapted to interpret information at the local urban scale, providing insights into the social aspects of renaturing measures. In this scope, the results from the last two chapters are explored through the NFF dimension to reveal how participants in each case study perceive the values of nature. For case studies in data elaboration and analysis, the qualitative input was translated into a quantitative framework using multi-criteria decision analysis methods to evaluate defined futures systematically. The process entails several sequential steps, including developing measurement indicators based on Chapter Two and contextual parameters, and then using the Analytical Hierarchy Process (AHP) to weigh the indicators according to the objectives and visions of each case study. A detailed description of the methodology is available in Chapter Five. Ultimately, in Chapter Six, with a focus on the Sorelle Mirabal case study, future development scenarios are developed over a 25-year time horizon using the DAPP framework. The input for this analysis is provided through Chapters Two, Three, and Five. The scenarios used for the DAPP framework are directly derived from NFF dimensions. The details of the methodology used are available in Chapter Six. The innovation in both chapters lies in utilizing and integrating NFF and DAPP at the local scale, while also incorporating them into the long-term SIA process.

1.4. Roadmap and structure

This thesis is organized into five core chapters (Chapters Two to Six), a conclusion chapter (Chapter Seven), and a policy outline (Chapter Eight). Chapter One introduces the problem, scope, aims, and objectives, as well as the thesis questions, providing an overview of the theoretical framework. Chapter Two reviews the existing literature to identify gaps regarding the integration of ES in SIA. Chapters Three and Four describe the implementation of findings in two case studies. Chapters Five and Six present the case

study findings and analysis. It is necessary to mention in Chapter Six that only the case of the Sorelle Mirabal Garden in Milan is analyzed. This is due to the distinct character of the Sorelle Mirabal Garden case study as a pre-intervention situation under transformation, where sufficient data (resulting from collaborative sessions) are also available for analysis. In contrast, the UUBG case study presents a post-intervention context with an established structure for maintenance and development, where changes have already taken place. In the UUBG case, however, monitoring sessions focused on exploring improvement options through policies rather than establishing a development vision, aims, and objectives. Additionally, the Sorelle Mirabal case study has a context containing several uncertainties regarding the future. In contrast, the UUBG case study has a robust development plan with fewer uncertainty variables, making it less suitable for such analysis. Finally, Chapter Seven draws together the overall conclusions, discusses implications for urban planning policy, and suggests directions for future research. Ultimately, Chapter Eight and additional Annex I provide a brief overview of the implications of the findings in policy making and urban planning (see Figure 3 for more information).

Chapter 2.

Scoping the emerging role of urban biodiversity in social impact assessment³

Abstract

The relationship between humans and nature in urban areas is complex, with dynamic interdependencies that necessitate in-depth evaluation to inform planners' decision-making. While knowledge of social values and impacts of nature-based solutions (NbS) is progressing, a notable gap exists in integrating urban biodiversity (UB) and ecosystem services (ES) into evaluations. The increasing recognition of UB values raises questions about how biodiversity emerges as a new primary parameter in assessment. What are the leading indicators of ES in assessing the social impacts of NbS in cities? How can we integrate ES and UB into social impact assessment (SIA) as the primary framework for identifying, monitoring, and evaluating the social consequences of NbS in urban areas? This contribution undertakes a non-systematic exploratory investigation combined with a systematic literature review on regulating ES indicators to address these questions. Focusing on regulating ES, we screened 696 and analyzed 65 publications to identify and extract 85 indicators for SIA procedures. By elaborating on the attributes, measurement methods, and approaches of indicators, we introduce six categories of classifications, revealing biodiversity-related indicators as an emerging trend in the literature, with considerable flexibility for measurement in urban areas. We conclude with an emphasis on the existing limitations of scientific references in regulating ES indicators for social impact, as well as the relatively minor attention paid by scholars to the role of UB. Further research requires the comprehensive integration of UB and ES in SIA.

2.1. Introduction

Social Impact Assessment (SIA) is the process of identifying, monitoring, analyzing, and evaluating the social consequences of interventions, considering their possible and potential impacts with a specific context (Esteves et al., 2012; Vanclay, 2024). Various studies have attempted to construct a framework and define social impact attributes and indicators for measurement, adopting a top-down perspective (H. A. Becker & Vanclay,

³ This chapter (citation below) is published at *Frontiers in Sustainable Cities* on 24 July 2025.

Ayatollahi, A. and Morello, E. (2025) Scoping the emerging role of urban biodiversity in social impact assessment, a systematic review of regulating ecosystem services indicator types. *Front. Sustain. Cities* 7:1623650. <https://doi.org/10.3389/frsc.2025.1623650>

2003; Vanclay, 2024). However, evaluation methods mainly depend on contextual variables, stakeholders, and involvement practices (Lockie, 2001). The SIA procedures are evolving to better adapt to the rapid changes in dynamic contexts. Becker (2001) suggested micro, meso, and macro levels for SIA, stating that micro and meso levels focus on individual behaviors and communities. On the other hand, participatory initiatives focus more on community interactions with a focus on smaller scales (D. R. Becker et al., 2003; Dumitru et al., 2020), although the engagement level limits are still a concern (Vanclay, 2024). New perspectives on SIA focus on flexibility in indicators, collaborative measurement methods, and opening the process to actors (Parsons, 2020) for a comprehensive framework. The new paradigm of SIA, with main characteristics like context-dependency, use of mixed methods, and a bottom-up approach with a socially constructed reality by practices (Aledo-Tur & Domínguez-Gómez, 2017), is more flexible and adaptable to dynamic contexts like urban areas.

Dynamic and pervasive assessment methods are increasingly required in cities and urban areas, where complex and constantly changing landscapes necessitate a variety of tools for monitoring. The interactions between humans and nature in cities, along with rapidly intensifying challenges such as biodiversity loss (BD) and sustainability concerns, underscore the necessity of integrating nature and ecosystem services (ES) into assessments to guide decision-making and planning processes. ES are the benefits people obtain through ecosystems and natural processes that contribute directly or indirectly to sustaining their health and well-being (Liquete et al., 2016; Santos-Martín et al., 2013). The incorporation of ES into social impact assessment (SIA) has received growing attention in the literature (e.g., de Groot et al., 2010; Karrasch, 2016) in the last two decades. Evaluations often emphasize ES's direct and indirect contributions to human well-being (Costanza et al., 1997), revealing the importance of natural capital endowment and using ES as a proxy for a quantitative assessment of results. The anticipated effects of ES on human well-being are generally categorized into security, health, social relations, freedom of choice, and access to essential materials for a good life (Romanazzi et al., 2023). The ES contribution measurement methodology falls into two main categories: monetized and non-monetized valuation, primarily based on biophysical measurements and cost-based approaches or citizens' preferences (S. Liu et al., 2010). Although these methods are easy to assess and evaluate, they do not fully cover biodiversity and nature's impacts and contributions to human lives. The role of nature and its non-monetary inputs to human well-being are examples of this matter.

In the last decade, the identification and measurement of ES indicators focusing on the evaluation and impact assessment have been followed through various multiscale projects (e.g., Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystems and Biodiversity (TEEB)). At the European scale, scholars comprehensively developed research to map ES and assess their environmental, social, and economic

contributions and impacts (EC, 2021; EC, 2020). Moreover, NbS—defined as ‘actions that address environmental, social, and economic challenges simultaneously by maximizing the benefits provided by nature and inspired by, supported by, or copied from nature’ (EC, 2015)—is increasingly promoted in various research projects. This trend indicates a growing concern about these issues (e.g., EC, 2021; Nikolova et al., 2018; Nilon et al., 2017). To establish a comprehensive approach to monitoring social and ecological dynamics, von Döhren and Haase (2023) suggested incorporating an ES cascade and Driving Forces-Pressures-State-Impacts-Responses (DPSIR) framework into SIA. These frameworks facilitate the monitoring of environmental and societal dynamics, enabling a better understanding of their contributions to human well-being. Although the overall structure for incorporating social values into assessment procedures is generally accepted, the details of attributes, indicators, and measurement methods remain a matter of discussion. The definition of ES covers the relationship between humans and nature, and much of the research reviewed by Longato et al. (2021) and Pinto et al. (2022) focuses on specific aspects of this relationship. While species richness and biodiversity values are essential in defining ES in urban areas, the relationship between biodiversity’s contribution and the function of urban ES remains unclear (Haase et al., 2014; Schwarz et al., 2017). The specific context in which practitioners apply the framework influences the parameters needed for developing an SIA framework. This context (as a social-ecological system (SES)) includes the biophysical environment, which affects various attributes of the assessment, as well as social-cultural differences that shape stakeholder perspectives and priorities (Guerry et al., 2023). Despite efforts to shape a holistic SIA framework using ES, the suggested literature does not fully integrate biodiversity-based indicators and context-dependent social interactions and impacts.

The aforementioned studies attempted to fully or partially cover these effects by analyzing one or more variables in interaction. Due to the broad spectrum of ecosystem services, disservices (the negative impacts of ecosystems on human well-being), and the complexities of these interactions, knowledge regarding comprehensive measurement remains limited. While monitoring and measurement methods should cover complexities beyond short-term economic gains (Moreau et al., 2022), the direct inclusion of ES in the SIA is not fully implemented (Dumitru et al., 2020; Karrasch, 2016). The dynamics of urban social-environmental relations and the attributes of biodiversity generate scenarios that require indicators capable of addressing multiple scales, timeframes, and relationships among various actors. Therefore, these indicators must be versatile enough to identify multiple aspects of social-ecological systems' relationships comprehensively.

In this contribution, we present how the integration of ES in SIA affects evaluation methods and outputs and how urban BD emerges as a new major category of indicators in the literature. The study aims to answer two primary questions: 1. What are the leading indicators and factors of regulating ES for SIA in urban areas? What are their value metrics,

and how do they relate to UB variables? And 2. How can these indicators be measured and localized in an urban context? To answer these questions, reviewing current knowledge concerning each regulating ES leads to a new proposed structure for indicators that integrate biodiversity in analyzing ecosystems and their possible services and disservices in urban areas. By systematically reviewing current scientific publications using SIA, ES, and biodiversity parameters, we demonstrate how extracted indicators differ from traditional measurements and how they should be more flexible and comprehensive for monitoring and measuring social impacts in urban areas. We close by proposing an emerging connection between biodiversity and ES in monitoring and evaluating social impacts in the dynamic environment of urban areas.

2.2. Materials and Methods

The methodology consists of three steps. The first step is a preliminary non-systematic literature review to assess the knowledge of the relationship between ES, NbS, and BD in urban areas. The second step is within a systematic literature review based on (Shamseer et al., 2015) and methods adopted in reviewing urban ES research (Brink et al., 2016; Luederitz et al., 2015). The third step, founded on the principles of SIA (H. A. Becker & Vanclay, 2003; Carley & Bustelo, 2019; Vanclay, 2024), adopted a constructivist paradigm (asserting that knowledge is actively constructed through social interactions and experiences, emphasizing the role of context and collaboration in understanding complex issues) with value system methodology (Aledo-Tur & Domínguez-Gómez, 2017; Domínguez-Gómez, 2016) to define indicators and factors. In summary, the research flow is as follows: 1. Identifying social impacts and leading connections of ES and biodiversity, as well as NbS in urban areas, for navigation in the SIA procedure to construct the eligibility criteria and formulation of indicators. 2. Pre-selecting (through data screening and cleaning) research on social impact evaluation and assessment using ES and biodiversity values in urban areas. 3. A full-text review of selected eligible articles and inclusion in the final review for the extraction of indicators, factors, impact, and measurement methods beneficial for SIA based on ES. 4. Organization and processing of the outputs from the final review integrate into the SIA procedure under a constructivist paradigm perspective.

2.2.1. Non-systematic literature review

To cover gray literature, reports, and established frameworks on ES and social impacts, a complementary non-systematic literature review facilitated the classification of ES and biodiversity indicators, factors, and quantification methods for assessment purposes. This review also covered necessary information for understanding the nexus between social-environmental and ecological systems in cities. The review process filled the gap in understanding urban ecosystem processes, leading to social impacts, and how to track and

link these social impacts to biodiversity factors and services resulting from urban ecosystems. The review conducted focused on ES classification, urban ES, and biodiversity (e.g., Belaire et al., 2022; Colavitti et al., 2020; Rega-Brodsky et al., 2022), NbS impacts and processes (e.g., EC, 2021; Moreau et al., 2022; Ommer et al., 2022), SIA frameworks (Karrasch, 2016; Sabater et al., 2021), and classification guides (e.g., MEA) in published papers, books, handbooks, and guidelines.

The basis of ecosystems and their services predominantly relies on different methodologies, primarily considering categories of services and contributions to human well-being. Among the classifications, TEEB, MEA, and the Common International Classification of ES (CICES) (Haines-Young & Potschin-Young, 2018) are the most used frameworks. This research adopts the CICES framework (version 5.1) due to its comprehensiveness and hierarchical nature of categorization (Nikolova et al., 2018), which enables this research to be flexible in its selections. The review focuses on the regulation and maintenance of the ES (biotic) section, investigating the contribution of biodiversity and natural features. As ES generally have anthropocentric attributes (L. Kim & Li, 2024; Liqueste et al., 2016), investigating their impacts and functions requires a socio-cultural profile and context in the review. Although a review of scientific literature demonstrates a gap in linking ES to the social-cultural context, the investigation and engagement of actors and stakeholders in measurements and decision-making is visible (Balzan et al., 2020). To fully integrate ES into the SIA process, the indicators and factors for measurement must account for both direct and indirect effects, enabling the assessment of contextual differences. To fully adopt the impacts of ES on society for an SIA, this research develops categories of calculation and tracing methods based on indirect effects (McElwee et al., 2020; Shennan, 2008), perception of users (Costanza et al., 1997; Pistón et al., 2022), and human-based interactions (i.e., effects that are health-related or mainly influence well-being and safety of users) (Harclerode et al., 2015). The purpose is to identify the chain of events or singular effects that within a process might have secondary or indirect results linked to human well-being. The effects may be derived from both ecosystem services and disservices. For economic evaluations, the research adapts standard methods for assessment (Farber et al., 2002; Hougner et al., 2006; S. Liu et al., 2010) to the specific context and type of ES effect.

2.2.2. Systematic literature review

We conducted a systematic literature review on the relations between SIA, regulating ES, and biodiversity in urban areas. The review broadly followed the framework proposed by Shamseer et al. (2015) and, specifically, methods adopted for reviewing ES in urban areas (Brink et al., 2016; Luederitz et al., 2015) in seven steps, summarized in Table 2 and Figure 4, represent the flow through the PRISMA framework. The procedure follows: 1. Data gathering, 2. Data screening, 3. Data cleaning, 4. Data scoping, 5. Paper appraisal, 6. Article

analysis, 7. Data analysis. Although the study is not exhaustive in all respects, the coverage of results relating to ES and social impact, as well as UB, is sufficient for analysis. Within this framework, the query of TITLE-ABS-KEY (“social*” AND “impact*” OR “social impact*”) AND TITLE-ABS-KEY (“ecosystem servic*” OR “eco-system servic*”) AND PUBYEAR > 1999 AND PUBYEAR < 2025 is constructed in the first step for data gathering from the Scopus portal using Boolean parameters (here and after the base query). Note that due to the variety of synonyms for ES, we selected the conventional term “ecosystem services” for the queries to control input quantity and ensure the content accuracy. Additionally, to clarify the expanded queries for each regulating ES, we added attributes with Boolean parameters, which did not affect the results. To narrow down the results further to regulating ES, we conducted searches separately for each class of regulatory ES based on the CICES V5.1 classification and definitions. This involved defining queries for each regulating ES (see queries in Supplementary Material 1) and then gathering publications containing ES and social impact in their title, abstract, or keywords. Although the results from the 2000s are limited, further research reveals no records within the aforementioned scope prior to that period. After gathering initial data in the screening step, each regulating ES query is expanded with “biodiversity” and “urban” keywords to narrow the records and direct the search toward the aim of this paper. For example, the query of TITLE-ABS-KEY (“social*” AND “impact*” OR “social impact*”) AND TITLE-ABS-KEY (“ecosystem servic*” OR “eco-system servic*”) AND TITLE-ABS-KEY (“pollinat*”) AND TITLE-ABS-KEY (“biodiversit*”) AND TITLE-ABS-KEY (“urban*” OR “city” OR “cities*”) AND PUBYEAR > 1999 AND PUBYEAR < 2025 serves for pollination ES (code 2.2.2.1). Summing all regulating queries bundle publications in regulatory ES by

1880 records for base query, 696 records for biodiversity query, and ultimately 151 records for base query plus UB for regulating ES.

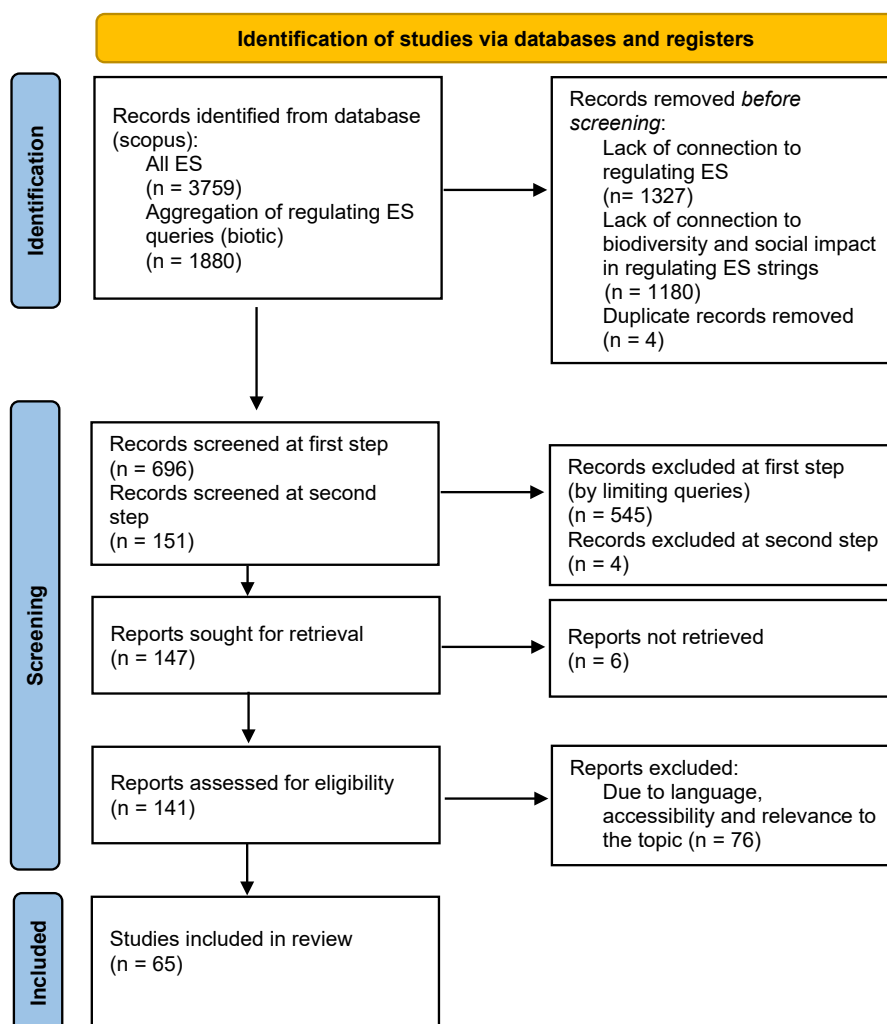


Figure 4: Identification of studies flow diagram through PRISMA framework (Page et al., 2021).

In the data cleaning step, the criteria are defined based on social impact relevance analysis or relevance in the abstract, use of biotic ES (as the research focus is on biodiversity), focus on social issues or impacts on society directly or indirectly, and adoption or use of any indicators, factors, questions, or measurement methods for social impacts. In this third step, if any search query produced zero results, we reused the nearest previous query that had yielded results. This approach increased the likelihood of finding and extracting relevant information for the SIA of ES in urban areas. We identified 109 records for full-text review, of which 91 were accessible for review. After reviewing, we selected 53 records of peer-reviewed original or review articles in English for data analysis.

Table 2: Systematic literature review procedure.

Steps	Procedures	Results
1. Data gathering	A database search on Scopus using the jointly defined search query.	Base query: 3759 Limiting base query Regulating ES (biotic): 1880
2. Data screening	Division of data load with search query focusing on each regulating ES, biodiversity, and urban.	2.1 (Base query for regulating ES) AND (“biodiversit*“): 696 2.2 (Base query for regulating ES) AND (“biodiversit*”) AND (“urban*” OR “city” OR “cities*“): 151
3. Data cleaning	Screening of abstracts guided by questions: 1. Does the paper contain or indicate assessment indicators for social impact? 2. Does the paper use biotic regulating ES, and their benefits in theory or practice? 3. Does the paper adopt or introduce any form of indicators, impacts, or measurement methods for the social impact of NbS?	147 A total of 147 potentially relevant case studies were identified.
4. Data scoping	English language and peer-reviewed publications (with full access) classified as potentially relevant.	141
5. Paper appraisal	Full-text analysis of peer-reviewed potentially relevant papers based on three main questions and ES classification to verify the selection.	65
6. Article analysis	Collect data from each selected paper based on ES for indicators, factors, impacts, and measurement methods.	85 Indicators 77 Factors 73 Impacts 66 Measurement methods

7. Data analysis	Apply qualitative and quantitative analysis, along with visualization tools, to the data for preliminary processing.	Statistical analysis, indicator types, and approaches, connections with the social-ecological systems
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2.2.3. Indicators' constructions and filters

A deductive coding approach was adopted to extract indicators, factors, impacts, and measurement methods from the systematic review. This involved selecting and modifying the extracted information to fully align with the objectives of SIA using ES in urban areas. The indicators and factors, beyond simplicity and ease of communication, require attributes that are explicitly tailored to the context of SIA. Among perspectives and reviews on social impact indicators and factors using nature or ES, this contribution adopts three main viewpoints on the relation of SIA to NbS. Primarily, indicators have to be sensitive enough to indicate change in time and, besides reflecting economic issues, indicate social-cultural matters affecting the well-being of humans (Haase et al., 2014).

Additionally, indicators may utilize biodiversity constituents (such as species richness, genetic diversity, functional diversity, and ecosystem diversity) to reflect the effects of ecological issues better. In cases where direct quantification of ES proves challenging, researchers can employ proxy indicators to estimate and represent the value of these services by adding additional steps in measurements (Liquete et al., 2016). Finally, constructing indicators and factors is inspired by the concept of benefit-relevant indicators (BRIs) as indicators using a causal chain of interactions (Olander et al., 2018). The BRI clarifies the impact on well-being by utilizing a chain of interaction based on ecological dynamics and possible outcomes for the welfare of users (ibid). The bundle of these methodologies facilitates the construction of indicators and factors that consider the economic consequences of ES and the chain of events and direct or indirect social-cultural effects on society. The indicators are not solely economic, but they reflect effects on society, which in some instances are not measurable by quantification. We exclude methodologies from the extraction process if they do not directly or indirectly cover social impacts.

2.3. Results

Following the retrieval of scientific publications on the social impact of ES and narrowing down the search to regulating the category of ES, 1880 scientific publications with potential relevance for analysis were gathered. Following the inclusion process and scans mentioned in Section 2.2, 141 papers were qualified for full-text scanning and information extraction. In some cases, the selected documents are cross-sectional between urban planning, health, ecology, and biology. We identified 85 impact indicators for measuring

the impacts of NbS through ES, based on a comprehensive review of 65 fully screened papers. We considered eight influential variables that are engaged in interactions and outcomes within the proposed multitiered framework. The study attempted to identify indicators, impacts, questions, and measurement methods that lead to identifying or measuring the social impacts of regulating ES. The results of this review illustrate bundles of relevant or closely related ES in the CICES V5.1 framework. The following sections primarily highlight the key findings of the literature review and categorize them based on their attributes. Ultimately, we discuss the contribution of these results to addressing current gaps and shortcomings in existing knowledge. Figure 5 illustrates a general overview of the number of extracted indicators from the literature for each regulating ES. A comprehensive list of results, including indicators, impacts, factors, and measurement methods, along with analysis, is available in Supplementary Materials 1 and 2.

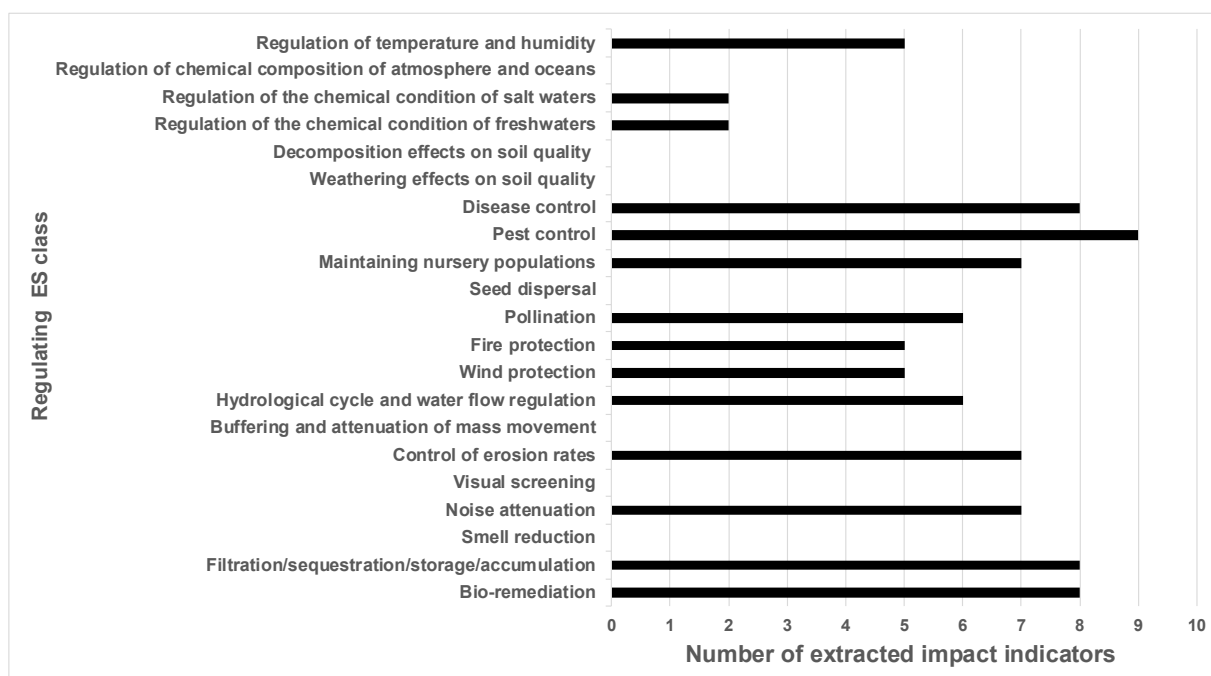


Figure 5: Number of extracted impact indicators for regulation ES from the literature based on the CICES framework (for the full name of each regulating ES class, see Supplementary Material 1).

2.3.1. Emergence of new categories of NbS in urban areas for SIA

A series of separate reviews conducted on each regulating ES resulted in varied outcomes for each class of ES, regardless of their presence in urban areas. Unlike the TEEB classification, the CICES classification does not contain an urban ES division. Within the inclusion criteria and UB extension in search queries, certain ES classes, such as bio-remediation (2.1.1.1), noise attenuation (2.1.2.2), and pest control (2.2.3.1), result in five or more entries. On the other hand, ES, such as visual screening (2.1.2.3), buffering and attenuation of mass movement (2.2.1.2), and regulation of the chemical condition of

freshwaters by living processes (2.2.5.1), yielded zero entries. When each step of the search yields zero results, researchers consider the results from the previous step for full review and extraction. Despite the complete division of ES into classes by the CICES framework, based on the proximity of services and review results, the presented outcomes are based on the grouping of two additional ES classes.

The extracted indicators, impacts, factors, and measurement methods cover various methodologies and perspectives on the SIA of NbS in urban areas. To fully address the wide range of differences in assessment and facilitate further use, it is necessary to categorize the results comprehensively. We propose six main categories of indicators to classify information based on the methodologies explored in the literature. The proposed categories are formed based on methodologies for measuring effects, the application of quantification methods or the use of qualitative data, and the level and scale of engagement with users, the biophysical environment, and biodiversity parameters. Below are illustrations of these category types and their descriptions.

Human-based: The direct effect of NbS or environmental changes that influence citizens' and users' lives and well-being might not be quantified in monetary terms but are observable through individual or common values. This category's indicators focus on human and general user relations and dynamics with nature. This type frames topics that investigate human health and well-being, security, physical activity participation, and environmental changes that affect humans. The amount of noise annoyance and irritation or quietness of spaces for users (van den Bosch and Ode Sang, 2017; Wang et al., 2014) are examples of parameters indicating the noise attenuation ES for users.

Biodiversity-related: Approaches that use or implement animal or plant engagement factors directly or through the chain of events to measure social impacts are placed in this category. For instance, the abundance of plants, an increase of tree canopy in streets, or richness in particular species of animals have proven to positively affect human health and well-being directly or indirectly (Bautista et al., 2020; Nicholls et al., 2020). The methods and approaches that apply parameters related to biodiversity or discover relations between biodiversity and users' life quality belong to this category. Biodiversity functions as a variable affecting interactions in urban ES; consequently, measures concerning this variable are practical for SIA. The literature has not deeply reviewed the use of biodiversity as a unique category for evaluation. However, its indicators help identify how ES benefits affect citizens' mental and physical well-being.

Proxies: The interactions between humans and nature in urban areas are interconnected and complex. A series of events may not have a direct social impact. However, a chain of events and the secondary result of their implementation might lead to service or disservice for users. For instance, urban green environmental characteristics, such as air and noise pollution, as well as pests, affect both human mental and physical health

(Nawrath et al., 2022). Although this relationship is not directly measurable, the cultural ES (resulting from increased possibilities of staying and interacting within nature) is facilitated by urban greens or a reduction in pests in these environments, which can lead to benefits for disease control by regulating ES. The foremost step in this type is revealing the pattern or chain of events leading to indirect results as a proxy for measuring the services or disservices provided by the ecosystem.

Financial-related: This category encompasses indicators that result in market-oriented values or economic benefits and evaluation procedures with monetary components. NbS at any scale may lead to direct or indirect financial benefits for citizens or local administrative systems. An example is maintaining natural habitats, which increases the annual value of services provided by fisheries (Liquete et al., 2016). Moreover, procedures measuring financial interests in the promotion or conservation of ES (mainly willingness to pay) are included in this type as they evaluate and reveal the socioeconomic settings of the study group.

Models: Models primarily measure ES's secondary and indirect effects through the chain of actions. These parameters dominantly evaluate the after-effects of services and reveal the efficiency or magnitude of impact through quantitative amounts. Changes in the annual amount of dust or sand by trees in a specific city or neighborhood, which lead to improvement in public health, reflect the functionality of wind protection services (Missall et al., 2018). Models help planners better illustrate the complexity of actions and the effects on beneficiaries of urban ES and nature.

Perception-based: Parameters that require direct interview, questioning from citizens and stakeholders, evaluation of public perception, and, in general, direct engagement with citizens and stakeholders through questionnaires are within this category. The results of the parameters in this category are mainly qualitative and based on public participation in the procedure. The social impacts of noise attenuation ES are possibly observable through public perception gathering on the impact of tree coverage on noise cancellation (Dzhambov and Dimitrova, 2014).

The categories of indicators mentioned above encompass various methods for identifying social impacts of NbS. In SIA, it is necessary to comprehensively assess the extent of impacts and effects using complex evaluation methods and various categories of parameters, based on contextual realities. Among the proposed groups, the biodiversity-related category represents high versatility in social impact assessment. Covering the primary and secondary effects of NbS with both qualitative and quantitative measurements lends this category value for further investigation and placement in evaluation procedures. The remaining categories exhibit partial coverage of effects in the literature. The newly proposed categories generally facilitate the selection of measurement methods based on context attributes. Figure 6 and Table 3 present the distribution methods and approaches

to measuring indicators for each type, based on selected indicators from the literature. The following brief sections present results for the ES-regulating category stemming from the review.

Table 3: Categories of indicators used for SIA using regulating ES based on their attributes. Among identified categories, biodiversity-related indicators have considerable flexibility and coverage for identifying and measuring impacts and effects.

	Quantitative	Qualitative	Direct social impact	Indirect social impact	Primary social effects	Secondary social effects
Human-related						
Biodiversity-related						
Proxies						
Financial-related						
Models						
Perception-based						

2.3.2. Mediation of wastes or toxic substances of anthropogenic origin

This group includes bio-remediation by micro-organisms, algae, plants, and animals (2.1.1.1) and Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals (2.1.1.2), ES classes. In the bio-remediation class, eight indicators were extracted in general. Most indicators (7 out of 8) focus on human-related or perception-based methodologies evaluating the life quality and safety of workers, citizens, and involved parties during or after bio-remediation. In one case (Harclerode et al., 2015), ethics and equality are complementary parameters for the SIA of bioremediation. Consequently, the assessment for this ES in the literature primarily links to biophysical variables, and interaction results influence users or governance systems. Bio-remediation actions in cities directly affect citizens' health and safety and, to a broader extent, communities and local governance systems (Harclerode et al., 2015; Quilliam et al., 2015).

The filtration and storage class shows limited results related to UB, and no studies directly measure social impacts in the literature. The indicators base their indexing of biodiversity factors or models on showing chain events that might affect society, which in both cases do not establish a strong relation for social matters. Non-social impacts are predominantly concerning soil and its chemical status, which does not immediately correlate with urban area specifications. However, the elements of biodiversity affect this ES's proficiency. Parameters such as tree coverage, bee and wasp richness, and vegetation density are effective in enhancing carbon storage and indirectly indicate improvements in biodiversity preservation (Belaire et al., 2022). As a result, the improvement in biodiversity status has a direct impact on the health and well-being of citizens and users. This relationship remains conceptual, and the literature does not provide evidence to support

it. In the conducted review, there is no direct evidence of social impacts for this class of ES. When establishing this connection, only indirect results of biodiversity conservation provide a strong connection for better observation of the effects. This ES requires further investigation to establish solid, directly measurable social impact indicators in urban areas that require improvement.

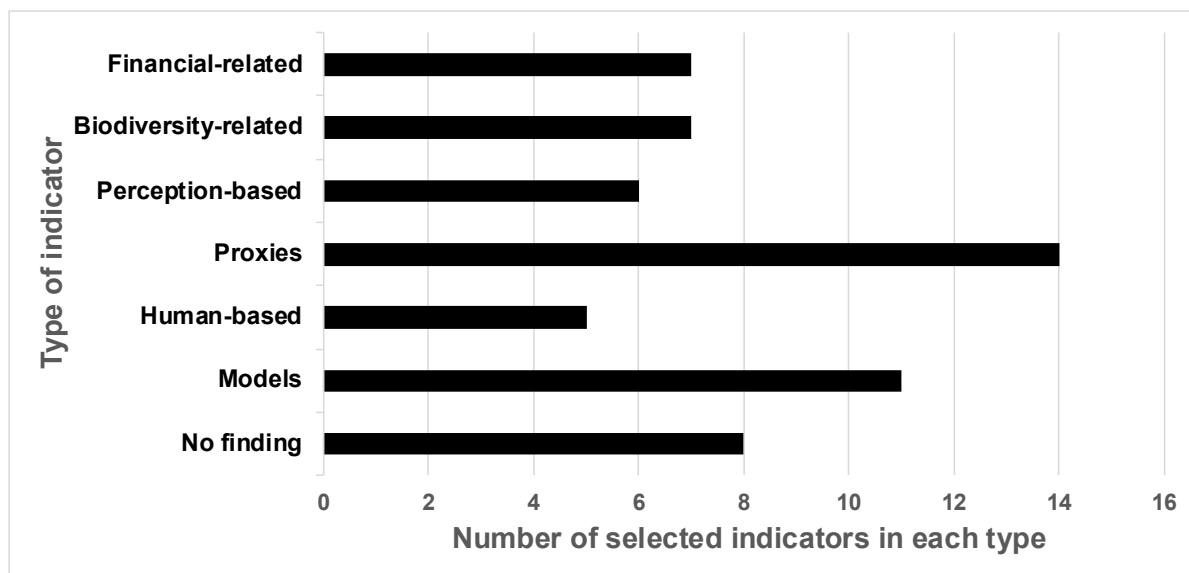


Figure 6: Connections between regulating ES indicators and defined types of indicators (no findings refer to ES classes without any extracted indicators from the systematic review).

2.3.3. Mediation of nuisances of anthropogenic origin

This group consists of smell reduction (2.1.2.1), noise attenuation (2.1.2.2), and visual screening (2.1.2.3) ES. The group's knowledge of its social impacts concerning UB is limited. Only three results appeared in the primary search on smell reduction ES, although none were directly related to UB in the screening phase. Consequently, no specific indicators, impacts, or factors related solely to biodiversity emerged in the reviewed literature. The gap in knowledge of social impacts on this ES demands further research for a more comprehensive understanding of the effects of NbS for nuisance mediation. The results of visual screening ES are also the same. None of the scanned documents, out of the fully screened papers, identifies clear parameters for SIA.

Out of 19 preliminary results that emerged on noise attenuation ES, only five papers contained UB terms. Due to the limited results, we thoroughly reviewed eight documents from the previous step (social impact and biodiversity). The indicators for SIA in this class focus on human perceptions and feelings of environmental variables and non-economic values. Citizens' mental health and psychological well-being are primary items in evaluations (Dzhambov and Dimitrova, 2014; van den Bosch and Ode Sang, 2017). Moreover, the tree canopy and greenery coverage for noise reduction are biodiversity-

related variables that identify the function of noise attenuation services (Bautista et al., 2020). Based on the results, users and the biophysical environment are the key variables for measuring and evaluating social impact in urban areas. The role and effectiveness of biodiversity, economic connections, and the number of financial benefits of this ES on society are still unclear and require a deeper understanding of the dynamics.

2.3.4. Regulation of baseline flows and extreme events

This class covers a wide range of ES, including the control of erosion rates (2.2.1.1), buffering and attenuation of mass movements (2.2.1.2), the hydrological cycle and water flow regulation (2.2.1.3), and wind and fire protection (2.2.1.4 & 2.2.1.5). Most research on controlling erosion rates and buffering mass movements could be more exceptionally structured for urban areas. At the same time, studies on water flow regulations have recently gained considerable attention, especially in coastal cities. Furthermore, the literature has not extensively examined the social consequences of NbS in urban areas for fire and wind protection ES. The types of extracted indicators on erosion rate control ES for social impact measurements are indirect or through financial approaches. The controlling activities that are categorized for erosion control (from agroforestry to urban agricultural activities) might create second-hand indirect benefits for engaged actors or the neighbors by providing financial (food production, increase in safety) or cultural benefits (Balzan et al., 2020). Studies conducted in Jakarta resulted in a financial-related indicator, revealing that citizens' willingness to pay for the conservation of greenery for erosion control purposes indicates the effectiveness of NbS (Vollmer et al., 2016). The SIA indicators for this ES focus on dynamics between users and other related ES variables, emphasizing the secondary or indirect results of interventions. The functions and role of biodiversity-related variables must be firmly present, and indicators must focus on the benefits of greenery and vegetation for control purposes. None of the four papers reported social impact indicators for buffering mass movements in their results. We anticipated a lack of results since the functionality of this ES in urban areas is strictly limited.

The social impacts related to UB and the hydrological cycle, as well as water flow regulation, within this search scope are minimal, as only seven papers were eligible for full-text screening. From this number, we extracted only one indicator that establishes an indirect monetary connection between the outcomes of this ES and the financial benefits of safeguarding water diversion, and the output values of primary and secondary industries (Cai et al., 2023). The ES functionality and social impacts are partially measurable through monitoring the financial outcomes of industries, changes in GDP, and population growth, as well as more directly by measuring the amount of water diverted during a specific period in the study area.

Despite the wide range of fire and wind protection services, the social impacts and values of these services through NbS, especially in urban areas, have yet to be extensively

reviewed. On wind protection ES, three eligible papers reviewed resulted in four indicators extracted, mainly devised to measure or evaluate indirect impact based on user perceptions. The wind protection services, through NbS, primarily enhance the perception of living quality conditions, which are measurable by direct questionnaires from engaged communities. The other indicator is the annual reduction of airborne materials (sand, dust) in urban areas, consequently leading to public health improvements (Missall et al., 2018). In any case, the measurements involve perception evaluation and indirect measurements of changes in the environment or direct measurements, such as measuring changes in water usage for plants provided for this ES compared to actual water provided for irrigation as a representation of the level of effectiveness (ibid). The scope of fire protection ES is narrower than wind protection (around 50 percent fewer results in each step), resulting in one paper in the UB step result. To cover a broader scope, ten papers from the biodiversity query analyzed (the previous step from the final query), and most indicators observed focused on non-urbanized areas. Despite no direct or indirect impacts on society or measurement of benefits, we observe an indirect co-benefit relation between fire protection and improvement in habitat nursing (due to risk reduction of fire hazards)(McElwee et al., 2020), which requires concrete development for applicability and proof of evidence in urban areas. Wind and fire protection ES needs more exhaustive research in urban areas to identify its benefits better.

2.3.5. Lifecycle maintenance, habitat, and gene pool protection

Among the three ES in this group, studies widely examine pollination (2.2.2.1) and the effects and impacts of maintaining nursery populations and habitats (2.2.2.3) in urban and non-urban areas. In comparison, the seed dispersal (2.2.2.2) search query for UB results in two outcomes, none of which revealed any relevant indicator for SIA purposes. We anticipated the outcomes in this case since most of the literature covers the pollination issue, which holds a higher priority in urbanized areas. Five papers were fully screened on pollination ES, resulting in three extracted indicators falling into three categories: biodiversity-related, financial-related, and models. As pollination, ES is wholly dependent on natural elements and the vectors of pollens; the biodiversity variables, such as the functional diversity of arable plants, bees, or butterfly species abundance, are eligible indicators for measuring the functionality of this ES and understanding the direct socio-cultural benefits they generate (Balzan et al., 2020). Regarding the preservation of biodiversity features, citizens' willingness to pay, like previous ES, can be a comparative indicator of the effectiveness of this ES on society (ibid). Biophysical attributes of the urban environment, like density, biological diversity, and landscapes available for nesting (Jansson and Polasky, 2010), are determining variables for the function of pollination. Other studies have previously discussed pollination's extensive economic and socio-cultural benefits (Hein, 2009; Lonsdorf et al., 2020). In contrast, the indicators in this study

focus on pollination ES's functionality and its procedures to render the extension of service delivery.

Primary and secondary social benefits resulting from managing habitats or increasing the number of inhabiting animals are all linked to intentional or unintentional habitat preservation for commercial and non-commercial purposes. The market value of natural products and growth in numbers on the market of oriented animals and plants are within this category. The other series of indicators evaluates the recreational values this ES produces. In this case, the increase or improvement indicates enhanced functionality and service creation resulting from interventions or preservation. Additionally, maintaining and protecting habitats in urban areas can lead to social benefits, such as increased awareness and social cohesion (Archiciński et al., 2024).

2.3.6. Pest and disease control

Pest (2.2.3.1) and disease control (2.2.3.2) are the significant roles and priorities in urban areas for the well-being and safety of citizens. However, the social impacts of NbS in this category are mainly indicated indirectly or through proxies in limited outcomes. Regarding the social effects of pest control ES, as a result of the final query, there were only four publications; all seven papers on the biodiversity step were reviewed (plus one from snowballing the citations). Similar to other results, the willingness to pay for pest control and the amount of participation (Alix-Garcia et al., 2018), in this case, indicate its effectiveness and the importance of its impact on citizens. Moreover, urban agricultural activities may lead to improvements in species richness and enhanced pest control, ultimately benefiting citizens' health (Nicholls et al., 2020). Although these indicators represent weak links between factors and elaborations and measurements are indirect, this relationship emphasizes the importance of biodiversity factors and urban greenery in the effectiveness of pest control. The exact status applies to urban fragmentation and its impact on the increase of pests, and consequently, the negative effect on society's perception (Shennan, 2008). Indeed, these chains of effects and variables are not optimal approaches for measurements, and in some instances, they require additional evidence. However, they indicate initial steps to further elaboration or investigations.

In general, results on disease control ES have more comprehensive coverage and outcomes, although they still need improvement on the urban side. Out of 101 primary outcomes, only six indicated UB, resulting in eight extracted indicators from two sources representing indirect impact relationships and models for measurement. Relationships with the functionality of other ES results, such as noise and pollution regulation, or the functionality of cultural ES, and the reduction of stress and artery disease (Elendu et al., 2024), and mental diseases in urban areas are examples of these relations (Nawrath et al., 2022). Most findings in this case evaluate indirect effects and qualitative data related to assessment. In this case, the social impact of NbS still requires a better understanding and

broader scope of studies focusing on the effects sequence. The range of social impacts is more comprehensive than the number of patients due to environmental factors. However, the studies for monitoring the effects do not indicate any direct, clear relation that leads to quantitative indicators. The outcomes in this section are still limited and need more data to be applicable in evaluation processes.

2.3.7. Regulation of soil quality

This group focuses on two classes of weathering processes and their effect on soil quality (2.2.4.1), decomposition and fixing processes, and their effect on soil quality (2.2.4.2) ES. The social impact of NbS through these two ES in urban areas is yet to be proven. Due to the nature of their services, identifying any direct relation with qualitative or quantitative data on society, especially in urban areas, is unexpected. A review of the results of both ES in this group (one paper on weathering processes and thirteen papers on decomposition) did not bring any social impact evaluation or monitoring indicators. Although the literature widely focuses on chemical quality and process, which have no direct relation to social impact, we anticipate that, due to the limitations, further research in this case might lead to long-term processes with indirect indicators. The lack of results and studies in this case renders the weak presence of social effects due to these ES in urban areas.

2.3.8. Water conditions

This group consists of two classes of regulation of the chemical condition of freshwater by living processes (2.2.5.1) and regulation of the chemical condition of saltwater by living processes (2.2.5.2). The previous scope of studies on social evaluation processes is limited, and urban settings still require adequate study to establish clear indicators. Like earlier groups of ES, these classes have limited functionality in urban areas, and their possible social impacts are limited. Among the reviewed literature from systematic processes (in total, three for both classes), the observations focus on drainage systems in urban areas and their maintenance status for preserving water quality (freshwater). The chemical condition of water and the effects of chemical exposure are other topics mentioned in the literature. The social impacts of these ES still need to be fully elaborated, and developing such relations still requires more effort, and identifying primary impacts first. The literature does not identify any social impact indicators or factors.

2.3.9. Atmospheric composition and conditions

The last group of biotic regulation ES covers a broad range of activities related to the atmosphere in various contexts. These include regulating the chemical composition of the atmosphere and oceans (2.2.6.1) and regulating temperature and humidity, including ventilation and transpiration (2.2.6.2). Both classes play vital functions and provide essential services in urbanized areas, such as cooling effects to mitigate urban heat islands,

reducing air pollution, and improving air quality. It is necessary to note that although the related results and benefits observed in urban areas link to these ES, identifying service sources (nature or humans) requires further identification of indicators for NbS. Furthermore, to ensure integrity in the methodology, the search query scope of the database search remained consistent with other ES, using keywords that described the entire ES. Due to this limitation and multiple reviews of the benefits of heat, thermal comfort, and air pollution, this research aimed to identify indicators that might need to be included in assessments or be considered more commonly. From the conducted search, we reviewed five papers for both ES (one for the chemical composition of the atmosphere and four for temperature regulation and ventilation), resulting in four indicators for temperature regulation. The indicators primarily focus on indirect measurements or models that assess human comfort in urban areas.

2.4. Discussion

With this contribution, through a systematic literature review, we have adapted the current categorization of ES to match their impact indicators to six new types of indicators. This study builds on previous research to present new developments in SIA methodologies using ES. Integrating ES in identifying (social) impact measurement methods primarily defines six new categories of indicators. As an extension to traditional methods (Karami et al., 2017; Olander et al., 2018), these categories offer a more resilient and comprehensive perspective on social impacts, especially on indirect and quantitative values generated by NbS. The extensive coverage of social complications and the consideration of secondary or indirect results of interventions add particular significance to this contribution. Secondly, the representation of a new approach to connections between new categories of ES indicators and social-ecological variables for addressing the social impacts of NbS in urban areas represents a step forward from current knowledge, covering the gap in SIA procedures. Previous studies (Rosa and Sánchez, 2016) emphasize the need for proper indicators to confirm that implementing ES enhances the coverage and procedure of SIA. Integrating biodiversity and biophysical features plays a critical role in this process. The relationship between ES classes and indicator types highlights an anthropocentric multiple-value system (Aledo-Tur and Domínguez-Gómez, 2017; Binder et al., 2013) integrating biodiversity and indirect values as new perspectives in SIA procedures. Interpreting the results suggests that biodiversity in urban areas serves as an essential variable for SIA, enabling a better evaluation of the societal impacts of nature preservation. In summary, this study advances the discourse on valuing biodiversity and biophysical features in SIA by proposing six novel categories using ES indicators that can account for indirect and qualitative impacts. Using ES indicators to uncover nature's interconnected qualitative and quantitative impacts on society in urban areas broadens the dialogue in current assessment approaches between science and assessment practices.

Our findings reflect an imbalance in the use of regulation ES indicators between different classes in urban areas. The imbalance in the development of indicators, particularly social impact indicators, results in fragmented assessment approaches and neglect of holistic monitoring for nature preservation. For example, the discovered evidence reflects a broad range of environmental and economic impact indicators for bioremediation and filtration ES, while few indicators measure the social impacts of these ES or involve biodiversity variables in their measurement approach. In contrast, few impact indicators (both social and economic) for noise attenuation or smell reduction are observable in the literature, despite the wide variety of effects these have on human lives. Discovering this gap in the literature and categorizing current indicators helps scientists and practitioners in two pathways. Firstly, based on the assessment context, scientists and practitioners can primarily select and use indicators that align with the assessment target, thereby broadening the assessment's coverage to include indirect and non-monetary impacts. Secondly, the proposed categorization highlights potential gaps in the literature and stimulates future research and the development of proper social impact indicators concerning variables such as UB and economic values.

Despite recent advancements in capturing human-nature relations in cities (e.g., Hernandez-Santin et al., 2023; Kowarik, 2023), research on the integration of ES into SIA procedures presents several shortcomings. Initially, ES' exact boundaries and attributes within various categories and descriptions still have ambiguities in covering services for each class. This lack of clarity and different translations of each unique ES led to difficulties in interpreting linked benefits and services. Furthermore, the current knowledge on SIA using specific regulating ES is very limited; in some cases, there is no reliable evidence. Within the performed systematic literature review, when defining the query of ES attributes, despite all the efforts to include the relevant literature, there might be the possibility of publication exclusion due to a lack of consensus on using standard wording or features. As this research topic is highly interdisciplinary and the literature is extensive, the scope of this research is mainly set on urban areas, considering the quantitative reduction in the number of outcomes at the screening step of the review. Further research and discussion in this field should prioritize developments in indicator quantifications and calculations, covering current shortcomings in the literature on ES and practices of applying such categories in a specific context. Finally, by emphasizing the role of UB and ES in SIA, our research shifts the focus from classical approaches to a novel perspective, positioning ES as an essential mediator in social-ecological evaluations in urban areas. Urban planners and policymakers can use these indicators to design and monitor NbS to align more closely with societal needs, enabling adaptive strategies for urban resilience. The general flow of this contribution and the highlight of the result, besides the contribution of planners and policymakers in SIA, are illustrated in Figure 7.

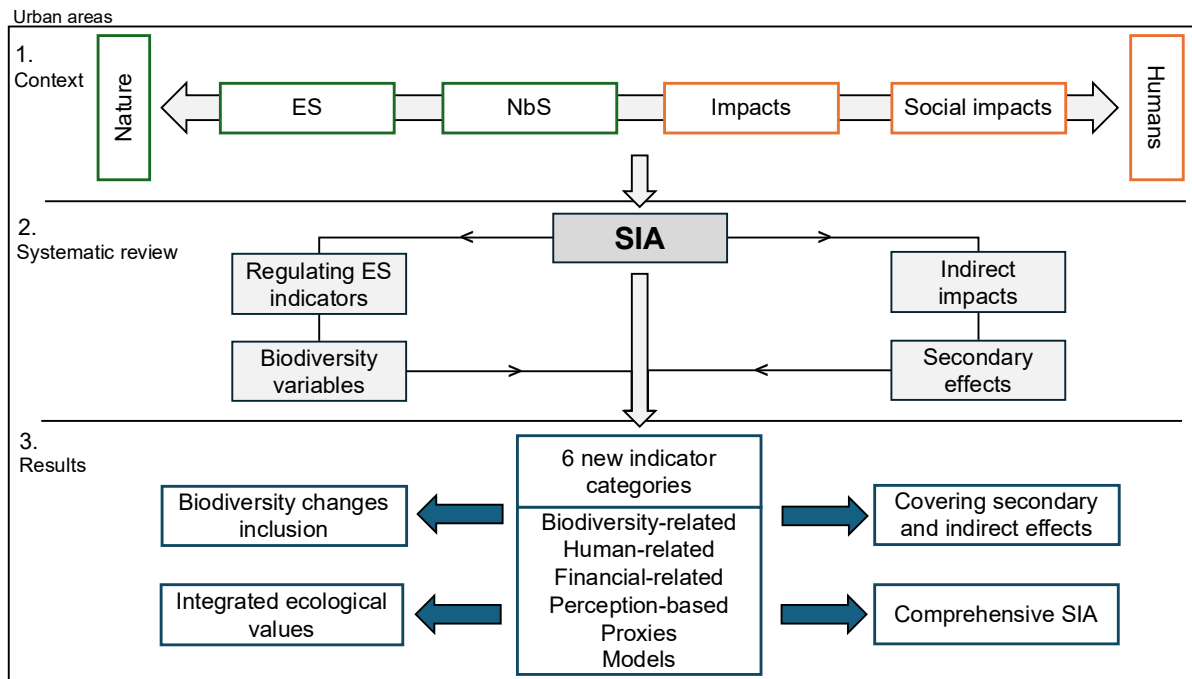


Figure 7: General procedure of the research for social impact assessment (SIA) of nature-based solutions (NbS) in urban areas using (regulating) ecosystem services (ES) indicators and emergence of biodiversity-related indicators as a new category alongside new categorizations of impact indicators.

2.5. Conclusions

The results of this study focus on the novel categorization of indicators extracted through a systematic literature review based on the social-ecological system's variables to conduct an SIA of NbS using regulating ES indicators in urban areas. The research scope primarily explores and refines UB indexing methods or parameters that can serve as indicators. The structured approach presented in this study addresses current gaps and lays a foundation for developing robust SIA methodologies that incorporate UB. Furthermore, during the elaboration, special attention was given to the coverage of the indicators and their ability to measure both direct and indirect social impacts. The reviewed papers represent a multidimensional and cross-sectional field of study. However, literature remains dominated by research on non-urban areas. We primarily conclude that using ES indicators and UB variables significantly improves the accuracy and coverage of SIA approaches in urban areas, based on compelling evidence. Secondly, we conclude that there is a gap and a lack of a systematic framework for integrating ES-based SIA indicators within the SIA of urban areas. This gap leads to reduced attention to monitoring the dynamics and trade-offs between human and natural systems. Although progress has been made in utilizing ES as a bridge to establish comprehensive indicators, shortcomings in reliable data and resources persist in certain groups of ES categories in both literature and practice.

Moreover, this review highlights a paradigm shift in the literature towards more dynamic and inclusive ES-based indicators for SIA. The review results reflect a tendency toward new categories of indicators, which, besides direct quantitative measurements, encompass indirect and qualitative measures across chains of actions and events. This study introduces six categories of indicators (human-based, biodiversity-related, proxies, financial-related, models, and perception-based) to support multidimensional social impact monitoring and evaluation. These proposed indicators represent a new perspective on integrating biodiversity into monitoring and anthropocentric measurements. The findings of this study are particularly relevant to planners and decision-makers involved in SIA, as they propose a structured process for identifying and using indicators related to urban ES. Utilizing this approach can enhance social monitoring and the evaluation of NbS in urban areas, emphasizing the role and value of biodiversity. Given these insights, we recommend further research into integrating ES and UB into SIA and identifying ES-based indicators, with particular attention to the complexities of social dynamics in urban areas.

Chapter 3.

Assessing the social impact of re-naturing in cities: case study of Milan, Italy⁴

Abstract

Urban areas are facing significant challenges due to the effects of climate change and biodiversity loss. In cities, as complex social-ecological systems, efforts to restore and preserve biodiversity are mainly focused on re-naturing measures. The re-naturing measures have a multifaceted impact on human-nature relations, which necessitate in-depth investigation and evaluation to optimize planning procedures. While quantitative large-scale measurements have enabled the study of human effects on nature, knowledge of nature's social impacts and its social values, especially at the local scale, remains limited and is still developing. To address this gap, by building on previous knowledge of framing social-ecological systems, a novel framework for enhanced coverage of human-nature interactions at the local scale is introduced to assist the process of social impact assessment (SIA) of re-naturing measures. The new framework suggests integrating ecosystem services (ES) and biodiversity variables into social-ecological systems. To operationalize this framework, during the SIA, collaborative methodologies and direct engagement with citizens and stakeholders are prioritized, in addition to utilizing ES in a collective procedure. By implementing the framework and methodology at a local urban park in Milan, the outcome presents a replicable framework reflecting social-ecological systems trade-offs at a local scale by using ES as a tool for evaluating the impact of re-naturing measures on human lives. This approach in SIA helps local aid decision-makers better optimize policies and interventions in relation to human needs and natural resources, and increase awareness among citizens and stakeholders.

3.1. Introduction

Climate change and biodiversity (BD) decay in urban areas significantly affect citizens' health, well-being, and the function of urban ecosystems from local to metropolitan scales (Marselle et al., 2021; McCarthy et al., 2010). In many cities, especially larger urban areas, ecological changes push socioeconomic or biophysical boundaries, resulting in tangible

⁴ This chapter is accompanied by a complementary publication as Supplementary Material 11.

Morello, E., Mahmoud, I., Lazzarini, L., & **Ayatollahi, A.** (2024). Co-creation for Urban Biodiversity: The experience of a public participation process in a living lab in Milan, Italy. Proceedings of the 60th ISOCARP World Planning Congress. <https://doi.org/10.47472/9EvnJGfC>.

consequences for health, safety, economic stability, and mobility (Hoornweg et al., 2016). Examples of these effects include extreme weather events, the temperature rise (Kumar, 2021), land use changes, and economic difficulties (Leong et al., 2018; Rega-Brodsky et al., 2022), and decreased life quality, encompassing both mental and physical well-being (Dean et al., 2011; Liekens et al., 2013). Beyond socioeconomic implications, biodiversity loss and the growing disconnection from nature affect citizens' cognitive and emotional aspects (Kronenberg et al., 2024). As dynamic and evolving landscapes, cities are uniquely fragile due to the tensions they embody between humans and natural systems. These conflicts underscore both tangible and intangible effects of climate change and BD loss on citizens' daily lives (Fuller & Irvine, 2010). Recognizing the co-evolution of cities and natural systems (Chapman et al., 2016), there is an urgent need for comprehensive, nature-based approaches to address these changes.

Efforts to mitigate climate change impacts and ecological challenges in cities have increasingly focused on restoring and preserving BD through re-naturing measures, especially nature-based solutions (NbS) (Díaz et al., 2015; EC, 2021; EC, 2015). Re-naturing is recognized as a critical and vital pathway for transitioning to nature-positive cities by integrating nature into built environments (Frantzeskaki et al., 2022). NbS provides a holistic approach to enable this transition (Sarabi et al., 2023). The effectiveness of re-naturing measures and NbS in cities has been widely debated among scholars and decision-makers, particularly regarding their ability to preserve BD (Connop et al., 2016; Rumble et al., 2019). While the ecological benefits of urban re-naturing are well-documented, its social impacts remain an evolving and critical area of ongoing discussion (Imperiale & Vanclay, 2024).

Social impact assessment (SIA) systematically identifies, monitors, and evaluates the social consequences of interventions within a specific, defined context (Burdge & Vanclay, 1996; Esteves et al., 2012). In the context of urban re-naturing, SIA is increasingly gaining attention for its potential to assess multi-dimensional human experiences in corporeal (physical), cognitive (perceptual), and affective (emotional) ways (Esteves et al., 2012; Vanclay, 2024). The SIA results aim to inform both governance systems and stakeholders, reflecting trade-offs between involved actors and enhancing communication between parties, ultimately reflecting stakeholders' needs. Despite advancements in SIA and urban re-naturing efforts, two major connected challenges hinder the adoption of a comprehensive approach. Primarily, SIA is still methodologically regarded as a top-down, expert-driven practice with limited focus on collaborative and collective values (Aledo-Tur & Domínguez-Gómez, 2017; Parsons, 2020; Vanclay, 2024). Secondly, most assessments prioritize nominal quantitative and monetized values, often overlooking cognitive and affective qualitative values and perceptions of nature's impact on humans (Cebrián-Piqueras et al., 2020; Raymond et al., 2017). These limitations are particularly pronounced

in urban areas, where most of the existing frameworks are designed for larger regional or metropolitan scales rather than localized or neighborhood-level contexts.

To address gaps in the SIA of re-naturing measures in cities, various frameworks have been proposed, each offering a unique perspective and approaches to the challenges and limitations identified. These frameworks aim to develop a collaborative, comprehensive, and multi-dimensional approach that values the impacts of biodiversity and nature on humans across all dimensions. Despite these developments, the conventional SIA framework and principles (H. A. Becker & Vanclay, 2003; Esteves et al., 2012; Vanclay, 2003) are still top-down, expert-driven, and lack the integration of the multifaceted contributions of biodiversity and nature to human lives, particularly at the urban scale (Aledo-Tur & Domínguez-Gómez, 2017). Recognizing societal challenges, the European Commission (EC) advocates for evaluating the effects of NbS across social, ecological, and economic dimensions in cities, with an emphasis on localized assessments (I. Andersson et al., 2023; EC, 2021). While the EC's report offers groundwork for SIA on the urban scale, a replicable framework that captures a wide range of impacts remains underdeveloped. Recent approaches, such as those proposed by the IPBES and Millennium Ecosystem Assessment (MEA) (Díaz et al., 2015; Millennium ecosystem assessment, 2005; Vadrot et al., 2018), offer comprehensive coverage and multiscale perspectives for evaluations. However, both frameworks have limitations when applied to urban contexts. The IPBES framework, for instance, still requires greater integration of social sciences and humanities (Vadrot et al., 2018). Meanwhile, the MEA conceptual framework prioritizes ecosystems and their services, representing a valuable link between nature and humans. Despite this strength, the MEA's focus on ecological aspects limits its practicality as an SIA framework explicitly tailored for urban and local scales.

It is worth noting that most reviewed frameworks provide practical tools, reports, or guidelines for policy-makers and decision-makers. A comprehensive SIA also has to communicate trade-offs and dynamics to the management systems and stakeholders to optimize the provision of services to both humans and nature. Based on previous studies and considering the challenges in SIA of re-naturing measures in urban areas, this research proposes a novel approach for covering SIA at the local urban scale. This new approach by using ecosystem services (ES)—benefits people obtain through ecosystems and natural processes that contribute directly or indirectly to sustaining their health and well-being (Liquete et al., 2016; Santos-Martín et al., 2013)—and the BD variable in assessment improves the SIA framework for urban re-naturing measures at the local scale.

Building on existing SIA frameworks and addressing their limitations—namely, top-down SIA methods, lack of public engagement, shortcomings in integrating nature values such as ES and BD in evaluation, and insufficient attention to local urban scales—this contribution, by focusing on human-nature relations, aims to provide a comprehensive

SIA approach to be applied at the local urban scale. The primary objective is to determine how ES and BD can be systematically integrated into the SIA of re-naturing measures in urban areas. Specifically, ES and BD variables serve as conceptual bridges between humans and nature, as well as analytical tools in the SIA procedure. To achieve this objective and overcome current shortcomings in SIA practices, bottom-up and collaborative methods are employed, including collaborative workshops, collective selection of ES benefits, and mapping of collective stakeholders, to explore qualitative values and reveal social values. The outcome presents a replicable framework that reflects social-ecological systems' trade-offs at a local scale, using ES as a tool for evaluating the impact of re-naturing measures on human lives. By aligning ES benefits to context-specific proposals, this approach aims to demonstrate the added value of using ES and BD variables in SIA for decision-makers. Finally, the proposed framework is applied and validated through analysis of the workshops' results in the SIA procedure for the regeneration of Sorelle Mirabal Garden in Milan, Italy, examining its applicability and limitations for planners, decision-makers, and stakeholders.

3.2. Conceptual framework

Cities function as complex social-ecological systems (SES), exhibiting daily trade-offs and interactions between humans and nature on multiple scales and sectors (McPhearson et al., 2016). On the social side, human population, governance systems, real estate, and economic aspects constitute the primary drivers. In contrast, on the ecological side, urban greenery, urban biodiversity, ecosystems, and, in general, nature are the main drivers of change (Elmqvist et al., 2004). In literature, it is well recognized that SES are complex, interrelated, nonlinear, and uncertain (Binder et al., 2013; Rounsevell et al., 2021). These traits are more intensified with the effects of climate change and biodiversity loss in cities. Given the multidimensional character of human–nature interactions and their cascading effects across sectors, SES are structured to (1) identify the key system elements, (2) map their interrelations and feedback, and (3) support the decision-making process. Such frameworks facilitate the SIA process and guide the procedure by tracking impacts and relationships throughout the system.

This study builds on the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework on human-nature relations (Díaz et al., 2015), which offers comprehensive coverage of interactions and flexibility across different scales. The IPBES framework identifies six key elements: nature, the benefits of nature to people, anthropogenic assets, institutions and governance systems, direct drivers of change, and a good quality of life. This framework distinguishes between the intrinsic, anthropocentric, instrumental, and relational values of nature, which is a key aspect in identifying values and trade-offs in SIA. Despite its advantages, as the IPBES framework is designed for the conceptual level, for SIA at the local urban scale, it is essential to use a

complementary SES framework that offers a structured and detailed focus on human-nature interactions. For the SIA of nature effect in urban areas, the SES framework primarily requires local interactions and, secondly, integrates nature, ES, and BD as elements of interaction in the framework in detail. Through attempts in SES framing (e.g., Allen et al., 2014; Gari et al., 2015; Ostrom, 2009), there is still a gap pressing for local-scale frameworks that explicitly cover ES and BD variables (Partelow, 2018).

Despite the advantages of the SES framework in coordination between social and environmental parameters, influencing variables such as biodiversity, economic parameters, and biophysical features are not directly considered. Under these circumstances, the SES framework necessitates variable adjustments to comprehensively encompass the multi-layered and complex connections between humans, nature, and the city. To address gaps in SES framing at the local scale for SIA, the proposed adapted framework aims to explicitly include ES, BD, and contextual variables, in contrast to classic impact assessment methods. The framework is an advancement relying on a multitiered analysis framework for SES and ES mapping (Grêt-Regamey et al., 2015; Ostrom, 2009) with the capability for monitoring and assessing the complexities of the urban context. The composition offers better integration of social dynamics and versatility in urban scales compared to other models in the literature (Binder et al., 2013).

The proposed framework aims to present a development of the nested framework for SES by Ostrom (2007) and Grêt-Regamey et al. (2015), within which the dynamics among variables are developed to a more interconnected stage with the explicit presence of ES and BD variables in the system. This analysis-based framework proposes equal attention to social and ecological aspects and scales (Anderies et al., 2004). Figure 8 outlines the overall proposed structure of assessment variables and values, providing details and descriptions of causal relations and procedures.

Urban ecosystems (UEs) are multilayered, interconnected systems where interactions between artificial, natural, and social-ecological variables (Babí Almenar et al., 2021) provide context for the living and well-being of users. To conduct SIA using ES on the urban scale, a broad spectrum of contextual attributes, ranging from natural to physical environments, is effectively engaged to shape actions and interactions (Colavitti et al., 2020). Conversely, the outcomes of interactions are multidimensional events that affect multiple variables in calculations. Consequently, the outcomes of the process change the city's economic landscape, benefiting (or even damaging) directly and indirectly, involving actors and stakeholders. Finally, connections and interactions between active components in each sequence might cause unique effects and outcomes, which are considered services or disservices for citizens (Pistón et al., 2022). The outcomes of these interactions affect not

only citizens' well-being (Tzoulas & James, 2004) but also the city's governance system, economic conditions, and socio-cultural characteristics (Ward & Winter, 2016).

Considering these premises, within the SES framework structure, variables are adjusted to align with the framework's purpose for SIA using ES. To achieve this objective, the original outcome variables remain unchanged, while the interaction variables are modified

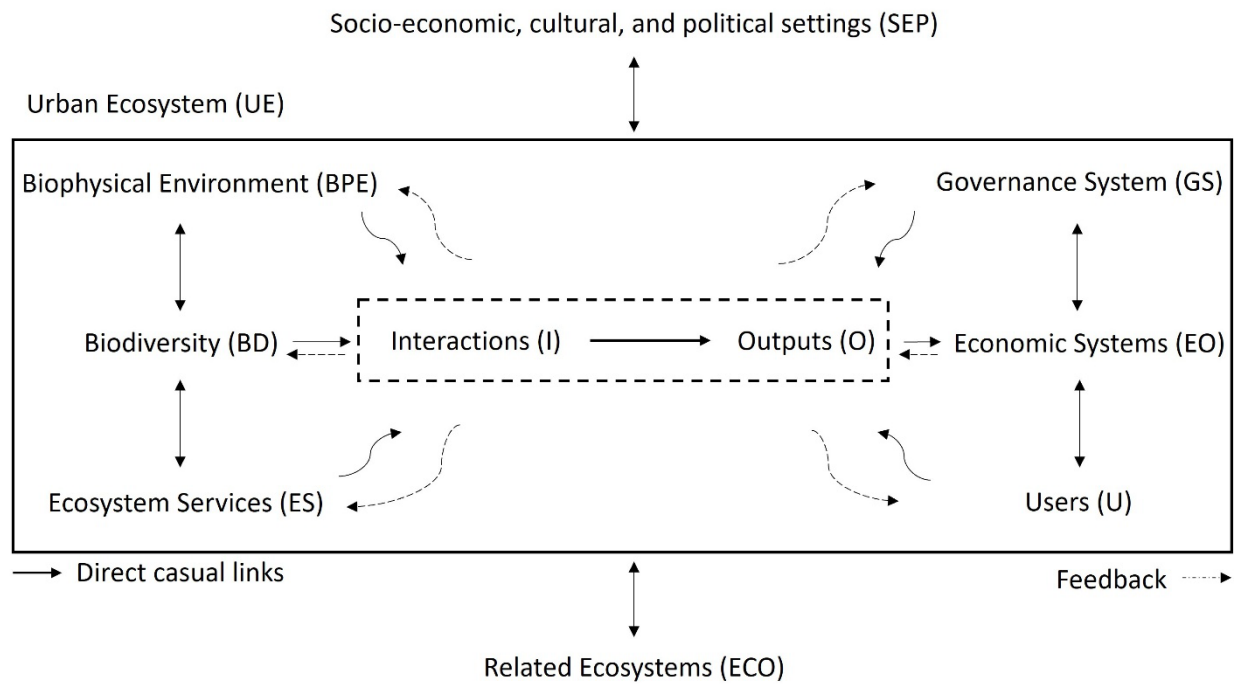


Figure 8: Repurposed social-ecological systems framework for SIA, elaborated from Grêt-Regamey et al. 2015 and Ostrom, 2009.

to fit the study's purpose. As a result, ES and BD indicators and factors correlate with the city's biophysical environment (BPE) (Liquete et al., 2016; Schwarz et al., 2017). The chain of actions among the above-mentioned variables in socio-economic, cultural, and political settings (SEP) (Cooper, 2013) forms interactions (I) and a series of outcomes (O). The outcomes, same as interactions, are multiscale and nonlinear, influencing users (U) (e.g., citizens and actors), governance systems (GS), and additional economic systems (EO). This process, alongside the primary outcomes, generates feedback for the continuation of further events and new effects.

The adapted SES framework identifies variables and their dynamics for monitoring, assessment, and evaluation processes. Naturally, economic and cultural effects and changes intertwine with social effects and impacts. The variables integrated into the new framework enable researchers to identify effects that, per se, are not social impacts but are nonetheless suitable for social impact evaluations. Widening the scope of consideration of indirect social impacts provides the flexibility required to address the complexities of social dynamics. Furthermore, biodiversity variables serve as linkages between ES and biophysical

environments. Applying BD indicators opens up the opportunity to incorporate nature into classic assessment methods.

3.3. Methodology

The established conceptual framework is applied for SIA through collaborative sessions at Sorelle Mirabal Garden in Milan, Italy. The park, which spans 17,900 square meters, is located in East Milan (Municipality 3), between the districts of Lambrate and Ortica, along via San Faustino. According to the municipality of Milan, as of 31/12/2024, this area has a population of 12592 residents, with an average age of 44 years, of which 17.9 are seniors (over 65 years old), which is 4.3 percent below Milan's average (Commune di Milano, 2026). The Municipality of Milan owns the area, which is currently closed to the public, with plans to reopen it after initial monitoring and co-creation sessions with citizens and stakeholders. The surrounding area comprises diverse land uses, with the western side primarily occupied by railyards. Private elderly houses neighbor the northern and southern sides. The eastern side is facing residential land use and development sites for new housing

projects. Figure 9 illustrates the location of the park in Milan, as well as notable surrounding features.



Figure 9: Aerial view of the location of the Sorelle Mirabal Garden, notable surrounding activities, and initial activities and areas considered for the reopening.

In this context and under the National Biodiversity Future Center (NBFC) research project in collaboration with the municipality of Milan, an urban biodiversity laboratory (Laboratorio per la Biodiversità Urbana (LABU)) was established. The initiative aims to establish a co-creation guidance and an *ad hoc* methodology specifically designed to preserve and enhance urban biodiversity, ultimately striving to research, raise awareness, and achieve a positive impact on nature. Within this structure, the SIA procedure, based on ES and BD variables, is designed to evaluate the impact of the re-naturing measure on citizens and provide a clear picture of stakeholder perceptions of nature and their desired re-naturing implementations at the park.

To conduct the SIA of re-naturing measures at the case study site, a series of open public workshops was organized (from May to September 2024), following an initial session with the municipality and decision-makers (May 2024), with invitations extended to nearby residents and actors (June 2024) and participants were resident volunteers from the neighborhood who signed up for the participation in the sessions with consideration a gender balance. The majority of participants were senior citizens, representing private actors or NGOs. In this case, their positionality toward specific topics of discussion was mediated in conversation with experts and moderators. The first workshop aimed to gather public opinion on the benefits of ES, the values of urban biodiversity, and the role of nature in urban areas through open discussion and gamification. This paper focuses on the methodology applied during the first workshop, using the benefits of ES as a tool for the SIA of re-naturing measures, facilitated through the gamification process.

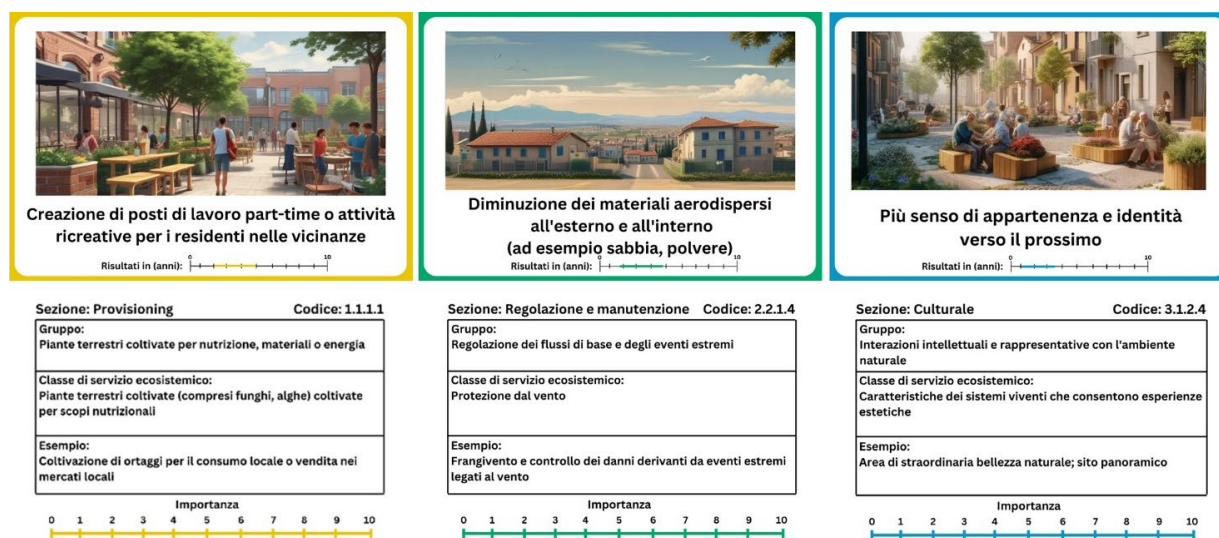


Figure 10: Sample of ES cards (front and back) in three categories from left to right of provisioning (in yellow), regulating (in green), and cultural (in blue) (credits: by the author).

As outlined in the introduction, people derive benefits from ecosystems and nature. In this study, ES are used as a tool to reflect the dynamics and trade-offs between humans and nature, across different classes of services (cultural benefits, regulating services, and provision of materials). Initially, to collect ES benefits, the Common International Classification of Ecosystem Services (CICES) (European Environmental Agency, 2018; Haines-Young & Potschin-Young, 2018) is adopted, and based on this classification, a systematic review of both scientific and grey literature is conducted. This review focused on extracting indicators, impacts, benefits, and measurement methods related to the social impact of re-naturing measures and biodiversity in urban areas. It emphasized the biotic classes of ES in all three categories: provisioning, regulation, and maintenance, as well as cultural services. Based on local observations and consultation with decision-makers and stakeholders, 29 benefits were selected from the literature, representing the three categories of ES, to be presented to the participants.

The selected benefits of ES were presented to participants during the first workshop in the form of 29 cards, which were designed and developed by the author. Figure 10 illustrates a sample of these cards from each category of ES benefits. To see the complete set of cards, see Supplementary Material 3. The front of each card features a description of the benefit, accompanied by an AI-generated image depicting its potential manifestation in the Italian context, based on the description extracted from the literature and the anticipated realization of the benefits in the years following the implementation of the re-naturing measure. On the back, the card provides related ES information and an example. During the workshop, the participants were divided into two groups of six people, each receiving a set of cards. They were given sufficient time to discuss and elaborate on the various benefits. Each group then presented its top five prioritized benefits and explained its rationale for each selection. The author analyzed the results from the workshops in collaboration with the research group (Politecnico di Milano advisory team), based on participants' feedback on the proposed questions during the co-creation process (using co-creation tools) and a synopsis transcription of the workshops.

3.4. Results

The social impact of nature and re-naturing measures in cities covers multiple aspects of human lives. While a stream of studies has followed the quantification of values to track social impacts (e.g., Davids et al., 2022; Ma & Yang, 2025; Ordóñez et al., 2023), this study presents a qualitative perspective on social impacts at the local scale. Pursuing a qualitative assessment of social impacts and values offers a broader coverage of social-ecological relations, presenting values and relations that cannot be quantified (Nilgen et al., 2024). This contribution presents the social impacts of nature and re-naturing measures in relation to urban biodiversity and ES, and showcases how these impacts and values take place in a broader frame for SES.

3.4.1. Urban biodiversity values

Definitions of urban biodiversity vary based on personal perspectives and contextual values, which are shaped by existing factors in urban areas. To establish a basic definition of urban biodiversity for the case study, workshop participants answered three questions regarding the definition of urban biodiversity, its benefits, and social values. To define a baseline, facilitators introduced a basic definition of urban biodiversity based on standard and agreed-upon definitions in the literature (Reid et al., 2005) and elaborated on the distinction between biodiversity and nature. In the next step, participants were asked to define urban biodiversity based on their own terms. The answers are divided into two general descriptive categories: urban biodiversity qualities and components, which highlight the dynamics of urban biodiversity linked to the daily experiences and interactions of citizens with the biophysical environment. The participants defined urban

biodiversity in qualities like “multiplicity of species”, “culturally distinct” and “unexpected animals” (animals crossing the neighborhood like foxes or wolves), “controlled wildness” and “compatibility”. Furthermore, participants introduced urban biodiversity components by local and invasive species (especially plants), “species with intrinsic values no matter what they do” and mentioned observation of animals like toads, foxes, hedgehogs, and green snakes around the neighborhood.



Figure 11: Selection and prioritization of the ES benefits card by participants during the collaborative activity.

The second question asked participants about the benefits of urban biodiversity for them. In this section, citizens reflected numerous answers reflecting multiple intrinsic and instrumental values and benefits with corporeal, cognitive, and affective dimensions. Responses like “connecting with nature”, “cultural growth”, “stress reduction”, “learning from nature”, “recognition of species for their usefulness (like rats or snakes)”, and visual aesthetics (flowers) reflect intrinsic values of biodiversity for citizens that have affective and emotional dimensions perceived by citizens from biodiversity. Meanwhile, benefits such as physical health, gene conservation, cultivation, conservation (including beekeeping), and water purification are mentioned as instrumental values with corporeal dimensions. The answers highlight the multifaceted benefits of urban biodiversity on the daily lives of citizens and how biodiversity generates social values that cannot be fully categorized through quantitative measurements.

In relation to the third question about added value co-creation processes to safeguard urban biodiversity, participants referred to educational and knowledge links. This question investigates human-nature relations with a shifted focus toward the human side. The answers primarily highlight the increase in knowledge and awareness, with an emphasis on previously unexplored natural values. Participants reflected on points like “recognition of species”, “education to respect nature”, “educating to the recognition of species, both those that produce benefits for humans and those that may pose a danger”, and raising awareness of the benefits on health and well-being. Additionally, participants reflect on the crucial role of food and habitat for species in urban areas and how species select relocation for optimized access to them, and how humans should react to these changes.

The responses to preliminary questions about urban biodiversity reveal the multiplicity of biodiversity social impacts in everyday lives at the local scale and strong support to sustain ES in cities. Beyond its intrinsic value to communities and citizens, urban biodiversity offers a natural cultural value, encompassing aesthetic significance, learning opportunities, and opportunities for bonding with nature. While urban biodiversity values can be quantified and presented through species measurement, social and cultural values present context-specific significance that cannot be quantified or presented in numerical terms. The qualitative social values of urban biodiversity require evaluation at the local scale in collaboration with citizens to fully present its impacts on society.

3.4.2. ES social benefits

Monitoring and evaluating social impacts and benefits of ES at the local scale has received much attention in recent years, and quantification of impacts using ES indicators through remote sensing data has shown considerable attention gain in recent years (e.g., Veerkamp et al., 2024). Despite the advancements in quantification, social values and impacts of ES cover a broader range than numerical evaluations. In this section, results from the collective process involving participants using ES cards, as presented in the methodology section, are elaborated.

To establish a basic definition of ES, participants were introduced to the basic definition of ES and three categorizations of provision, regulating, and cultural, with examples of services for each category. After being divided into two groups, five participants were asked to discuss, select, and prioritize their top five co-benefits of urban biodiversity from ES benefits cards within a given time frame. Figure 11 represents the selection of the cards by participants during the collaborative activity. The selected ES benefits reflect citizens’ priorities for the future of Mirabal Garden and preferred

interventions for improvements. Figure 12 presents the synthesis of top ES benefits and their corresponding ES, and the categories selected by participants.

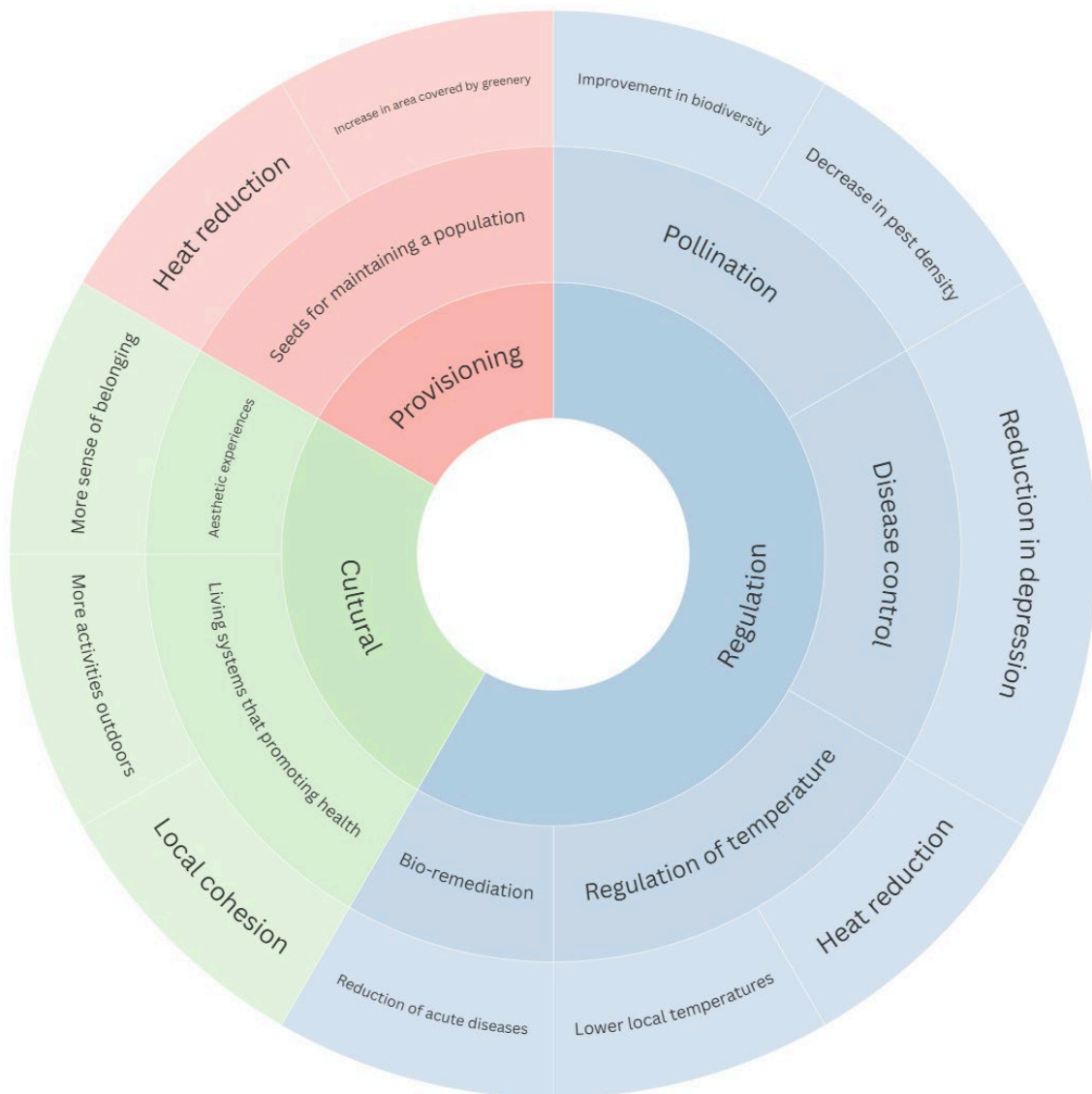


Figure 12: Relations synthesis between selected ES benefits and ES categories selected by participants. From inner circle to outer circle in order are ES section, class, and ES benefits selected

Group one has selected the following benefits in order of preference: 1. Increase in area covered by greenery and heat reduction, 2. Improvement in biodiversity and better habitats for plants and pollinators, 3. More interaction between neighbors, local cohesion, and identity, 4. Reduction of acute diseases and health risks for residents, 5. Reduction in depression and anxiety disorders. Additionally, group one presents their sixth preference as 6. Lower local temperatures in hot seasons and during heat waves. Group two presented their preferences in the order of 1. Increase in area covered by greenery and heat reduction, 2. Reduction in depression and anxiety disorders, 3. Lower local temperatures in hot seasons and during heatwaves 4. Decrease in pest density and better landscape aesthetic, 5.

More sense of belonging and identity to the neighbor and 6. Opportunities for more outdoor activities in nature.

The outcomes of ES benefits cards reveal how contextual values are shaped in response to local challenges and what participants anticipate from re-naturing measures in local parks and green areas. Selections, like an increase in green area coverage for heat reduction, and lower local temperatures during hot seasons, represent local concerns about temperature rise and demand for regulating ES in the neighborhood. Similarly, the selection of benefits related to pest and disease control ES guides decision-makers to implement re-naturing measures that avoid an increase in pest population or less allergic species. In parallel, the emphasis on cultural ES, with benefits such as reduced stress, aesthetic values, and increased cohesion and sense of identity, highlights the value of green spaces as an essential component in planning. Re-naturing measures with a focus on space creation for citizens not only invite more visitors to green areas but also provide a context for communication and enjoyment for users. For example, in a neighborhood with a higher elderly population, green areas can provide a relaxing space and an opportunity for social interaction. Selected cultural ES benefits present a synergy with an emphasis on participants learning from nature and biodiversity at earlier stages. ES, like living systems that enable education and training, and living systems that enable scientific investigation, or the creation of traditional ecological knowledge, were both selected directly by citizens and indirectly mentioned through discussion. Providing a green space to communicate with both humans and nature, and learning from the surrounding area, is a major expectation in this case study.

3.4.3. SES interactions and benefits

The results from the collaborative sessions with citizens and stakeholders confirm proposed interactions among variables at the SES framework and the crucial role of ES and biodiversity in such systems. Mirabal Garden has substantial value for residents as a place for interaction, enjoyment, and learning (as part of cultural ES). Selected ES by citizens and stakeholders for re-naturing measures provides the opportunity to shape the direction of improvements in environmental quality. The current direction of improvements through re-naturing measures is toward responding to social and cultural challenges. The improvements resulting from re-naturing measures are directly impacting users' (citizens) welfare and consequently improving coordination with the governance system and welfare status on the neighborhood scale.

For example, high temperatures and a lack of space for interactions were two challenges that citizens addressed directly and indirectly during the sessions. Implementing NbS that can provide shelter from the heat and offer a calm space for interaction with neighbors is a priority in the future plans of decision-makers. Another selected ES is focused on pollination. NbS, such as placing an insect hotel for pollinators,

can improve the biodiversity status and function of related ecosystem services at the neighborhood scale. This improvement directly affects the mental and physical health of users and enhances the quality of the biophysical environment, ultimately leading to better economic status in the long term. In general, selected benefits and ES classes help planners and decision-makers match the needs and desires of citizens with current challenges and propose tailored re-naturing measures. ES in this can guide the focus of implementation to enhance measurement of impact and match challenges to solutions in consultation with residents. Implementing re-naturing measures based on local challenges and users' preferences helps to increase governance system efficiency and better target challenges at the neighborhood level.

3.4.4. Mapping actors and stakeholders at the local scale

In contrast to conventional SIA approaches that follow an expert-oriented, top-down approach, the collaborative methodology employs a bottom-up approach, involving the engagement of stakeholders and decision-makers. In a collaborative methodology, besides consultation with experts, citizens and stakeholders play a crucial role in addressing values or impacts that cannot be monetized or quantified in numbers. In addition to the initial mapping of stakeholders, participants were asked to mention potential actors or interested parties in monitoring and reopening Mirabal Garden. Through this activity, 33 potential actors were identified in six categories: public, private, administrative, non-profit organizations (NGOs), local communities, and research institutions. From the suggested actors, nine fall into the private category, consisting of experts in the field, and seven consist of communities that are active on the local scale. The division of suggested actors by participants for engagement is illustrated in Figure 13. The diversity of suggested actors at the local scale suggests that the dynamics in SES impact a wide range of actors, characterized by the multiplicity of values and interests. The results indicate that SIA cannot be limited to experts' knowledge and requires the integration of contextual parameters for consideration. Previous studies (e.g., Mahmoud et al., 2021; Schröter et al., 2023) proved that co-creation approaches lead to activation of local communities, while current results extend the implications of co-creation for engaging actors in navigating through monitoring and assessment processes at the local scale.

3.5. Discussion

Through this contribution within a repurposed framework for SES, a new approach to SIA of re-naturing at the local urban scale is studied by utilizing ES and BD social values. Initially, within defined SES frameworks and by addressing existing gaps, a local-scale framework is introduced that addresses the multiplicity of human-nature relations in SIA. The new SES framework enables decision-makers and planners to map and analyze the various impacts of re-naturing across multiple dimensions at the local scale, thereby avoiding the pitfalls of generalization or oversimplification. Secondly, this study suggests integrating BD and ES social values and variables into SIA procedures. To facilitate communication between citizens and planners for capturing the multifaceted effects of nature on humans, it is necessary to consider the role of nature in assessments. Thirdly, within a local case study, the novelty and added value of using a repurposed SES with integration of BD and ES variables is showcased. While SIA at the local scale, using qualitative approaches, might face limitations, such as a lack of participation or communication barriers throughout the procedure, it offers an in-depth perspective on social values and human-nature relations.

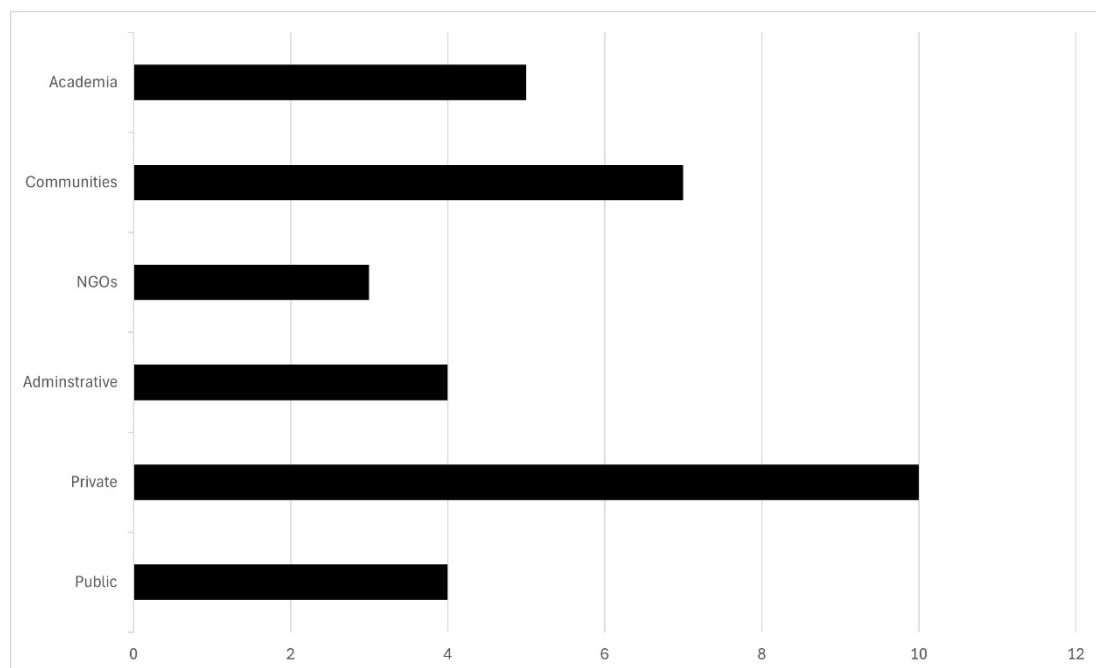


Figure 13: Division of actors based on their areas of activity, based on participants' suggestions during the workshop.

3.5.1. SIA at the local scale and limitations

This study qualitatively evaluated the social impact of re-naturing interventions at a small local park based on analyzing social-ecological dynamics by using ES. In contrast to classic perspectives on SIA, this research process is based on a collaborative approach involving

citizens and stakeholders. Classic approaches to SIA focus on linear, expert-based, and top-down evaluations, or the projection of social impact through the use of checklists during the process (Imperiale & Vanclay, 2024). To address social complexities and cover the multiplicity of social values, later developments focus on the constructivist paradigm as a bottom-up, context-dependent, socially construct approach to SIA (Aledo-Tur & Domínguez-Gómez, 2017). The constructivist paradigm in SIA involves stakeholders in the assessment process to offer a broader range of perspectives and values in evaluations.

This research, following a constructivist perspective, offers a replicable methodology for SIA of re-naturing measures specified at the local urban scale. This procedure requires uncovering social values and tracking changes in expectations and perceptions over time, following interventions or changes. An extensive coverage of perceptions and values requires tools beyond quantification by generic indicators or remote-sensing mapping. A qualitative SIA at the local scale is primarily dependent on the participation and collaboration of local actors with stakeholders (Moreira et al., 2024). Consequently, local participation is limited for SIA. Through this case study, despite public announcements and invitations, public participation was limited to actors related to NGOs and local senior citizens with a special interest in the Mirabal garden. Lack of participation results in a lack of diversity in perspectives and inputs, which might lead to limited or biased information about the study area. To address this limitation, it is necessary to invite and interact with local actors actively and to lay out a concrete plan for ongoing communication with all involved actors and stakeholders throughout the assessment process.

3.5.2. SES dynamics and urban biodiversity

In this contribution, the adaptation of a repurposed SES framework for monitoring and the SIA of re-naturing measures was proposed, based on ES indicators and emphasizing the role of biodiversity. While various impact assessment methods exist, the field of SIA is still evolving and lacks a clear structure for providing a comprehensive understanding of the social impacts of re-naturing in urban areas. Within this scope, this contribution builds upon previous studies. Firstly, it advances the SES framing by integrating values of nature and biodiversity, as well as changes in economic systems, as outcome variables. Unlike Grêt-Regamey et al. (2015), the proposed framework directly incorporates biophysical and biodiversity variables in the assessment and evaluation processes. This approach unifies perspectives from both SIA and environmental impact assessment, offering a multidimensional framework that addresses areas that, despite their significance, are currently overlooked in existing assessment models.

Secondly, integrating ES into the identification of SIA methods introduces new categories of indicators for more advanced assessment (Remme et al., 2024). As an extension of traditional methods (Karami et al., 2017; Olander et al., 2018), these categories

provide a more resilient and comprehensive perspective on social impacts, especially on the indirect and qualitative values generated by re-naturing interventions. By extensively covering social complexities and incorporating secondary or indirect outcomes of interventions, this approach significantly enhances the value of this contribution. Thirdly, the representation of a common framework for connections between new categories of ES indicators and SES framework variables in urban areas is a step forward from current knowledge, covering the gap in SIA procedures. Despite emphasizing the need for proper indicators, previous studies (Fielding et al., 2023; Rosa & Sánchez, 2016; Vihervaara et al., 2018) confirm that implementing ES and valuing biodiversity and biophysical features in assessments improves coverage and procedure. Furthermore, as a continuation based on literature, the constructed connections from ES to indicators and the SES framework represented in Figure 8 render the form of an anthropocentric multiple value system (Aledo-Tur & Domínguez-Gómez, 2017; Binder et al., 2013) that integrates biodiversity and indirect values as new perspectives in SIA procedures. In summary, this contribution expands the discussion on valuing biodiversity and biophysical features in SIA through the use of ES indicators. The suggested framework, which utilizes ES, also provides a replicable methodology for SIA, aiding decision-makers in monitoring and policy-making. Future studies in SIA at the local scale require integrating local values and variables in evaluations and avoiding oversimplification of values and human-nature relations.

3.6. Conclusions

Assessing the social impact of re-naturing measures at the local urban scale is still an evolving procedure, as human-nature relations in urban areas entail a wide range of interactions and values in multiple dimensions. This contribution, using ES through an adapted SES framework, introduces a novel approach for SIA on a local urban scale. In contrast to classic SIA approaches, the current methodology emphasizes local engagement, the use of ES benefits, and qualitative inputs to uncover the social values of citizens. The SIA approach is tested at a local urban park in collaboration with the municipality and citizens to gather perceptions about nature and biodiversity. To facilitate the data gathering and assessment process, multiple methods are employed, including the use of ES benefit cards and stakeholder mapping, as well as direct conversations. The results demonstrate how the integration of ES and BD social values can enhance the assessment process. Within this study, the use of qualitative information, which is often overlooked in mainstream SIA approaches, proves to reveal practical insights that aid decision-makers and planners, thereby enhancing their understanding. The research and assessment led to a synthesis between ES, ES benefits, and the relationship between actors and stakeholders, based on citizens' perceptions and opinions. A clear application of ES and nature values in the assessment of social values, through citizen engagement, yields a low-cost, replicable approach for assessors and planners to identify social values more effectively.

Chapter 4.

Co-evaluating social benefits of urban biodiversity: a case study of the Botanical Gardens of Utrecht University, the Netherlands⁵

Abstract

Green spaces, as a critical part of urban infrastructure, provide a wide range of social, cultural, and economic benefits through ecosystem services to humans. Human-nature relations and social values created by nature at the urban scale are unique to each context, and therefore, for a concise planning approach, it is essential to fully grasp the benefits through local social values. By addressing the gaps in the literature, this research aims to develop and apply an engaging, adaptable, and replicable monitoring methodology that focuses on co-evaluation, building upon experiential narratives of the social benefits of urban nature. Focusing on a local case study of Utrecht University Botanical Gardens, and relying on transdisciplinary methods such as public workshops, semi-structured interviews, and gamified ecosystem services benefits selection, this research emphasizes a co-evaluation that builds on experiential narratives of the social benefits of urban nature and biodiversity. The results initially identify narratives of urban biodiversity explicating how and what people recognize as urban biodiversity in the Botanical Gardens and the related social values using ES benefits. Secondly, alongside narratives, the social benefits of nature and biodiversity are explored through the benefits selected by participants, which indicate the perception of visitors and locals about the place. Ultimately, the results of co-evaluation are reflected in direct recommendations for improving the Botanical Gardens. This proposed methodology, as a replicable and engaging approach, provides a participatory framework that bridges the gap between ecological metrics and local social values when evaluating the recognized and perceived social-ecological benefits of urban nature.

4.1. Introduction

Green spaces in urban areas are a critical part of urban infrastructure as hotspots for biodiversity preservation (Wang et al., 2024). Biodiversity, as an intrinsically valued part of nature (Morrow, 2024), provides direct and indirect benefits for human well-being, especially in densely populated urban areas (Gong et al., 2024). Beyond ecological functions, urban greenery provides benefits to citizens recognized as ecosystem services (ES) - benefits people obtain through ecosystems and

⁵ This chapter (citation below) is published in the journal *Urban Forestry & Urban Greening* in February 2026.

Asef Ayatollahi, Niki Frantzeskaki, Eugenio Morello, Co-evaluating the social benefits of urban biodiversity: A case study of the Botanical Gardens at Utrecht University, the Netherlands, *Urban Forestry & Urban Greening*, Volume 116, 2026, 129236, ISSN 1618-8667, <https://doi.org/10.1016/j.ufug.2025.129236>.

their natural processes that contribute directly and indirectly to sustaining their health and well-being (Liquete et al., 2016; Santos-Martín et al., 2013). The social benefits of (being in, with) nature encompass the non-material benefits and meanings that people derive from nature and natural elements, which improve overall life quality and well-being, including cultural, spiritual, aesthetic, recreational, and sense-of-place values. These benefits are not only limited to tangible effects with direct utility for humans, such as cooling or food provision, but also include broader cultural benefits (Jabbar et al., 2022). The cultural benefits of nature in cities encompass individual and communal benefits, including a sense of belonging and identity, aesthetic experiences, and immersion (Haines-Young & Potschin-Young, 2018; Smith et al., 2017). Cultural benefits are integral components of a broader spectrum of nature's contributions to people, shaping social values and encompassing both tangible and intangible aspects of human well-being (Díaz et al., 2018; Keniger et al., 2013). In this research, social values of nature are defined as meaningful relationships and shared principles that communities and individuals have with the natural environment and elements (Pascual et al., 2023). These values are often shaped by the social benefits of nature and contextual elements that influence our perception of these benefits. Social values represent how nature is experienced and appraised within society. The recognition of social impacts nature—measurable changes in humans' relation and physical and mental well-being from exposure to and interaction with the natural environment—remains underrepresented, especially in urban planning and policy, while traditional evaluation methods often fall short in accounting for the full spectrum of social values at the local level.

To grasp the extent of nature's social benefits and to design interventions and urban plans to realize them, it is essential to systematically evaluate nature's social values (Pascual et al., 2023). In this research, the emphasis is on co-evaluating social values related to nature at the local urban scale. While there is no universally established definition of co-evaluation, it can be defined as a place-specific approach to integrating the participation of actors (participants involved in the co-evaluation process, such as visitors, residents, stakeholders, and other relevant groups throughout the evaluation process. This process spans from data collection to analysis and evaluation, intending to inform the design of interventions or policies. Such interventions aim to enable and stimulate the delivery of social (co-)benefits of urban biodiversity and nature-based solutions (NbS). The co-benefits of nature are understood as secondary or complementary—and, in some cases, side-effects—positive outcomes of re-naturing measures in urban areas and beyond (Matsiliza, 2012; van der Jagt et al., 2023).

Human-nature relations and the related social values created by nature at the urban scale are unique to each context and vary based on local attributes such as ecological memory, ecological literacy, and history of place (Soga & Gaston, 2020). Environmental, spatial, social, and biophysical factors influence how residents and actors experience and prioritize nature's benefits (Thiemann et al., 2022), highlighting the need for context-sensitive evaluation methods. Consequently, evaluating the social benefits of nature at the local urban scale requires a comprehensive yet replicable and flexible methodology that adapts to contextual differences

(Raymond et al., 2017). Additionally, at a local scale, values and perceptions of benefits are shaped by citizens and various actors, including non-citizens such as tourists and visitors who may temporarily use urban green spaces as destinations, during short stays or single visits (Nóblega-Carriquiry et al., 2023). Consequently, their engagement in the evaluation process is fundamental.

To evaluate social benefits, a methodology that uncovers the social values of nature is required to be comprehensive in capturing diverse social values, replicable to ensure applicability across diverse case studies, and engaging in terms of involving local actors and stakeholders in the evaluation process to include local experiences. Such a methodology requires moving beyond mono-dimensional evaluations, such as monetary calculations, to reveal the multifaceted social values embedded in local contexts through a collaborative approach. It also requires sensitivity to contextual differences, including spatial dimensions—such as existing environmental elements, the history of area development, and future orientations—as well as users' characteristics, since expectations and experiences may vary according to demographic, cultural, economic, and educational factors.

Quantitative methodologies cover the evaluation of social benefits through a wide range of approaches, like remote sensing and performance analysis of ES (e.g., de Araujo Barbosa et al., 2015; Gai et al., 2022), monetary evaluations and cost-benefits analysis (Bekoe et al., 2021; Wegner & Pascual, 2011), or analysis of geospatial information (LaReaux & Watkins, 2025). Due to the diversity in evaluation methods and availability of implementable data, quantitative evaluations are regarded as replicable methodologies. In contrast, as a top-down type of methodology, quantitative evaluations have shortcomings in engaging local actors and stakeholders (Haase et al., 2014; Ma & Yang, 2025). Additionally, without the engagement of local actors and identifying local values, quantitative measurements fail to address the full spectrum of social values and consequently have shortcomings in their evaluation (Sharifi et al., 2021). In response to these shortcomings, hybrid methods (a combination of quantitative and qualitative ones) offer a flexible approach to engaging local communities, while complementary data is gathered through quantitative evaluations. The primary challenge of implementing hybrid methodologies is their inflexibility for replication. Hybrid approaches require both local participants and integration of data with possible quantitative data, which adds an additional layer of complexity in evaluations.

Using qualitative methods for evaluation at the local scale offers both advantages and disadvantages in comparison to conventional methods. Primarily, qualitative approaches offer more flexibility in the engagement of actors and stakeholders in the process of evaluation (Chrisman et al., 2002) and are less dependent on the availability of data or data sources for each specific case study (McCormack et al., 2010). Qualitative evaluations are more replicable compared to other evaluation methods at the local scale due to the simplicity of the applied methods used (such as interviews and surveys) and the versatility of the method to acquire data for evaluation. Despite the advantages, as qualitative methods are built upon descriptive data and

vary by contextual attributes, they require concrete interpretation and narratives (Herranz-Pascual et al., 2023; van der Jagt et al., 2023). The literature on qualitative methodologies for evaluating the social benefits of local urban NbS that are at once comprehensive, replicable, and engaging remains limited (Mahmoud et al., 2021).

Additionally, social impact evaluation at local or neighborhood scales in urban areas is dependent on multiple contextual and social-ecological variables (Vanclay, 2024). Values, norms, and perceptions often differ in each context of study based on parameters shaped by social, economic, and cultural status (Soma et al., 2018). Social differences across contexts lead to distinct perceptions and interpretations of ecological effects on human lives. Several studies have investigated a methodology for evaluation at the local scale through quantitative approaches, yet challenges like coverage of social-ecological dynamics remain as topics of discussion (Ribeiro-Rodrigues & Bortoleto, 2024).

Top-down and quantitative approaches show shortcomings in reflecting these social values at a local scale (Sterling et al., 2017) and fail to involve actors and stakeholders in the evaluation process adequately. Another shortcoming in monetary interpretations is the mono-dimensionality in reflecting the benefits and, consequently, the lack of comprehensive coverage of social values (Menezes da Silva et al., 2023). As a result, moving beyond monetary evaluations at smaller scales seems necessary. At the local scale, bottom-up approaches are efficient in terms of stakeholder involvement and coverage in evaluation (Kati & Jari, 2016), thereby considering social values. The challenge in collaborative evaluation mainly lies in reconciling diverse perspectives and rigorously interpreting heterogeneous data beyond monetary evaluations. Figure 14 summarizes the dimensions and attributes of a co-evaluation approach at the local scale. By addressing knowledge-to-practice gaps and, in contrast to traditional methodologies, co-evaluation explicitly integrates social values and stakeholders' priorities into the assessment process, which is essential to the scope of this research. This research seeks to answer the question of how the social benefits of biodiversity in urban areas can be evaluated through a co-evaluation process that involves actors and citizens in general. This research aims to develop and apply an adaptable, replicable monitoring methodology that focuses on co-evaluation, building on experiential narratives of the social benefits of urban nature. This research engages citizens through workshops and interviews to create experiential narratives capturing local social values of nature. These narratives are then linked to social benefits of nature and biodiversity via a gamified ES benefits selection or targeted interview questions, illustrating how local values shape these benefits. Finally, based on these insights and participant consultation, tailored recommendations are developed to enhance human-nature interactions. This methodology provides an in-depth view of social values by engaging citizens throughout the evaluation process.

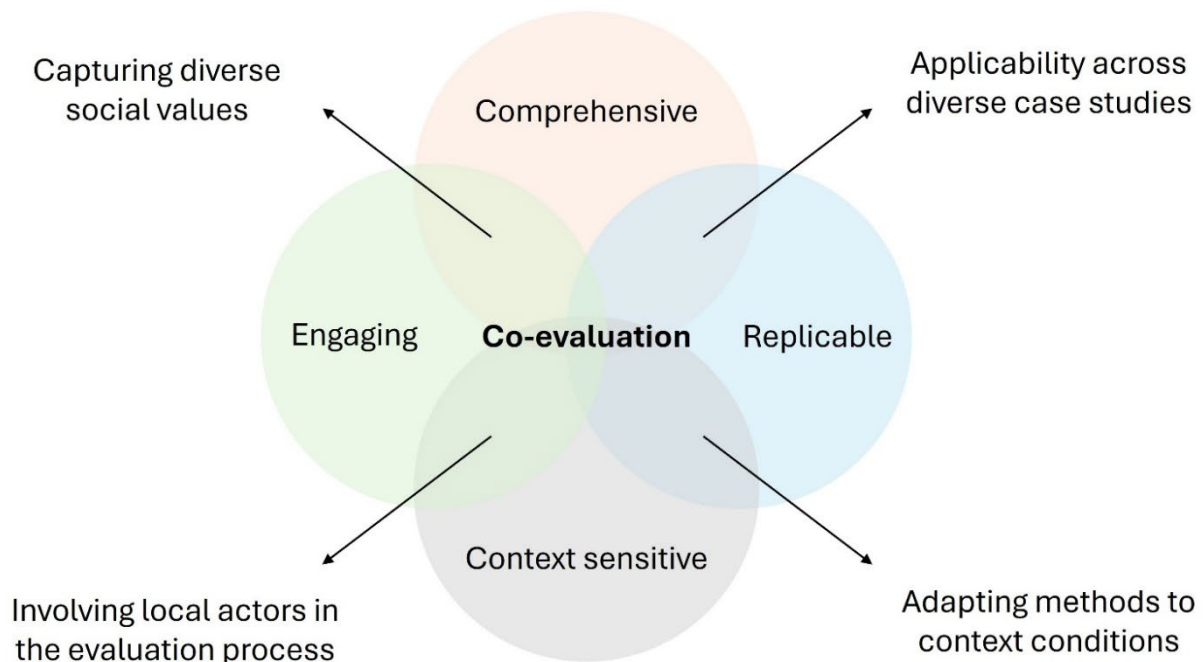


Figure 14: Dimensions and attributes of social benefits co-evaluation of urban nature and biodiversity at the local scale.

4.2. Methodology

4.2.1. Case study

We explore this research question with a case study of Utrecht University’s Botanical Gardens, in the Netherlands. The Utrecht University Botanical Gardens are situated southeast of Utrecht, within the Science Park, along the eastern green corridor of the town. Figure 15 illustrates an aerial image of the location of the Botanical Gardens in Utrecht. Organized by Utrecht University, the botanical gardens span 100,000 square meters and comprise nine thematic gardens that focus on immersive storytelling and the discovery of various species. The gardens feature free walking paths and open spaces equipped with benches and seating areas. Public entry to the Botanical Gardens is limited to a ten-euro fee, with discounted prices available for youths, the elderly, and holders of municipal or institutional passes. The entries to the garden consist of one main entry at the west of the Gardens and controlled entries for affiliated users at the north and east. Entry to the Gardens is free for affiliates of institutions located at Utrecht Science Park. Botanical Gardens are open from March to November, every day from morning to evening, with a winter closure. As a functional, in-use urban green space, this evaluation views the Botanical Gardens as a case of co-evaluation focusing on the results of having urban greenery and biodiversity for society.

The Botanical Gardens, due to their location at Utrecht Science Park and their established role in species preservation, education, and research, assume distinct meanings and functions for visitors. The Botanical Gardens are multifunctional places that are viewed as spaces for learning and education, restoration and health enhancement, and social interaction and community connection. The specific value of Botanical Gardens as a case study for co-evaluation lies in its social and ecological multifunctionality, as well as the specific nexus between humans and nature. While the Botanical Gardens support learning and education by providing a diverse range of species, they also offer a biodiverse and distinct context for public interaction. The interactions between humans and nature in such a unique context, with opportunities for social benefits, make this case study suitable for investigating the social benefits of urban nature.



Figure 15: Aerial view of the Utrecht University Botanical Gardens location at Utrecht Science Park.

4.2.2. Collaborative activities and observation methodologies

Semi-structured interviews: Twelve semi-structured interviews were conducted during visiting time frames of botanical gardens, working days, and weekends between September and November 2024. The interviewees were selected using purposeful quota sampling from different age groups and genders among visitors to the Botanical Gardens. Quotas were set for broad age categories (younger adults, middle-aged adults, and older adults) and both genders, based on approximate visual assessment, with participants randomly recruited in the field to fill these

quotas and minimize selection bias. Interviews were conducted in English and lasted an average of 7 to 12 minutes, on different days and at various times (weekdays and weekends, mornings and evenings) to capture a diverse range of visitor profiles. Five open questions were asked to each interviewee on three general themes of defining values of urban biodiversity and nature, the benefits of biodiversity on human lives, and ultimately, values and suggestions about improving the Botanical Gardens. Figure 16 illustrates the structure of the questions used with the interviewees. Details on interview themes are available in Supplementary Material 4.

1. How do you define urban biodiversity? What comes to your mind? (open-ended response, responses will be categorized during the analysis)
2. What is the value of urban biodiversity to you?
 - 2.1. Why is it important to you, and how does it impact your daily life? (open-ended response, responses will be categorized during the analysis)
3. What are the benefits of urban biodiversity in your life? (open-ended response, responses will be matched and categorized during the analysis)
 - 3.1. Are there any drawbacks or disadvantages in your daily life? (open-ended response, responses will be matched and categorized during the analysis)
4. What does it mean to you to be in the Botanical Gardens? (open-ended response, responses will be categorized during the analysis)
 - 4.1. How do you describe your visiting experiences and feelings when in this place? (open-ended response, responses will be matched and categorized during the analysis)
5. Do you have any suggestions for improving the Botanical Gardens? (open-ended response, responses will be matched and categorized during the analysis)

Figure 16: Structure of the questionnaire for interviews at the case study.

Field observations: In parallel to semi-structured interviews and collaborative sessions, direct user observations for a total of 50 hours (30 hours during weekends (morning to afternoon) and 20 hours during the week (mornings, noon, and afternoons)) took place during the working hours of the botanical Gardens between September 2024 and February 2025 to capture visitors' behaviors and differences through different time frames.

Observation points were selected to represent key zones of ecological and social interest (such as hotspots of Botanical gardens with high user density, high-biodiversity areas, resting zones, and frequent pathways). Key elements included visitors' use of space (routes and stop points), engagement with natural and biodiversity features (such as plant species, water features, and animal sightings), social interactions (group dynamics, solitary reflection), and physical activities (resting, walking, educational participation). The observer also looked for indicators of emotional responses, such as relaxation or curiosity, manifested through body language or sustained attention to specific natural elements.

Through observations, the observer recorded the following variables:

- **Visitor activities:** Visitors were observed in a variety of activities, including walking through pathways, resting on benches and accessible grassy areas, photographing landscapes and species, studying and learning about species, social interactions in groups with companions, and discovering new species (mainly sighting small-sized fauna species). Movement patterns were observed to discover preferred routes and hotspots, and the output was compared with the layout of the Botanical Gardens. Most visitors preferred

short-distance walks in accessible and designated pathways around the open grassy areas and water features. Visitors selected their resting places mostly in sports with landscape views or within areas with dense natural elements.

- **Interactions with nature and biodiversity:** The observer documented interactions with biodiversity elements, including observing species (such as exotic and native plants, birds, lizards, and insects), touching or smelling flora, and noting behavioral responses towards fauna. Engagements ranged from passive observation (such as watching butterflies or bees) to more active participation (photographing species or touching flora species around designated pathways). The observation revealed that biodiversity presence not only motivated curiosity and emotional responses but also served as focal points for environmental learning and restorative experiences. These interactions aligned with ES benefits described by collaborative sessions participants and interviewees, such as mental well-being, spiritual fulfilment, relaxation, and learning.
- **Environmental and spatial context:** The spatial setting of interactions was recorded, including vegetation structure (e.g., green coverage and density, canopy cover), and sensory elements such as soundscapes dominated by bird calls, water features, or human-sourced elements. Such contextual factors enriched the understanding of how natural elements, environmental complexity, and design, alongside surrounding elements, influence and impact visitor behavior and experience. The observer also noted how human-made features, such as the placement of informational panels, seating arrangements, and accessibility pathways, impacted the flow and interaction of visitors. In most observations, visitors with natural elements were accompanied by an informative panel or clear boundaries. Most visitors preferred to use pathways and green areas that are far from the noise sources, such as the sports complex on the northern edge and the street on the southern edge.
- **Behavioral cues:** Observer followed non-verbal cues indicating visitor engagement, including focused attention on flora and fauna species, body language reflecting relaxation (e.g., slow walking, sitting quietly), and expressions of curiosity such as pointing, questioning companions, or prolonged observation or photographing. Behavioral indicators, such as photographing or note-taking, suggested active learning or appreciation, whereas social sharing moments (e.g., explaining to others) pointed to knowledge transmission and social valuation of nature. These cues helped focus on experiences and perceptions and provided evidence on the social impacts of biodiversity exposure in the case study.

Data was recorded through direct observation notes and geo-tagged photographs using a mobile data collection form to ensure standardization. Each observation session lasted between 60 and 120 minutes, depending on the number of visitors, the intensity of interactions, and weather conditions, with weather and contextual conditions noted. Observer minimized

interaction with participants to prevent behavioral alteration and to ensure a non-intrusive mode of data collection. Observers applied purposive sampling to focus on a mix of visitor types (families, individuals, tourists, and locals as individuals or groups) and activities. Observer discreetly selected subjects who demonstrated varied modes of engagement with biodiversity, thereby enriching data diversity without intruding on visitors' experiences. Subsequent analysis applied descriptive coding to identify recurrent patterns linking visitor behavior with ecological features and spatial elements. Observers noted a range of behaviors, including clustered gatherings around resting areas with an open field of view, individual moments of quiet observation (often near exotic species or discovered fauna species), and active participation in guided tours or workshops. Common themes included the prevalence of contemplative experiences linked to floral diversity and the social enjoyment of natural spaces. Visitors often exhibited positive emotional responses, such as calmness and attentiveness, which align with the mental and physical well-being benefits highlighted in interviews and workshops.

Observations were interpreted jointly with workshop and interview data to integrate findings and enhance the reliability of qualitative insights. Unstructured notes supplemented these with contextual descriptions and noteworthy events. To enhance consistency and reduce observer bias, cross-checks were conducted with experts (the authors and scientific research team from Utrecht University and Politecnico di Milano (the supervisory team) and administrators of the Botanical Gardens, and outputs were discussed in two debriefing sessions with experts. This observational component provided contextual grounding for interpreting the social values of biodiversity, nature, and the perceptions of ES benefits.

Workshops: Two open sessions with public invitation took place at Utrecht University, one in person in November 2024 and an online one in January 2025. In total, ten people participated in the sessions, which were conducted in English with the presence of a facilitator. Workshops lasted two hours each, led by planning facilitators (author). Facilitators ensured reflexivity, avoided assumptions, and allowed participant narratives to emerge. Participants openly answered and discussed four main questions related to the themes of defining urban biodiversity and its benefits, as well as suggestions for the Botanical Gardens. In both sessions, participants were asked to answer questions by writing in the designated areas and then elaborating and discussing their reflections with other participants. The line of questions follows the same structure and aims as the question themes in the semi-structured interviews. Through a collective procedure, participants selected the desired benefits from the botanical gardens by selecting ES benefits cards. To view the boards used during the workshops, refer to Supplementary Material 4. Despite an open public call for participation in the workshop, disseminated within the Science Park and its surrounding residential areas of Utrecht, most participants were affiliated with one of the academic institutions located in the Science Park. This was mainly due to the Botanical Gardens' location within Utrecht Science Park, as its frequent visitors are mainly students and academically affiliated staff who use the Gardens for day breaks or recreation, given their proximity and the waived entry fee. An appraisal of the

balance between the methods used in this research, aimed at supporting replication in co-evaluation processes, is presented in Table 4. For a list of responses in interviews, see Supplementary Material 7, and for responses in workshops, see Supplementary Material 6.

Ecosystem services cards for the participatory workshops: To facilitate communication with participants during the participatory workshop, 28 ES benefit cards were designed and proposed to participants, which were used and refined in previous studies (Morello et al., 2024). The cards in the front contain information about the unique benefit of ES, accompanied by an AI-generated image that represents this benefit. The selected benefits on the cards are elaborated from a review in the literature on the benefits of nature and biodiversity on humans in urban areas through the use of ES based on Version 5.1 of the *Common International Classification of Ecosystem Services* (CICES) (Ayatollahi & Morello, 2025; European Environmental Agency, 2018). At the bottom of the benefits, a timeline indicates the possible waiting time in years to experience the benefit. This combination of information provides a simple yet informative message to participants regarding selection. At the back of the cards, information related to the corresponding ES, such as the ES section, code, group, class, and an example, is mentioned. The cards come in three colors: yellow represents provisional ES, green represents regulating ES, and blue represents cultural ES. The cards were designed to present a range of potential ecosystem service (ES) benefits, allowing participants to select those most relevant to them. Some cards did not directly relate to the specific ES in the case study but were included to provide context and broaden the scope of choice. This approach ensures the set is replicable across different case studies and helps to minimize potential bias by preventing the steering of participants towards specific topics. Figure 17 shows a sample of cards. The complete set of cards is available in Supplementary Material 5.

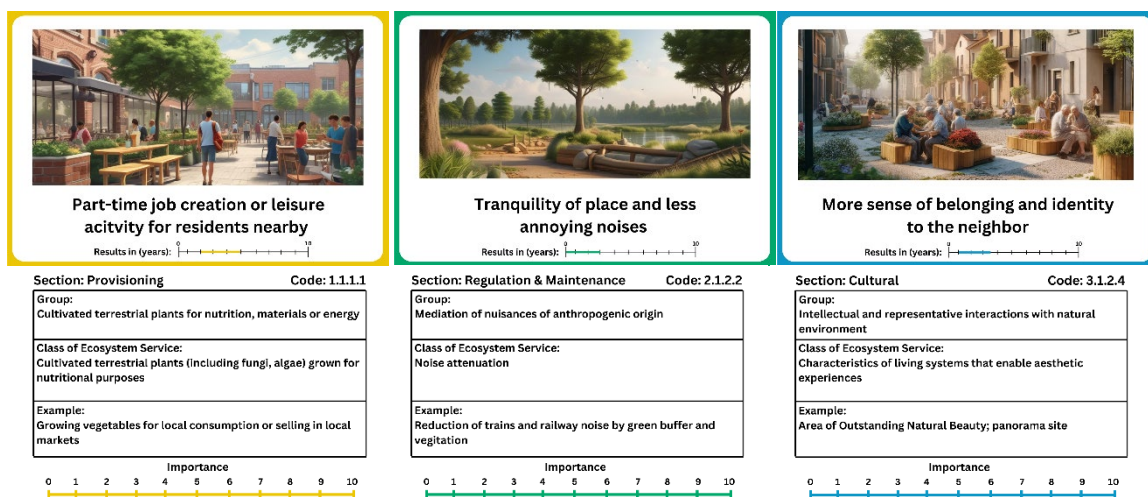


Figure 17: Sample of cards presented at collaborative sessions for priority selection.

During both collaborative sessions, before presenting the cards, participants were introduced to a basic, conventional definition of ES and given a simple example for each of the three sections of ES to familiarize them with the activity's context. Furthermore, participants discussed their selections and priorities with one another to clarify their motivations.

Table 4: Appraisal of the balance between the methods used in this research for replication in future co-evaluation processes.

Collaborative sessions (primary activity)	Replication baseline: Plan 2-3 sessions with 4-8 participants, including gamified ES benefits, elected activity from 60-90 minutes (numbers vary based on case study size and visitors).
	Stop or expansions: Continue sessions until there is consensus across groups in answers or similar patterns emerging; otherwise, add 1-2 more sessions.
	Rebalancing criteria: If participation interest is very low, or if the results are too homogenous, assemble larger sessions with experts. Add a targeted session to focus on emerging themes. Split the sessions if there are more than 8 participants.
	Quality check: Presence of a subject expert and a facilitator in sessions, with debriefing sessions with experts to evaluate outputs. Summarize and validate the information with participants at the end of the sessions.
Interviews (primary activity)	Replication baseline: 10-20 semi-structured interviews with open-ended questions (numbers vary based on case study size and number of visitors). Ensure to engage with key stakeholders.
	Stop or expansions: Stop if consecutive interviews yield the same codes or no new information, and resume in different time frames and days.
	Rebalancing criteria: Increase interviews if any new stakeholder group is identified or after major changes in the case study (4-6 more). Expand the focus beyond hotspots or concentration points, and vary the days and times of interviews.
	Quality check: Match the outputs with the constructed codes and patterns through other methods. Ensure demographic diversity among interviewees.
Observations (complementary activity)	Replication baseline: Schedule at least six observation periods, each lasting at least 1 hour, on workdays and weekends, both morning and evening, to scan environmental and social elements and interactions between humans and nature.
	Stop or expansions: Expand observation periods during temporal activities, festivities, or peak times, or changing weather conditions.
	Rebalancing criteria: Add extra observation periods if off-peak or peak hours show different patterns in user behavior.
	Quality check: Match the information with elaborated codes from collaborative sessions or interviews. Consult with experts or administrative units to identify key areas. Predefine target areas and assign paired observers.

4.2.3. Analytical framework for qualitative information

This study used an inductive analytical framework, starting with edited transcripts of interviews and workshops conducted according to standardized, ethics-approved protocols. Workshop participants were recruited through a public call, whereas interviewees were selected using a purposeful quota sampling approach from visitors to the Botanical Garden. Workshops lasted two hours, each led by planning facilitators (authors). Facilitators ensured reflexivity, avoiding assumptions, and allowing participant narratives to emerge. The analysis proceeded with a first round of descriptive coding to summarize interview content, followed by structural coding to categorize emergent themes. Subsequently, pattern coding grouped similar excerpts under thematic categories. Coding was conducted by the workshop and interview facilitator-analyst, with discrepancies resolved during debriefing meetings with two experts (a scientific research team consisting of a professor from Utrecht University and a professor from Politecnico di Milano (the supervisory team), to ensure inter-coder reliability. After the initial thematic structuring, thematic analysis, and the final coded synthesis, two rounds of peer debriefing were held to enhance interpretive validity and reduce bias. These sessions provided critical feedback, improving the credibility and robustness of the findings. In this process, no specific software was used during the coding. In specific cases, such as the association between social benefits and specific categories of ES (e.g., "mental and physical well-being" and "recreational and restorative experiences"), the classifications were grounded in explicit operational definitions derived from participant narratives and literature on ES categorization, ensuring conceptual clarity and consistency. The classifications were grounded in explicit operational definitions derived from participant narratives and literature on ES categorization, ensuring conceptual clarity.

4.3. Results

The co-evaluation process takes place in an ex-post situation at Utrecht University's Botanical Gardens, evaluating the social benefits of urban greenery and biodiversity. The co-evaluation results in identifying narratives of urban biodiversity (Section 4.3.1, which explicates how and what people recognize as urban biodiversity in the Botanical Gardens) and the related social values through the use of ES benefits (Sections 4.3.2 and 4.3.3). Recommendations for improving the Botanical Gardens are also reported in Section 4.3.4.

4.3.1. Narratives of urban biodiversity

How people view and value urban biodiversity is captured by three distinct narratives that also reflect how citizens perceive it and point to the underlying values they attribute to it. These narratives present a distinct 'definition' of urban biodiversity and offer a unique perspective on it in this locality. Overall, urban biodiversity is perceived as an essential component in urban areas, and participants recognize its intrinsic values. In all narratives, nature and biodiversity are used interchangeably.

Urban biodiversity as fauna and flora: The primary narrative defines urban biodiversity as flora or fauna species rarely observed in contemporary urban spaces. All participants in both sessions and interviews mentioned at least one species that relates to urban biodiversity. Participants describe urban biodiversity with animal species like “squirrels”, “lizards”, “butterflies”, “hares”, or with different trees or insects. Furthermore, “unique” or “rare” species, especially among animals, are other ways of describing biodiversity in this narrative. The distinguishable species are often related to special living environments (such as “woodlands”), which have a higher density of vegetation and greenery than urban environments. Species richness and diversity living in dense green spaces (especially those featuring unique or symbolic animals) and the possibility of observing them through daily activities are defined as urban biodiversity for most participants.

Urban biodiversity as controlled wilderness: The second narrative encapsulates the nexus between biodiversity, nature, and wilderness in urban areas with reflections on its spatiality. The concept of “controlled wilderness” or similar descriptions like “maintained wild nature”, “different inhabitants of cities in different green environments”, or “wild nature” highlight the definition of urban biodiversity by participants. In this narrative, urban biodiversity is perceived as closely associated with the presence of “green and blue spaces” either in the center or peripheral parts of the city. Differences in biodiversity are visible to participants, especially between built environments, where biodiversity is less apparent, and outside city boundaries, where it is more observable. According to one of the participants, “nature/green is always willing to be, but it does not get enough space [in cities]”.

Urban biodiversity for supporting living systems: The third narrative views urban biodiversity through the creation of social values and supporting living systems. Besides “intrinsic values that require recognition” and “biodiversity supports services to people”. Through this narrative, participants mentioned a broad range of services biodiversity provides, like “providing a food chain for living things” or “improving the appearance of the neighborhood” or examples that cover human well-being (mental and physical), like providing access to green, walkable areas and supporting walking experiences in cities. The narrative links the definition of urban biodiversity with the concept of ES and how values of biodiversity are perceived differently based on personal framings. The attributes and differences between the three narratives highlight the importance of contextual values and personal framing in perceiving and defining urban biodiversity. Acquiring such narratives is the first step in defining contextual variables and dynamics for evaluation.

4.3.2. Social benefits and values of urban biodiversity

Participants reflected on the educative role of Botanical Gardens through direct observation of nature, plants, and animal species, which is also stated directly as “it is more like a museum...” or by reading the provided informative panels or boards throughout the Gardens. Studying rare species and their interactions in a unique habitat also falls under the topic of learning and

education, as two participants stated their intention to visit for such activities. As the Botanical Gardens include a variety of specialized gardens for education (e.g., evolution and the discovery gardens and tropical greenhouses), this category of response, as expected, appears in almost all participants' responses. Despite the importance of the Botanical Gardens for education and learning, the most frequently mentioned value and meaning of the Gardens for participants falls within the categories of recreation and health enhancement. Due to the proximity of several institutions, especially between 11 AM and 2 PM, the Gardens are primarily visited by affiliated visitors from academic institutions at the Science Park.

Specifically, responses regarding the perceived impacts of urban biodiversity on people encompass a diverse range of both benefits and negative impacts on both personal and community scales. The social benefits mentioned encompass a broad range of perceived effects. To synthesize the results, based on their attributes, benefits are divided into four main categories. According to responses from interviews and sessions, the categories are: 1. Mental and physical well-being, 2. Cultural and aesthetic appreciation, 3. Recreational and restorative experience, and 4. Social cohesion and community engagement. Among the responses, multiple respondents reflected the intrinsic value of urban biodiversity and its role in supporting living systems (following the third narrative). The negative social impacts of urban biodiversity are generally perceived through the lens of community safety and well-being, which is elaborated upon in this section. A list of narratives is observable in Table 5.

Among the categories of social benefits, mental and physical well-being have the most direct mentions from participants, while recreational and restorative benefits follow in order of preference. These two categories have a close relationship with each other, and most health benefits are perceived alongside recreational experiences. Reflections on health and being in nature for recreation, like “it boosts my immune system”, “... emotionally, it is refreshing, and it encourages my health, both mental and physical”, and “It gives me an escape from work—a break in the afternoon that really recharges me” are examples of this issue. Despite attention to physical health, urban biodiversity is of significant importance to participants' mental well-being. Managing stress through activities like observing nature and plants, or finding a sense of relief and belonging in places with natural elements, are examples of this.

Another aspect that also closely connects with recreational and restorative benefits is the passive influence of nature and biodiversity in surroundings on mental well-being, which is described as “It has passively influenced me ... because I feel relaxed and enjoy seeing the seasonal changes presented by them, and they actually drive me to be more physically active”. The effects of urban biodiversity on mental and physical well-being are often perceived through interaction with nature or spending time in natural areas, which offer distinct differences from the dense urban fabric. These benefits correlate directly with the narrative of perceiving urban biodiversity as “controlled wildness”, where people use such places to reduce their stress or escape work routines.

The benefits associated with the social cohesion and community engagement category highlight how urban biodiversity and nature foster human-human and human-nature interactions and how nature can reinforce collective human bonds. Through field observations and interviews, participants emphasized the value of green spaces and parks as a context for interacting with others or discussing daily life with friends or family. Quotes like “Nature in cities makes people come together more, especially in parks or community gardens” and “I enjoy being in nature because it is a place where people interact in a more relaxed way compared to the rest of the city” are examples of using green spaces as a context for social interactions. Besides, learning from nature through collective or individual actions is another perceived benefit by participants. For instance, two participants reflected on learning opportunities for the younger generation and community initiatives by mentioning, “people learn a lot just by being in nature together—someone always knows something about the plants or the birds and shares it”. Social benefits in this category are primarily aligned with the third defined narrative, which posits that nature and biodiversity provide a context for common value creation at both the individual and community levels.

The cultural and aesthetic appreciation category of benefits is principally based on valuing nature and its cultural heritage, regardless of any utility. This category has a strong connection with a sense of identity and belonging. This benefits category was often associated with the first narrative of perceiving urban biodiversity by observing (symbolic or rare) species in or around urban green spaces, primarily through sensory activities. Observing squirrels, hearing birds, and learning about plants or flowers are examples of benefits mentioned through interviews and sessions. Like well-being benefits, this category is also closely tied to recreational restorative experiences. Participants largely elaborated on how the beauty of nature, or specific green spaces like “open museum-like” places, resembles cultural value or significance for them. A general example of this category is observed in the following quote: “I think it was also nice just finding something beautiful, wanting to live together with other species”.

Alongside the benefits of nature, participants pointed out examples of disservices, mainly around the lack of (sense of) safety in dense green areas and increased pests. A lack of safety or a sense of insecurity, especially in areas with limited lighting or surveillance, is also frequently discussed in the literature (Hosseinalizadeh et al., 2022; van Rijswijk & Haans, 2018). For example, a participant explains safety conditions as, “I feel unsafe if it is too wild or very rural, especially at night.”

Table 5: Relation of narratives and their primary and secondary social benefits elaborated from collaborative sessions and interviews.

Narrative of urban biodiversity	Primary social benefits category	Secondary social benefit category
1. Urban biodiversity as fauna and flora	Cultural and aesthetic appreciation	Recreational and restorative experiences / Mental and physical well-being
2. Urban Biodiversity as Controlled Wilderness	Mental and physical well-being	Social cohesion and community engagement
3. Urban biodiversity as supporting living systems (values)	Social cohesion and community engagement	Mental and physical well-being

The Botanical Gardens, as a place, is perceived as an opportunity for relaxation, recreation, and “relief from stress during working hours”. Participants defined the use of the Botanical Gardens through phrases like “a short break from the office afternoon”, “escape from academia for inspiration”, and “a place for thinking and slowing down” to highlight this recreational and restorative aspect. The Botanical Gardens are perceived as a place for social interaction and community engagement. Based on observations and responses from participants, gardens are the context for “having a walk with friends or colleagues” or “participating in social activities and tours”. The distinguishing feature of this category from previous ones is its focus on human-human relations within the context of the Gardens. On weekends or during morning visiting hours, the presence of families or small groups of visitors is more noticeable than during business days and working hours. The perception of using green spaces beyond their intended use is the main importance of this definition to participants, as highlighted by one participant: “The Botanical Gardens are not just for nature – they are social spaces where I connect with colleagues and friends”.

4.3.3. Prevailing ecosystem benefits from the co-evaluation



Figure 18: Top five selections of ES benefits by participants in the first (in-person) session. Participants chose benefits that are associated with regulating (B) and cultural (G) ES.

This section presents the prevailing recognized ecosystem benefits from the collective ES cards selection at collaborative sessions and the highlights of interviewees' responses. A complete list of responses is available in Supplementary Materials 6 and 7. The top selections of participants in collaborative sessions are mainly focused on cultural and regulating ES benefits, followed by provisional related benefits. The top ES benefits selections among participants are place for spiritual fulfillment, cognitive development, reflection (cultural), opportunity for more activities outdoors within nature (cultural), Improvement in biodiversity and better habitats for plants and pollinators (regulating), more sense of belonging and identity to the neighbor (cultural) and

increase in area covered by greenery and heat reduction (provisional). Benefits such as opportunities for participation in local events and community formation (cultural), reduction in depression and anxiety disorders (regulating), and increased interaction between neighbors, local cohesion, and identity (regulating) are frequently selected and mentioned by participants and interviewees. Figure 18 presents the top selections by participants, ranked by priority and relative ES category.

The selected benefits show alignment with participants' perceptions and narratives of urban biodiversity. The selected benefits related to cultural benefits align with the narrative of perceiving biodiversity through species in unique environments, as they are associated with cultural and aesthetic appreciation. Furthermore, regulating ES benefits or benefits related to human well-being is linked to the second narrative of nature as a controlled wilderness, as it provides indirect benefits. Figure 19 shows the relation between social-ecological values at the Botanical Gardens. This figure's innermost circle presents three main urban biodiversity narratives defined by participants. While these narratives share social values of nature, they highlight different human perceptions of biodiversity in their surroundings. The second circle shows the social benefits linked to each narrative, illustrating their impact on visitors' experiences in the Botanical Gardens. The outermost layer links the previous two layers to examples of ecosystem service (ES) benefits identified in workshops and interviews. For example, observing diverse species, especially exotic and non-native ones, fosters understanding of urban biodiversity

as a controlled wilderness, which enhances mental and physical well-being through ES benefits like spiritual fulfillment and anxiety reduction by promoting relaxation in the Gardens.

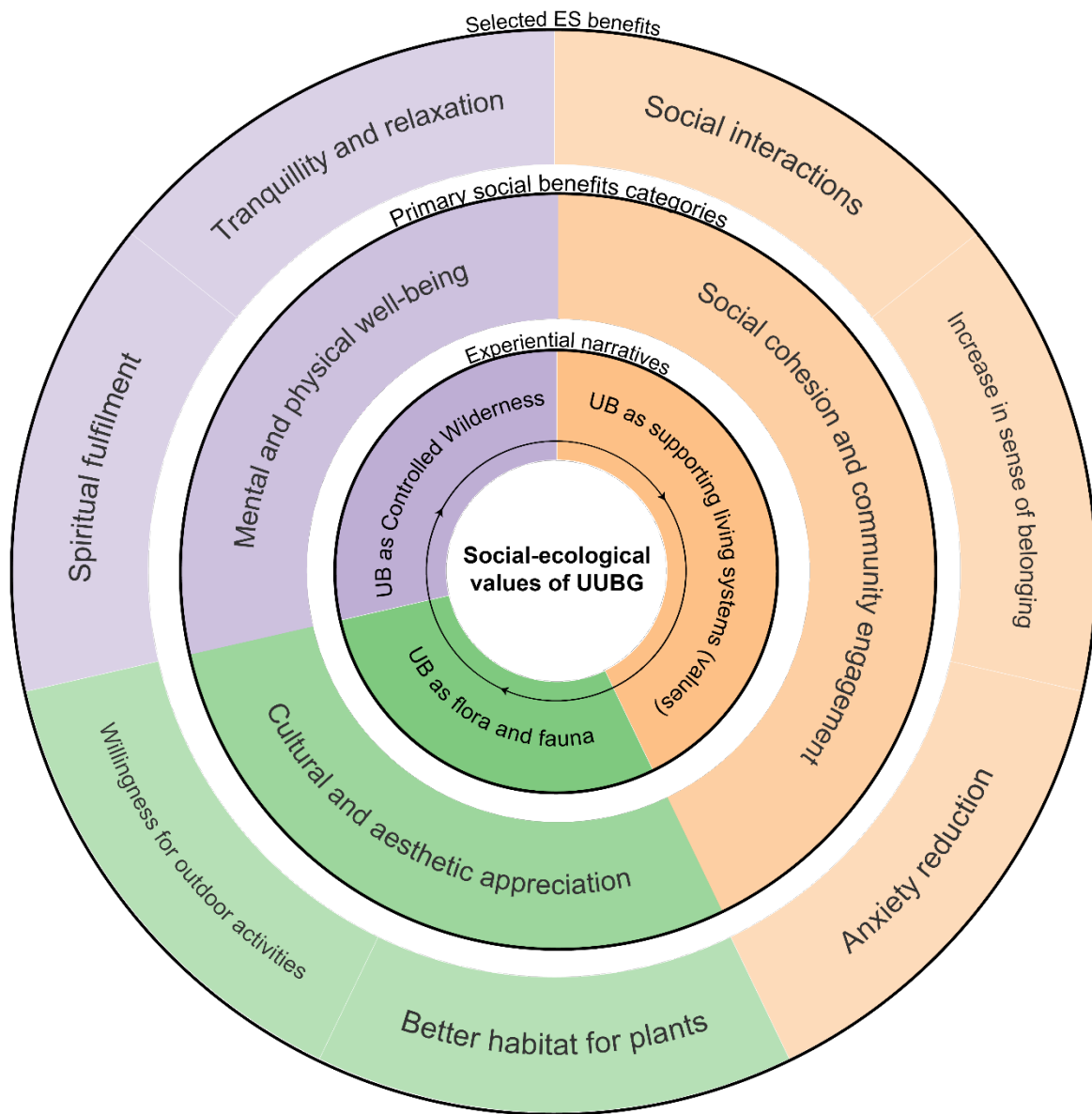


Figure 19: Social-ecological values of Utrecht University Botanical Gardens (UUBG) represented as narratives, social benefits, and selected ES benefits by participants. UB: urban biodiversity.

4.3.4. Recommendations for improving the Botanical Gardens

Two key recommendations for improving the Botanical Gardens have been gathered from the interviews and participatory sessions: first, suggestions for improving the facilities required to enhance urban biodiversity, and second, suggestions for improving the experience in the Botanical Gardens. The green infrastructure category encompasses developing walking paths that are separated from bike lanes to connect nature with benches, reducing the use of concrete in green open spaces, and incorporating vertical green structures rooted in soil with varying height

differences, similar to urban furniture. Increasing safety around dense urban greenery and counting biodiversity as a separate layer are other suggestions in this category. Nature conservation suggestions include removing invasive species regularly, protecting animals against roadkill, and refraining from intervention in lush urban green spaces. Community engagement suggestions include developing family farms in neighborhoods, offering free entry to private or semi-private green spaces, and promoting community activities like bird watching. For a list of responses in interviews, see Supplementary Material 7, and for responses in workshops, see Supplementary Material 6.

Suggestions for Botanical Gardens focus on three improvement categories: accessibility, learning and education, and community engagement. Accessibility suggestions follow the general theme of making the Gardens more accessible to the public by increasing the number of entry gates, relocating the main entry near the main road, and enhancing the visibility and legibility of the main entrance. Participants emphasized the need to improve accessibility for visitors with wheelchairs or baby carriages. Learning and education suggestions focus on increasing workshops and public sessions by planning educational activities on plants, seeds, and plant exchange programs, as well as public exhibitions. The other focus in this category is on improving signs and information on informative panels and increasing English interpretations. Community engagement suggestions include low-barrier activities such as open days at the Gardens, public collective events at the Gardens, and public historical exhibitions for the general public. A list of place-based recommendations for Botanical Gardens is observable in Figure 20.






No.	Area/View	Recommendation
1	<p>Path to discovery gardens, east of UUBG</p> 	<ul style="list-style-type: none"> - Provide information on landscape - Maintain species - Increase vertical greenery
2	<p>Park area at the southern edge of UUBG</p> 	<ul style="list-style-type: none"> - Organize local social events - Conduct low-barrier public activities - Install outdoor workspaces
3	<p>Green areas at north of Rock Garden Island</p> 	<ul style="list-style-type: none"> - Organize birdwatching activities - Develop discovery paths - Provide learning activities
4	<p>Southern areas at east of discovery garden</p> 	<ul style="list-style-type: none"> - Increase relaxing spaces - Increase accessibility - Preserve untouched nature
5	<p>North of UUBG, from the Island to the edge</p> 	<ul style="list-style-type: none"> - Promote public collective activities - Reduce outside noise - Develop community farms

Figure 20: A location-based list of suggested recommendations by participants in workshops.

4.4. Discussion

The research opens new perspectives on monitoring and evaluating the social benefits of nature in urban areas by uncovering social values through participatory procedures and the use of ES benefits to facilitate and organize the evaluation. By providing local, in-depth information about social values, the benefits of nature, and its impact on society, co-evaluation helps planners and decision-makers through policy optimization and decision-aiding within a cooperative, cost-effective approach. The novelty and limitations of co-evaluating the social values of urban biodiversity using an adaptable methodology that incorporates ES to construct an experiential narrative and uncover these values are discussed in this section.

The co-evaluation of social values of urban biodiversity requires frameworks that address the plurality of values in a participatory process. Previous studies in this field emphasize contextualizing values and gaining awareness of the positionality of one's own value perspectives (Horcea-Milcu et al., 2019) through participatory processes that involve a wide range of actors and stakeholders (Leino & Puumala, 2021; Sterling et al., 2017; Villamor et al., 2014). This participatory co-evaluation and narrative making is essential for exploring plural valuation paradigms (Colléony et al., 2021; Moreira et al., 2024; C. M. Raymond et al., 2014), which employ a diverse range of methods, such as collective mapping, gamification, and dialogue-based approaches, to simplify and unravel complex social values associated with specific urban green spaces. In this context, experiential narratives serve as an interpretive medium that enables planners to translate intangible values into actionable policy insights. Such an approach is also in line with findings that demonstrate social values of nature biodiversity are context-dependent, relational, and often shaped by everyday interactions with urban green areas (Bernardo et al., 2021; Ives & Fischer, 2017; Steger et al., 2023). By situating co-evaluation within recent plural valuation and participatory frameworks (Haase & Dushkova, 2025; van der Jagt et al., 2023; Villamor et al., 2014), this research contributes to a deeper understanding of how social values of nature and urban biodiversity can be operationalized in decision-making and urban planning contexts through an adaptive methodology. The findings underline the significance of co-created narratives as dynamic tools that connect ecological values with social perception. This multidimensional approach not only enhances the interpretability of social values for decision-makers but also supports adaptive planning through iterative engagement between citizens, experts, and institutions. The following subsections (4.4.1 and 4.4.2) elaborate on the methodological adaptability and implications of co-evaluation for optimizing policy design regarding urban biodiversity.

4.4.1. Co-evaluating social values of urban biodiversity

Biodiversity and nature in urban areas not only serve as ecological assets but also as a reservoir of social values. To address challenges around the diversity of values and perspectives, we propose a package of co-evaluation through direct engagement with actors.

The narratives render a clear yet multifaceted understanding of the Botanical Gardens. The narratives are constructed in collaboration with visitors and actors regarding the Botanical Gardens' status, showcasing the perceptions, definitions, benefits, improvements, and possible interventions. The use of qualitative data extracted from sessions, interviews, and direct engagements is often limited by the broad scope of information (Campbell et al., 2016) and challenges in practical interpretations for management and planning (Toomey et al., 2025). The experiential narratives offer planners and decision-makers a novel approach to elaborating on information by engaging actors in the process. Narratives showcase how definitions of urban nature and urban biodiversity can overlap for citizens. The presence of green spaces, per se, equals more biodiverse spaces for participants. Participants contribute to narrative-making (as part of the co-evaluation process) through their inputs in each section of the narrative (perceptions, definitions, benefits, and interventions), directly by answering associated questions, or indirectly through prioritizations (like ES benefits). The contributions are then categorized and organized by facilitators and planners into coherent narratives. Additionally, the disbenefits mentioned often relate to the second narrative of urban biodiversity as controlled wilderness. It is evident that the division of narratives closely follows the general ES divisions (provision, regulating, and cultural). This relation shows how, within defined boundaries of nature benefits, social values differ based on contextual attributes and public perceptions.

In this case study, most interviewees and participants in collaborative sessions were mainly highly educated individuals affiliated with academic institutions. While this issue, per se, does not obstruct the evaluation, it might affect the scope of responses by having a bias towards specific values. For future research, it is necessary to involve actors who are distant (less concerned) and marginalized actors regarding the case study to offer a more comprehensive evaluation. The same limitations might apply to the pre-intervention evaluation, which primarily requires increasing interest in participation among potential participants—defined here as individuals who may be less concerned, more distant, or less willing to engage in the evaluation. Future research in this field should engage more closely with citizens and explore ways to reach out to and include citizens from diverse interest groups through the active dissemination of collaborative events. This could involve reorganizing how these events and engagement approaches are structured to improve recognition and justice in the process. Additionally, the co-evaluation participation rate is another limiting factor that might demand additional collaborative activities to acquire additional data (values and narratives). To ensure adequate participation in the proposed co-evaluation approach, separate public engagement methods (interviews, collaborative sessions, observation, and gamified priority-making) could be offered to engage actors in co-evaluation in future research.

4.4.2. Adaptable methodology for co-evaluation

Our proposed methodology provides a participatory framework that bridges the gap between ecological metrics and local social values when evaluating the recognized and perceived social-ecological benefits of urban nature. The co-evaluation process consists of direct face-to-face

discussions and interviews with the actors and stakeholders in the case study, as well as the gathering of perceptions and narratives through focus groups and collective procedures (ES benefits card selection). Implementing the ES card game facilitates the interpretation of narratives on the social benefits of urban biodiversity and connects them to future intervention priorities.

The co-evaluation and narrative-making processes in this research face limitations and challenges regarding participation rate and diversity of participants in terms of affiliations and age groups. Despite public announcements and communications, the total number of participants in interviews and collaborative sessions is still relatively low compared to the total number of visitors to the Botanical Gardens. In scenarios where participants and interviewees are not representative of the majority, the procedure requires a higher number of participants. Due to the time limits on the Botanical Gardens' operating hours and prevailing climate conditions, the number of visitors during the survey period was lower than expected. While the gathered information reflects a significant portion of opinions and narratives, it may not comprehensively cover all perspectives. Additionally, all participants in collaborative sessions and the majority of interviewees are affiliated with at least one institution at the Utrecht Science Park. Being affiliated with institutions does not impose any general limitation on the research, given the Botanical Gardens' location near an academic institution. Moreover, the majority of participants aged 20 to 40 are affiliated with academic institutions and hold higher education qualifications. As a result, reflected opinions and elaborations are mainly affected and limited by the scope of specific visitor groups. In this context, since the co-evaluation was carried out in English, future studies aiming for broader sampling should consider conducting the process in participants' native language.

Ultimately, the selected case study imposes certain limitations on the co-evaluation process and visitors' experience. The winter closure of the Botanical Gardens to the public (the site is open to academically affiliated users) limits direct experience of existing ES under different conditions with seasonal change and omits distinctive winter use profiles by omitting off-season use patterns. Comparing social perceptions of nature during peak seasons (such as spring) with those during winter provides a comparative element on the perception of greenery, which, in this case, was not achievable. Future research in such a context must consider the effects of seasonal change on greenery and how this may affect human perception. Furthermore, the existing entry fee might limit the public's accessibility to and attractiveness of the Botanical Gardens. These barriers may limit the participant pool and potentially underrepresent the perspectives of groups unwilling to pay the entry fee during the co-evaluation process. Although these limitations may not invalidate co-evaluation, implementing policies like occasional multi-seasonal open days or free days (as suggested by participants) could help address these conditions.

The proposed co-evaluation procedure can facilitate communication between citizens and decision-makers by providing interpretations of the social values of nature in narratives and by prioritizing the perceived social benefits of nature for actors interacting with urban nature.

Evaluating priorities (as presented in the narratives) through a participatory, collective approach provides a rigorous interpretation based on multiple data sources. The co-evaluation approach, therefore, serves as a complementary yet essential component of decision-making at the local scale, alongside top-down evaluation approaches, to provide a comprehensive understanding of human-nature dynamics across all spectrums of socio-cultural and socio-economic variables (Dumitru et al., 2020).

4.5. Conclusions

Co-evaluating the benefits of nature in local urban areas is a crucial step in understanding humans' social values, perceptions, and relationships with nature. The knowledge and scientific methods for in-depth evaluation of the social benefits of nature and biodiversity in urban areas are still evolving, and research applications and experience are at an early stage. This research provides an adaptable and replicable methodology that focuses on the co-evaluation of social benefits of urban biodiversity based on ES categories. The methodology was applied in the pilot area of the Utrecht University Botanical Gardens. The methodology focuses on direct engagement with citizens and stakeholders through collaborative workshops, interviews, and collective ES selection to inform, engage, and educate people about the values of biodiversity, while also supporting planners and decision-makers in improving local policies and the design of urban green areas. The authors argue that the tested application is cost-effective, generates rich qualitative information, and increases awareness and participation among local stakeholders. The method is easy to replicate because it is based on ES categories. Future research on this topic requires consolidating a decision-making process that embeds stakeholder engagement in discovering the values of biodiversity and co-evaluates the social values and co-benefits that people prioritize when establishing policies or promoting urban transformation of green spaces (van der Jagt et al., 2023).

Chapter 5.

Local nature future framework in practice, operationalizing the experiences in Milan and Utrecht

Abstract

In a state of deep uncertainty, planning for urban social-ecological systems faces the challenge of navigating the future of human-nature relations amidst an accelerating biodiversity loss. While adaptive planning through future-scenario making is a recognized approach, established frameworks are primarily designed for regional or city-wide scales, utilizing quantitative data, which leaves a gap at the local level where collaborative action often occurs, relying on social values and qualitative information. This research addresses that gap by introducing and examining the Local Nature Futures Framework (LNFF), as a novel approach tailored for adaptive planning of local green areas. The primary innovation of LNFF is its function as a live framework. Unlike other NFFs, it is designed to be iterative, continuously learning and adapting to new contextual information and inputs. LNFF, as derivative of NFF for local scale application in urban areas, operationalizes this by structuring local knowledge into a multi-criteria decision-analysis procedure, creating a dynamic feedback loop between community values and scenario optimization. The framework's effectiveness was validated by application in two distinct case studies (Milan and Utrecht). In both contexts, the framework translated qualitative social values into an evaluation model. Initially, applying Pareto optimization principles identified all efficient pathways (plausible futures), and then optimal scenarios were selected using a weighted analysis based on local indicators through LNFF dimensions. Ultimately, using plausible scenarios and contextual attributes from each case study, optimal development strategies and policies are defined. This research enables planners and decision-makers to utilize NFF at the local scale by incorporating qualitative values to address future uncertainties and leveraging local data through stakeholder collaboration.

5.1. Introduction

Cities and urban areas function as complex social-ecological systems characterized by human-nature relations (Lemes de Oliveira & Mahmoud, 2024) that are under conditions of deep uncertainty (Marchau et al., 2019; Walker et al., 2013). In recent decades, with intensified effects of climate change and urban biodiversity loss, the state of nature in cities has deteriorated (Liu et al., 2025), and consequently, its benefits on human life are deteriorating (Gong et al., 2024; Marselle et al., 2021). Loss of biodiversity and lack of effective interaction with nature in urban areas are causing direct (e.g., reduction in air quality or pluvial floods) and indirect impacts (e.g., reduced mental well-being and increased depression) (Romanazzi et al., 2023) on multiple

aspects of human well-being. Moving beyond planetary boundaries in urban areas (Hoornweg et al., 2016; Richardson et al., 2023), coupled with an imbalance in human-nature relations, causes a wide range of negative impacts in economic, sociocultural, cognitive, and emotional aspects (Kronenberg et al., 2024).

Alongside its social impacts, the persistence of imbalance in urban social-ecological systems results in more layers of uncertainty about the future (Rounsevell et al., 2021). Uncertainty functions as the core feature of complexity (Moroni & Chiffi, 2021), which jeopardizes the understanding of possible future scenarios of development (Maier et al., 2016). Consequently, these constrain capacity for adaptive decision making (Arlati, 2024; Nuno et al., 2014). Disregarding uncertainty in the planning process leads to missing future opportunities and unsustainable plans for policy or interventions (Walker et al., 2013). To address the challenges of biodiversity loss and deep uncertainty, urban planning approaches must integrate nature and biodiversity throughout the planning process and subsequently operationalize this integration into adaptive interventions and policies that can cope with future uncertainties.

Addressing and mitigating biodiversity loss challenges in urban areas has received attention in the literature over the last decades (Dearborn & Kark, 2010; E, 2021; Hernandez-Santin et al., 2023). Following this discourse, biodiversity and nature have to be integrated into the planning process. While still few studies in the interdisciplinary stream of urban planning literature address this concern (Rega-Brodsky et al., 2022), the research planning theory is evolving rapidly (Kowarik et al., 2025; Pickett et al., 2024). Values of biodiversity preservation and integration in planning are indicated or conceptualized in several international studies (Kowarik, 2023; Kowarik et al., 2025; Nilon & Aronson, 2023) and guidelines (Díaz et al., 2015; Reid et al., 2005; Zulian et al., 2022). Followingly, biodiversity and nature futures have become an important part of local planning at the urban scale (Haase & Dushkova, 2024; Ignatieva et al., 2023; Mahmoud et al., 2025) and with frontier practices at the local scale (Morello et al., 2024). Despite these advancements, the practices that operationalize knowledge on urban biodiversity preservation at the local scale planning (like at urban blocks and neighborhoods) for adaptive decision making are still limited and require further development. Building actionable approaches at the local scale beyond quantitative, measurable targets and indicators (Nilon et al., 2017a) requires an in-depth understanding of local perception about nature and a clear vision of possible human-nature future interactions.

The primary step for building actionable approaches at the local scale is envisioning possible futures and scenarios of human-nature relations. In the process of adaptive decision-making, in urban areas, as human-nature relations are in a state of deep uncertainty, establishing possible future pathways can facilitate the process of policy-making for optimal interventions (see e.g., Haasnoot et al., 2013; Lawrence et al., 2025). A comprehensive attempt to frame such a future vision is the Nature Futures Framework (NFF) developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Pereira et al., 2020). This framework, which is more appropriate for a bottom-up approach (ibid), envisions how

people relate to nature by constructing future visions. Building on intrinsic, instrumental, and relational values for nature (Díaz et al., 2015). The NFF suggests three visions of Nature, namely Nature for Nature (NN), Nature for Society (NS), and Nature as Culture (NC). The NFF builds on the diversified and multiple contributions of nature to people (Díaz et al., 2018; Pereira et al., 2023) through time in three horizons (now, near future (short-term), and far future (long-term), with multiple possible pathways for the future (H. Kim et al., 2023). By providing alternative visions and scenarios, NFF helps decision-makers explore pathways for managing nature in cities (Mansur et al., 2022). This construction clarifies how people perceive nature and its benefits or services (or disservices). Hence, planning for the future of nature should be oriented to addressing these perceptions.

NFF has been conceptually adapted to be applied for use in urban or regional contexts in different variations (e.g., Bina et al., 2024; L. Kim & Li, 2024; Mansur et al., 2022; Shaikh & Hamel, 2023). Despite larger urban-scale adaptations, the practical implementation of NFF at the local urban scale (especially for operation at the neighborhood scale) for policy making and interventions is still evolving (e.g., D'Alessio et al., 2025; Durán et al., 2023). While NFF has the capacity for collaborative visioning of future scenarios (Pereira et al., 2020), a direct connection between the use of NFF and its application in planning for neighborhoods, with a focus on policy-making, is limited. Operationalizing NFF at the local scale entails a participatory process of stakeholder engagement (Mansur et al., 2022) and a collaborative interpretation of perceptions for fluent translation in policies and interventions on using different resources to bring back balance in human-nature relations. The NFF initially envisions the future of nature, while for planning in cities, it is also necessary to consider the effects of nature on humans, which can entail both positive and negative dimensions (Oostvogels et al., 2024). In this context, models that frame nature contributions on human life with a focus on social values and beyond quantifications are also limited (van der Jagt et al., 2023).

To operationalize NFF at the local urban scale, two main challenges and shortcomings are observable from the literature and practice. Primarily, a few studies focused on using NFF at a local urban scale (conceptually or practically). While numerous studies cover national to metropolitan and urban scales, smaller scales, such as neighborhoods, have garnered less attention since the introduction of NFF. Secondly, limited research has explored the direct application of NFF conceptualization outcomes for use in policy-making and interventions at the local scale. Frameworks like Urban NFF (UNFF) (Mansur et al., 2022) attest to the capacity of constant monitoring of NFF for policy-making, while paying less attention to social values and qualitative contextual attributes as fundamental variables at the local scale. By considering these gaps and shortcomings, this research, within the scope of human-nature relations in urban areas and with an emphasis on urban biodiversity valuation, aims to propose an actionable development of NFF for the local urban scale that can guide decision-makers in the process of planning policies and interventions. By imposing the question of how the concept of NFF can be operationalized for local-scale planning on the matters of human-nature relations, the

objective is to primarily construct an actionable NFF for local-scale planning and secondly validate (examine) its functionality in two distinct local contexts of a local park in Milan, Italy, and a Botanical Garden at Utrecht, Netherlands. In addition to contributing to the conceptual development of NFF, the results will also reflect the practical application of this framework for policymakers and planners.

5.2. Conceptual framework

This section consists of two parts. The first part is dedicated to exploring the definition and application of NFF, while the second part focuses on establishing a local methodology based on the adaptation of NFF.

5.2.1. Nature Futures Framework (NFF)

To address existing gaps in scenario-making approaches, NFF is primarily established to explore and capture positive values in human-nature relations across three main dimensions of Nature for Nature, Nature as Culture, and Nature for Society by emphasizing the multiplicity of nature's contribution to human lives (Pereira et al., 2020). In this framework, by triangulating between the three main values of nature and locating the current status of human-nature relations, NFF provides pathways (strategies) for moving toward a desired future vision based on defined targets (ibid). To achieve defined visions, NFF deploys short to long-term pathways that are each based on plausible future scenarios (Díaz et al., 2015; Pereira et al., 2020). These scenarios outline how the future unfolds, and which values must be prioritized to achieve the established objectives. NFF, as a flexible heuristic tool, aims to provide nature-centric scenarios that support positive human-nature relations. NFF methodology follows an exploratory target-seeking scenario development approach, which relies on community contribution and collaboration for data collection. Rolling out NFF in real-world case studies is still a work in progress and evolving as NFF has been applied to a variety of case studies, dominantly at larger scales (like global or regional)(Chibwe et al., 2024; Dou et al., 2023), while the knowledge on local-scale applications is still limited (Dunn-Capper et al., 2023; Okayasu et al., 2025).

Beyond the NFF application at the local scale, NFF, as a framework, faces several criticisms and challenges, particularly in areas such as the inclusion of natural values, novelty, anthropocentrism, and a lack of multispecies thinking. Most importantly, concerning this research, the exclusion of time parameters is a key concern. These limitations and challenges, as well as their advancements regarding these issues within Local NFF, are elaborated upon in Section 5.5. Discussion.

5.2.2. Local Nature Futures Framework (LNFF)

To establish a Local NFF (LNFF), this research builds on the original research on NFF by Pereira et al. (2020) and Díaz et al. (2015). The original NFF is explored in many research studies by minor adaptations and modifications to better fit the framing and visioning with the context of

the study (e.g., Diogo et al., 2025; Mayer et al., 2023; Schmitt et al., 2025; Shaikh & Hamel, 2023). Additionally, the NFF concept has been revised and modified conceptually to enhance coverage of contextual variables, the possible impact and interaction between humans and nature, and to provide a better vision of futures and pathways. To scope the conceptual framework for the local urban scale, besides the original IPBES and NFF contributions, this research focuses on the UNFF by Mansur et al. (2022), Integrated NFF (I-NFF) by Oostvogels et al. (2024), and general future modelling approaches by Haga et al. (2023) and H. Kim et al. (2023). To adapt, apply, and examine LNFF at the local scale, modification and development are necessary at the conceptual, structural, and practical levels. It is essential to mention that the structure of LNFF is derived from previous studies and an established framework to provide a tailored yet adaptable framework for local-scale case studies. In this context, the information from both case studies is not used to modify or develop LNFF, but to examine it in two different contexts. The basis of development of LNFF are based on NFF structure and its later derivatives and variations.

To establish LNFF, at the conceptual level, in addition to the four key components in the process of visioning UNFF (identifying social-ecological feedbacks, assessing indirect impacts, establishing a monitoring framework, and developing scenarios) (Mansur et al., 2022), this research proposes adding two further steps of constant collaborative monitoring and developing a learning and feedback procedure for contingency plans. Human-nature relations evolve over time; local actors and decision-makers might change, or their preferences may differ based on contextual development or external challenges. As a result, a constant monitoring and learning process helps planners adjust their vision of the future in response to changes over time (Frantzeskaki et al., 2022). LNFF is a live framework that adapts and changes in response to changing circumstances, optimizing possible scenarios and pathways. In contrast to one-time evaluation and establishing vision through a long-term horizon, dynamic monitoring and assessment increase the reliability and precision of scenarios. Additionally, to broaden the scope of scenarios and envision the totality of interactions, both positive and negative feedback of the social-ecological system are integrated within the framework (Oostvogels et al., 2024). Anthropogenic changes (e.g., vandalism, entering protected green areas, or exploiting natural features) or natural disturbances (e.g., an increase in pests or the transmission of diseases from animals or plants) may lead to feasible, undesirable future scenarios, which planners need to prepare for in the course of decision-making and contingency planning. For example, a decline in biodiversity status or a lack of local participation in social events each brings negative consequences for the present and possible future status. Unlike I-NFF, the current framework integrates disvalues from social-ecological systems within the same spectrum of positive values. This enables planners to gain a comprehensive understanding of the outcomes of interactions within the system. Conducting all six steps in constructing LNFF is feasible through bottom-up collaborative activities with citizens and stakeholders, thereby achieving an inclusive approach to planning. As most remote sensing data lacks reliable accuracy at the local scale, using local knowledge is crucial for enhancing the collected data. Figure 21a shows the conceptual procedure of LNFF and its realization in different futures.

At the structural level, the local urban context as a social-ecological system entails six main variables for human-nature relations. Biophysical and biodiversity variables are natural factors that, through ecosystem services (ES), impact citizens, the governance system, and economic systems, and vice versa, as local interventions and policies for urban green spaces alter the status of nature. Measuring feedback between these variables through collaborative sessions with actors or by defined indicators from the literature identifies direct and indirect impacts on each component of the social-ecological system. Using ES at this stage as a tool for understanding the impacts of nature on multiple levels of human lives. Furthermore, the monitoring framework established by Mansur et al. (2022) emphasizes quantitative indicators applicable to different measurement levels, especially at smaller scales, such as neighborhoods. While this research follows the same approach, special attention is given to qualitative values (for instance, the cultural values of ES) without direct quantification or assigning social values to a numerical scale. Quantifying social values that are elaborated through direct interactions with actors and stakeholders oversimplifies the information values. The limited accuracy of quantitative data can be addressed by supplementing it with qualitative descriptive information to provide more precise insights. The methodology for gathering information, as outlined in previous frameworks, is based on local knowledge through engagement with actors and decision-makers.

At the practical level, to establish future scenarios and pathways for policy-making, this framework relies on contributions of Haga et al. (2023) and H. Kim et al. (2023) focus on multiple plausible futures (PF) within the system. In a collaborative process, after establishing the aims and objectives for the future of human-nature relations, depending on changes in social-ecological variables, multiple plausible futures emerge. Plausible Futures can be projected based on historical development pathways and desired or defined objectives and values, all of which are in nature's futures frontier (H. Kim et al., 2023). In a local context-based functionality of social-ecological variables, both positive and negative futures (human-nature win-win, win-lose, or lose-lose) scenarios are plausible. Despite a wide range of possibilities, finding optimal pathways or desired futures is possible, for example, through quantifications and the use of mathematical models, such as Pareto optimal strategies (Haga et al., 2023). In other words, Pareto optimal strategies for this study, in relation to NFF, are defined as strategies or scenarios where there are no other strategies that increase Nature for Nature, Nature for Society, or Nature as Culture values without decreasing at least one of the other values (ibid). This definition is based on a broader understanding that considers Pareto optimality as a measure of efficiency in multi-objective optimization, where a design (in this research scenario) is considered Pareto optimal if no other design (scenario) can improve any objective without worsening at least one other objective. The set of all such non-dominated designs forms the Pareto front—the subset of non-dominated scenarios that represent the most efficient trade-offs—illustrating the optimal trade-offs between the objectives. The limitation of these approaches on the local scale is a lack of quantifiable data, especially on social variables and cultural values. While few studies have addressed this gap, knowledge about using qualitative values at the local scale remains limited.

To overcome these shortcomings, within LNFF, the Plausible Futures are defined by both involved actors and practitioners. The desirable future is defined through the establishment of objectives, approaches, and strategies in collaboration with local actors. To systematically identify optimal pathways among these alternatives, this research employs the multi-objective optimization approach developed by Haga et al. (2023), which proposes a process that operationalizes NFF by identifying Pareto-optimal strategies where no single nature value perspective can be improved without compromising others. This approach demonstrates that optimized futures in the NFF context refer to equally good solutions that balance trade-offs between Nature for Nature, Nature as Culture, and Nature for Society perspectives rather than maximizing a single objective. The other Plausible Futures and optimal pathways are thus defined using professional knowledge based on input acquired through collaborative sessions, reviews of local policies and plans, and ongoing monitoring procedures, subsequently evaluated through Pareto optimization to identify the optimized futures in relation to defined indicators and actions. The qualitative values that cannot be quantified in this procedure are then integrated into the decision-making process by planners to facilitate informed decisions in selecting indicators and actions. The conceptual framework of LNFF primarily relies on local knowledge and public participation in all steps of defining future visions. Planners' knowledge and remote sensing data facilitate the interpretation of information on social perceptions and the evaluation of social values concerning nature. Figure 21b presents the LNFF general adaptation procedure

and the realization of results in different Plausible Futures through LNFF dimensions. The next step involves investigating the application of LNFF in the local context.

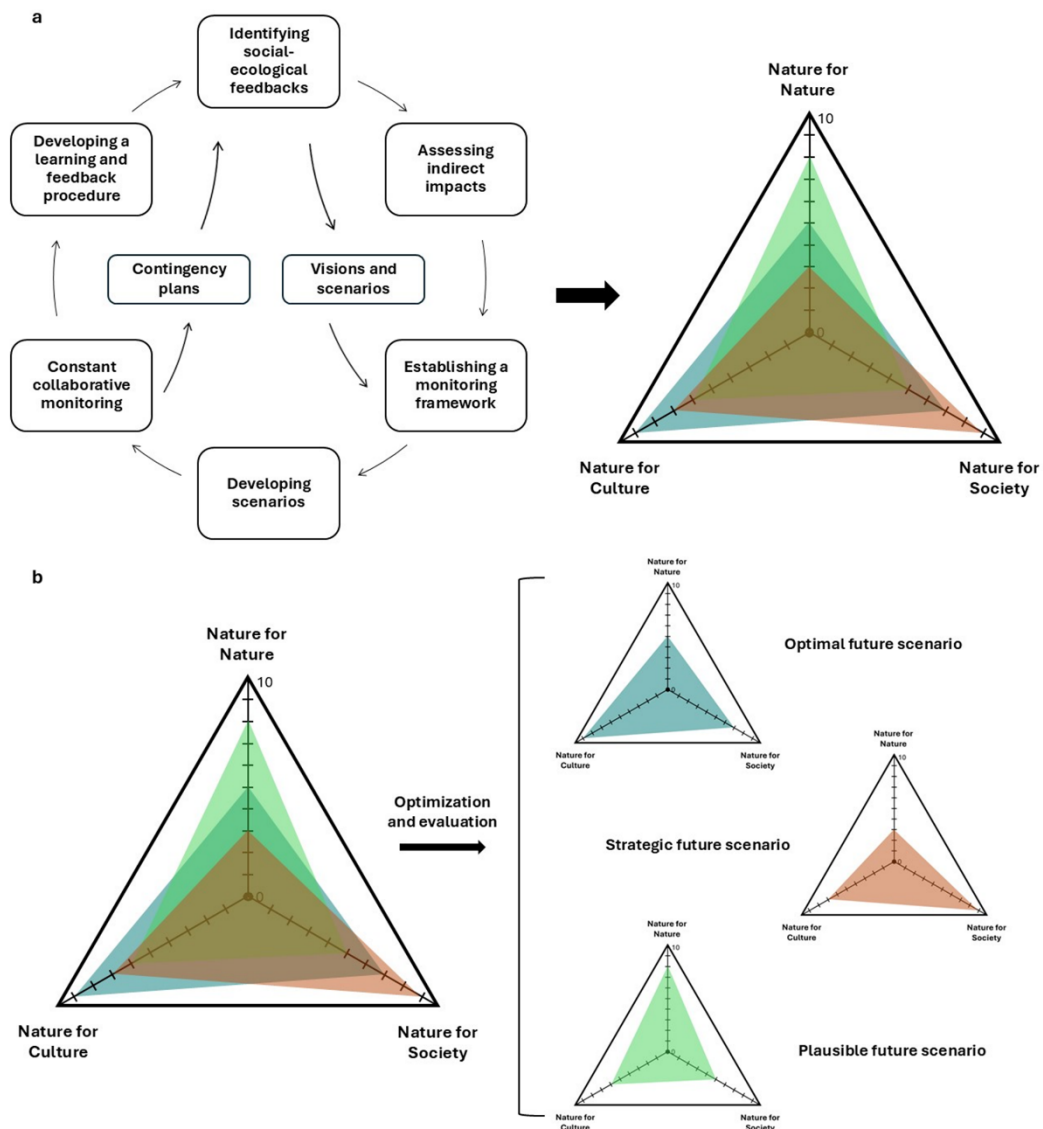


Figure 21: (a) LNFF conceptualization, which results in multiple futures with Nature for Nature, Nature as Culture, and Nature for Society triangulation. (b) LNFF Realization within multiple futures after optimization and evaluation.

5.3. Methodology

This research employs case study analysis to apply and test LNFF in two different case studies. The methodology integrates qualitative data from collaborative activities in both case studies, combined with a quantitative Multi-Criteria Decision Analysis (MCDA) to identify optimal future pathways. The methodology is structured into three sections: case studies, data collection and collaborative activities, and data elaboration and processing.

5.3.1. Case studies

To apply and test LNFF, two case studies are selected: Sorelle Mirabal Garden in Milan, Italy, and Utrecht University Botanical Gardens in the Netherlands. Sorelle Mirabal Garden (SMG): The case study in Milan is a local urban park located in eastern Milan (Ortica neighborhood) and is limited on the west by active railways, on the north and south by nursing homes, and on the east side by a street and residential developments. The Garden, owned by the municipality, covers 17900 square meters of area and was closed to the public during the COVID pandemic. After a co-creation process, the garden reopened to the public in May 2025 with a dedicated inaccessible area for biodiversity preservation, a biodiversity monitoring area, a recreational site, and areas for public use equipped with furniture. Figure 22 presents the location of the Gardens and employed interventions. Currently, besides public and private actors, non-profit organizations and the academic sector are active in the use and maintenance of the Garden. For a complete description of the SMG, see Section 3.3, and for Utrecht University Botanical Gardens, see Section 4.2.1.



Figure 22: Location of the SMG case study and general activities within the area.

Utrecht University Botanical Gardens (UUBG): located southeast of Utrecht within the Science Park on the eastern green corridor of the town. Organized by Utrecht University, the botanical gardens span 100,000 square meters and comprise nine thematic gardens that focus on immersive storytelling and the exploration of diverse species, as well as free walking paths and open spaces equipped with benches and seating areas. Public entry to the Botanical Gardens is

limited to a 10€ fee, with discounted prices available for youths, the elderly, and holders of municipal or institutional passes. The entries to the garden consist of one main entry at the west of the Gardens and controlled entries for affiliated users at the north and east of the Gardens. Similar to the case study in Milan, active actors encompass the public, private, and academic sectors. Figure 23 presents the location of activities designed in the Botanical Gardens.



Figure 23: Location of the UUBG case study and general activities around the area.

5.3.2. Collaborative activities and data collection

To collect data from both case studies, as outlined in the conceptual framework, a series of interactive activities comprising collaborative sessions, semi-structured interviews, and field observations took place. In the case of Milan, a process of co-design and co-creation, facilitated through four public workshops with actors and stakeholders, identified general objectives, aims, goals, vision, and desired benefits of nature, as well as perceptions and social values. Followingly, in collaboration with decision-makers, the results were applied to the context of the SMG (see Morello et al., 2024). The results from this case study, which are used for LNFF, are primarily established in collaboration with citizens and stakeholders. These results are then further elaborated by facilitators and experts (the author and the scientific research team) for analysis and presented to local decision-makers for implementation.

In the case of UUBG, two public collaborative sessions were held, with a total of nine participants (one in person, in November 2024, and one online, in January 2025). Through both

sessions, participants answered open questions about the benefits of biodiversity and ES in the city and UUBG, and also suggested their improvement for UUBG from their experiences. Additionally, as part of the evaluation procedures, a series of semi-structured interviews was conducted at the UUBG. In total, 12 interviews were conducted during the visiting time frames of botanical gardens, working days, and weekends, between September and November 2024. The interviewees were selected randomly from different age groups and genders among visitors to the Botanical Gardens. In total, five open questions were asked of each interviewee on three general themes of defining values of urban biodiversity and nature, benefits of biodiversity on human lives, and ultimately, values and suggestions about UUBG. In both cases, the raw qualitative data from workshop transcripts and interview notes were then analyzed by the research team (the author and supervisory team).

5.3.3. Data elaboration and analysis

For data elaboration and analysis, the qualitative input from case studies was translated into a quantitative framework using MCDA to evaluate defined futures systematically. The process entails several sequential steps. First, to measure defined vision and objectives, as defined in collaborative sessions based on qualitative input and expert opinion (author), a set of social and ecological indicators is developed for each case study. These indicators were validated against scientific literature to ensure their relevance in each case. Secondly, the relative importance of these indicators was quantified through the Analytical Hierarchy Process (AHP) (Saaty, 1987), based on input from sessions and expert opinion. In this step, a unique weight is assigned to each indicator that reflects its priority for the context of the study. For using these weighted indicators for the analysis, these were grouped (based on their object of measurement) and correlated into one of three core LNFF dimensions (Nature for Nature, Nature as Culture, and Nature for Society). Thirdly, besides a desired future (DF) (defined through collaborative sessions) and a strategic future (SF) (based on contextual attributes, existing strategies, and policies), a set of Plausible Futures was defined for each case study. Each of these futures (scenarios) was then evaluated against the LNFF dimensions (using a group of weighted indicators), receiving a performance score (on a scale of 0-10) for its expected outcome in each of the Nature for Nature, Nature as Culture, and Nature for Society dimensions. The state of each case at the time of the study was considered the baseline for this evaluation.

With the futures scored and the dimensions weighted, a two-phase optimization was performed. The first phase applied the principles of Pareto optimization to the complete set of scored scenarios. This acted as a filtering step to identify the Pareto Front. Any scenario found to be "dominated" (i.e., objectively worse than another scenario) was identified as an inefficient path concerning defined indicators (while being plausible). The second phase ranked the efficient, non-dominated scenarios from the Pareto Front. This was done using a weighted sum model. For each scenario, its performance score in each dimension (Nature for Nature, Nature as Culture, Nature for Society) was multiplied by that dimension's aggregated weight. These results were then summed up to calculate a single, final performance score. The scenario with

the highest score was identified as the most optimal future, representing the best possible alignment with the stakeholders' prioritized objectives and indicators. To see the complete list of calculations of this step for each case study, see Supplementary Material 8.

5.4. Results

The proposed LNFF is tested and operationalized in two distinct case studies. In both case studies (SMG and UUBG), the results follow five steps: 1. Discovering visions, objectives, and values collaboratively (for identifying social-ecological feedback), 2. Defining social-ecological indicators and prioritizing them (for identifying social-ecological feedback and assessing direct and indirect impacts), 3. Defining strategic, desired, and other Plausible Future scenarios within LNFF (Nature for Nature, Nature as Culture, Nature for Society) based on citizens' inputs and expert (author) opinion (for assessing direct and indirect impacts and establishing a monitoring framework), 4. Constructing possible strategies, policies, and actions based on defined futures and finding optimal approaches through Pareto optimization principles (for establishing a monitoring framework and developing scenarios), 5. Developing contingency plans for various scenarios (including developing scenarios and collaborative monitoring). The sixth step, designing plans for future monitoring and learning (for collaborative monitoring and developing learning systems, is elaborated for both case studies within the Discussion section. Additionally, the comparison between case studies for LNFF analysis is elaborated in the Discussion section.

5.4.1. Application of LNFF for the Milan case study

The case of SMG in Milan is an ex-ante evaluation case study, where the garden is planned for reopening. Besides regenerating social and cultural activities, promoting biodiversity conservation was among the main aims of the municipality and academic facilitators through collaborative sessions (Morello et al., 2024). The focus on biodiversity and reviving cultural activities is a fundamental aspect of shaping LNFF in this case.

5.4.1.1. Discovering visions, objectives, and values

The vision defined for SMG is based on the previous activities of the garden as a place for social gatherings, cultural activities, and recreational activities, alongside a new perspective defined by decision-makers for promoting and preserving biodiversity, which citizens supported. For the reopening of SMG, through collaborative sessions with citizens and stakeholders, SMG is envisioned as a multifunctional and multispecies garden. To achieve this vision, the gardens have to be a place for “collective use and enjoyment for everybody” and provide a context for “participation in the life of the garden.” Additionally, SMG has to be a place that activates “sensory activities and observation [of nature]” and be a shared place both for “human activities and nature” with “collective use and enjoyment” with “increased sense of belonging”. The participants also indicated the idea of having “an educational garden” with “a variety of

initiatives” for different activities. With the defined vision and objectives for SMG, the social values are centered on cultural and collective activities within the garden. In contrast, ecological values focus on preserving and promoting biodiversity (in general, nature) while enjoying its benefits. These values are later confirmed through the selected ES and benefits reported by participants, as their selections mainly were focused on cultural and regulating ES (such as controlling noise and heat, reducing depression, observing different species, aesthetic aspects, and immersive activities within nature). Discovered visions, objectives, and values initially aided the process of defining the indicators and helped to define Strategic Future and the Desired Future.

5.4.1.2. Defining social-ecological indicators

The social and ecological indicators are defined based on input from collaborative sessions, selected ES benefits identified by citizens, priorities set by decision-makers in the case study, and elaboration from the context, visions, objectives, and values. As SMG is envisioned as a multifunctional garden with a variety of cultural activities for socio-cultural benefits, the social indicators are defined based on the social functionality of the garden and changes in perception over time. The social indicators consist of 1. Number of park visitors in different age groups (S1), 2. Number of sociocultural activities/gatherings held in SMG (S2) 3. Perception of SMG functionality (S3), and 4. Local sense of belonging regarding SMG (S4). The first and second indicators are measured through field observations and local activity logs submitted by citizens. The third and fourth indicators are measured through constant monitoring and direct interaction with citizens over time, as well as through interviews, while also collecting information via online questionnaires. For a biodiverse garden, ecological indicators are established based on the priority of preserving biodiversity and nature in SMG, the perception of nature by citizens, and the use of information provided by sensors in SMG to measure the presence of animals. The ecological indicators consist of 1. Perception of greenery (perceived flora/fauna richness) (E1), 2. Level of green coverage and seasonal stability (E2), 3. Pollinators' abundance (E3) and 4. Temperature and heat level within SMG (E4). The first two indicators are measured through direct interactions and interviews, as well as online information submission by citizens. The information of the last two indicators is collected by planted sensors and cameras and provided information through remote sensing with SMG.

Based on the discovered vision, objectives, and priorities (in relation to social-ecological variables), the status of SMG, and experts' opinions (including botany and biology experts and counselors from the municipality and cooperatives, the research team involved in the co-creation, and the author), the indicators are weighted using the AHP method. The weighting helps planners to focus on indicators that have more value for citizens (Mahmoud, 2024). Additionally, weighing renders the trade-off between the indicators, which are crucial for building future scenarios and evaluating changes in social-ecological systems. Based on the AHP results, S4, E4, S3, and E4, in that order, have the highest weights. These results are consistent with what citizens indicated as priorities through collaborative sessions, especially challenges such as high heat,

improper use of the garden, decay of biodiversity in the SMG, and the surrounding environment. See Supplementary Material 8 for the AHP matrix of indicator pairings and the weighting of each indicator. The results in this section enable planners and assessors to track changes over time using defined indicators and priority challenges established by citizens and stakeholders, and to develop future scenarios based on the importance of these challenges and the changes they represent.

5.4.1.3. Defining desired, strategic, and plausible future scenarios

Based on the collaborative activities and assessment results, and considering the established vision, objectives, selected ES, indicators, and input from citizens, the resulting Desired Future envisioned for SMG focuses on Nature as Culture and Nature for Society, with less emphasis on Nature for Nature. Visioning SMG as a multifunctional space with a variety of initiatives for cultural activities and enjoying nature, along with immersive experiences, indicates this trend. Additionally, the selection of ES benefits for the future of SMG primarily focuses on regulatory and cultural benefits, such as living in harmony with nature, which aligns with the general aim of the vision. While SMG is envisioned as a multispecies garden for citizens, the values of nature and biodiversity take on meaning within cultural use and interaction with nature. Figure 24a renders the position of the Desired Future for SMG within the LNFF triangulation (in each triangulation of LNFF for each of Nature for Nature, Nature for Society, and Nature as Culture, the minimum value is zero, and the maximum value is ten). The conditions of the Desired Future (as described in previous sections) are based on citizens' desire for the future, while the Strategic Future might be different. The status of the Strategic Future is determined by contextual attributes, citizens' desires, political and administrative constraints, and current policies and strategies tailored to the context. In short, a Strategic Future covers more variables and challenges than it covers limitations and contextual variables. In the case of SMG, the Strategic Future has a greater tendency toward Nature for Nature, provided that policies by the local administration are in place for the preservation of biodiversity and the establishment of an inaccessible biodiverse area. Simultaneously, in the Strategic Future, Nature as Culture has relatively lower values than the Desired Future, as a variety of cultural activities proposed in collaborative sessions are more feasible than those in SMG. The Nature for Society values in this case take on a higher value in certain areas of SMG that are designed for direct utility from nature (e.g., the recreational area and dog area). Figure 24b illustrates the positioning of the Strategic Future of SMG within LNFF.

Besides Strategic Future and Desired Future, there are a variety of Plausible Futures for SMG. Based on changes in social-ecological status (multifunctionality and multispecies), each of Nature for Nature, Nature as Culture, and Nature for Society might get different values. Among all possible futures, certain conditions, including minimal or maximized use of SMG, rapid decline or increase in biodiversity status, changes in use patterns (e.g., from cultural to utilitarian), or changes in policies and the limiting of biodiversity areas, are more plausible. A

series of these futures is also indicated through collaborative sessions (such as the rise of biodiversity or social use), and experts (as defined in 5.4.1.2) or decision-makers assume the rest based on possibilities and existing challenges. Defining plausible futures helps planners to gather an overview of future possibilities and prepare strategies and policies accordingly. Additionally, establishing Plausible Futures is essential for developing contingency plans. Plausible Futures in each case might differ based on contextual specifications, policies, challenges, and limitations. For the case of SMG analysis, the five most Plausible Futures are 1. Public overuse and biodiversity diminish (PF1), 2. Stabilized biodiversity status and minimized public use (PF2), 3. Focus on cultural activities in harmony with nature (PF3), 4. Balanced development with trade-offs (PF4), and 5. Local climate adaptation interventions for social support (PF5). Figure 24c shows a set of Plausible Futures within the LNFF structure for SMG.

After defining Plausible Futures (including Desired Future and Strategic Future), to aid the decision-making process, an optimal future (OF) (the most aligned scenario with stakeholders' values and priorities in relation to the defined indicators, and in comparison to other scenarios) must be identified. Discovering OF aids planners prioritize the next steps and define more precise strategies and policies in conditions of deep uncertainty. After optimization within defined Plausible Futures (see section 3.3 and

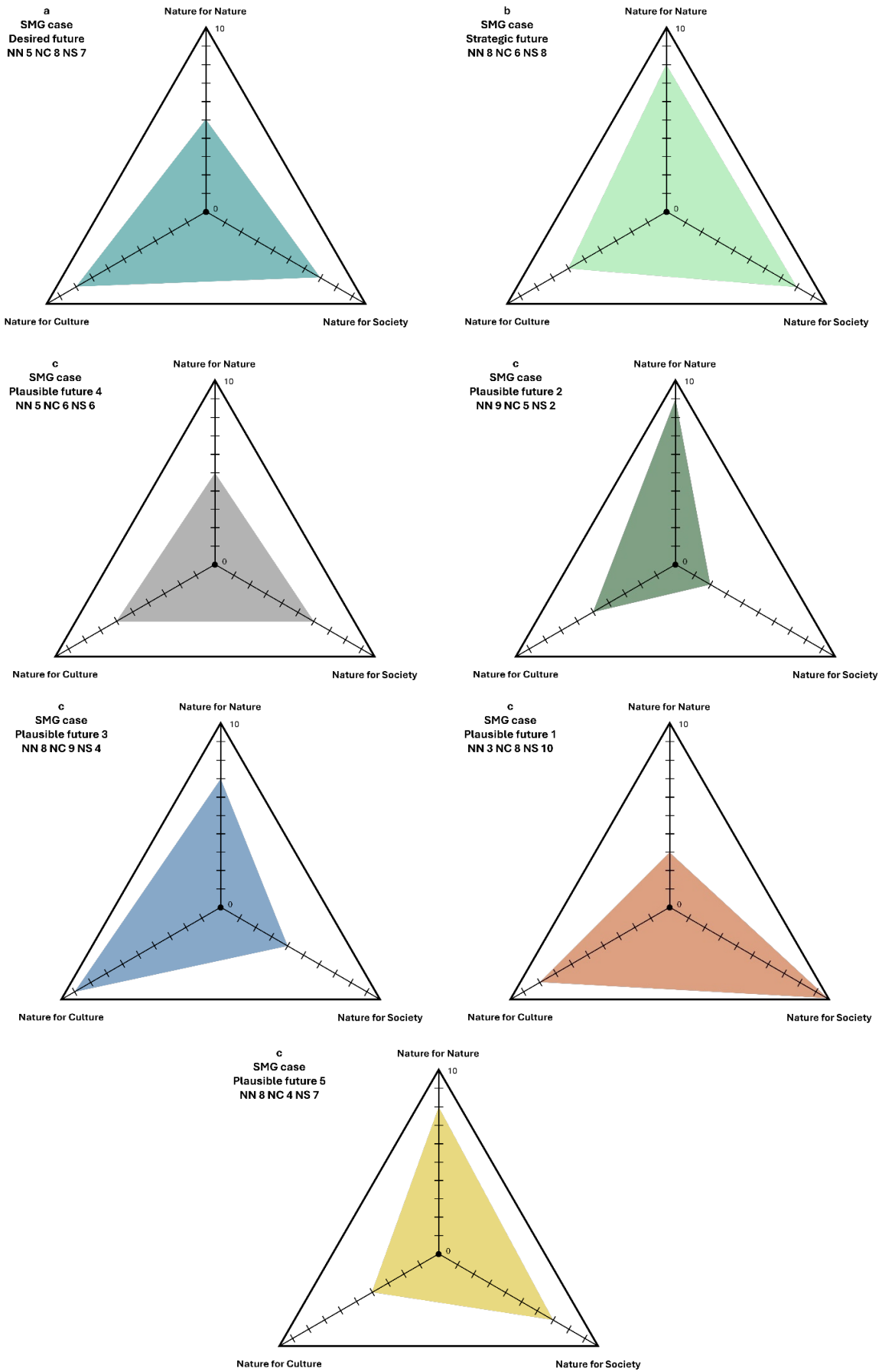


Figure 24: (a) Desired future, (b) Strategic future, (c) Plausible future scenarios at SMG.

Supplementary Material 8 for the process and calculations), within non-dominated Plausible Futures, PF3 has the highest utility values of 7.45, followed in order by Strategic Future (7.35), PF5 (6.46) (Strategic Future logically dominates this Plausible Future), Desired Future (6.44), PF1 (6.21), and PF2 (6.13). PF7, with a utility value of 5.56 in process optimization, is deemed to be dominated, indicating that while it is plausible, it is least aligned with stakeholders' values and is objectively less efficient compared to Pareto Front choices. The Plausible Future on the Pareto Front represents optimal trade-offs between the competing objectives. In contrast, the dominated future represents sub-optimal trade-offs, as its outcomes could be improved without necessitating sacrifices in other dimensions. The results of this section form the foundation for defining strategies and policies for the future.

5.4.1.4. Constructing possible strategies and policies

While Optimal Future, Desired Future, and Strategic Future are identified, the future of SMG remains in a state of deep uncertainty, facing challenges such as biodiversity decline and a lack of public engagement. This step involves building prioritized and efficient Plausible Futures, defining general strategies and policies that lead SMG towards a stable social-ecological system with the objective of being multifunctional and multispecies. The analysis reveals that the highest-ranking scenarios (PF3, Strategic Future, PF5, Desired Future) are those that demonstrate higher performance in the most heavily weighted dimensions of Nature for Nature and Nature as Culture. This indicates that achieving an optimal outcome, as defined by stakeholder priorities, requires a strategic focus on these two primary objectives. In SMG, the preservation of biodiversity has priority for both decision-makers and citizens. Additionally, SMG is a local urban park, where public use and cultural activities are granted and must be maintained. To maintain a balance, the primary strategy must be to promote biodiversity alongside local-scale sociocultural activities that do not compromise the status of nature. This approach limits the Ns perspective and avoids domination of public activities in the system and overuse of SMG. Additionally, as biodiversity is decaying in its baseline status, interventions with a focus on biodiversity promotion are encouraged. Ultimately, as indicated through collaborative sessions, due to extreme heat and lack of proper social infrastructure in the park, providing basic furniture and nature-based solutions for public activity is essential to provide a certain level of social activity.

To bring strategies and policies into action and achieve a multifunctional garden, local sociocultural activities are encouraged by reviving green shading structures, adding local furniture such as benches, and providing small gathering spaces. Additionally, informative panels are provided to educate visitors about biodiversity and the garden's perspective. To control public use of SMG, entry with dogs is limited to designated areas only. Also, small patches of open green spaces surrounded by natural elements are provided to allow visitors to enjoy themselves through immersive activities. To achieve a multispecies garden, an area with high biodiversity is considered alongside the border with the railyard (separated by a green barrier), which is not accessible to the public. Additionally, small ponds, insect hotels, and birdhouses are provided in

the high-biodiversity area and dense green patches through SMG, which facilitates the living conditions of different species. Ultimately, installed sensors for monitoring species activities (e.g., pollinators and birds, local flora) aid planners in establishing a constant monitoring procedure.

5.4.1.5. Developing contingency plans

To reduce uncertainty and enable adaptive management, it is necessary to indicate the risks involved with Plausible Futures. In this section, we focus on contingency plans for PF3, Strategic Future, and Desired Future, as these align most closely with local perceptions and indicators and are more efficient. Additionally, PF5, with the same approach, is considered dominated by Strategic Future. In the case of SMG, three major risks associated with the biodiversity crisis are perceivable: lack of social function, budget constraints, and conflicts among actors. In the event of a biodiversity crisis or decline, focusing on nature policies defined for PF3, PF5, and PF2 is encouraged, as these Plausible Futures have a more focused approach on the Nature for Nature dimension. In the absence of social functionality, social activities must be facilitated. This facilitation can be achieved by focusing on policies that promote intensive social use of the park (policies from PF1, Strategic Future) or sociocultural activities that are more in harmony with nature (policies and actions from PF3, Desired Future, or PF1). In cases of budget constraints or conflicts among actors, low-barrier activities (such as collective gardening or community gatherings) are recommended. In this case, following policies from a more balanced Plausible Futures (such as Desired Future or Strategic Future) is advisable. Additionally, PF5 is considered to be dominated by Strategic Future and is an alternative option for Strategic Future. In the event of PF4 occurrence (as it is dominated by all other Plausible Futures), following policies from any other Plausible Future could result in a more efficient situation.

5.4.2. Application of LNFF for the Utrecht case study

The case of UUBG in Utrecht is an ex-post case study where the garden is established and functional. The primary aim in this case is the preservation and promotion of biodiversity, with a secondary priority to provide learning, research, and opportunities for visitors. The focus on biodiversity and nature, as well as activities in harmony with nature, and the structure of UUBG are the main aspects that shape LNFF in this case. This section, for brevity and simplicity, is brief. Results are presented with shorter elaborations, following the same logic described in Section 4.1. The conceptual framework, methodology, and analysis approach are identical to those outlined in the preceding sections.

5.4.2.1. Discovering visions, objectives, and values

The collaboratively defined vision at the UUBG case focuses on preserving and promoting biodiversity in an area that offers opportunities for learning and engagement among citizens. In this case, ecological aspects take priority over social aspects in the future vision due to the special attributes of the UUBG. The objectives are to maintain the status of nature and biodiversity, provide space for learning and engagement with nature, and provide a place for sociocultural

activities beyond daily life. The third objective is beyond the defined activities for UUBG; however, as participants in collaborative activities were mainly involved with institutions surrounding the case study and spent most of their daytime at the Science Pak, this objective has gained priority. The intrinsic values of nature in this context are widely recognized and acknowledged, which underscores the importance of maintaining the natural status of UUBG. As a result, the values of UUBG for participants are mostly defined through the intrinsic (more aligned with Nature for Nature) and cultural values (aligned with Nature as Culture) of nature (through activities and enjoyment). These values are confirmed and further elaborated by selecting ES benefits such as UUBG as a “place for spiritual fulfilment, cognitive development”, “improvement in biodiversity and better habitats for plants and pollinators”, “tranquility of place and less annoying noises”.

5.4.2.2. Defining social-ecological indicators

The indicators are the same as those in Section 4.1.2, but with different weights and measurement methods, based on collaborative inputs, defined objectives, and contextual realities. The measurement methods for S1 are based on entry inputs and the UUBG registry. For E1 and E2, data alongside local observations are obtained through remote sensing sources and local indicators. Considering the general objective at UUBG as a place for preserving biodiversity and social inputs from collaborative sessions, in total, ecological indicators (Nature for Nature dimension) have the highest priority and weight (total weight of 44.8 percent). The intrinsic values of nature and the priority in biodiversity preservation are both acknowledged by participants and decision-makers in UUBG as the first priority, which attests to the dominance of the Nature for Nature dimension in indicators and calculations. Sociocultural indicators (Nature as Culture dimension) (total weight of 33.10 percent) and social indicators (Nature for Society dimension) (total weight of 22.20 percent) are also aligned with priorities at UUBG and social inputs. As a result, besides ecological values, the cultural values (Nature as Culture) dimension has a higher priority than the Nature for Society dimension in UUBG. These priorities help to better construct the LNFF based on the perceptions of participants and the opinions of decision-makers.

5.4.2.3. Defining desired, strategic, and plausible future scenarios

Given the defined vision and objective, input from collaborative sessions, and ES selection by participants, the Desired Future at UUBG primarily builds on Nature for Nature and Nature as Culture dimensions, while the vision for Nature for Nature has a higher overall value. The selection of cultural ES and emphasis on biodiversity preservation priorities are attestation for this case. Figure 25a renders the triangulation of the Desired Future within LNFF for the UUBG case. The Strategic Future, in contrast to the Desired Future, places greater emphasis on the Nature for Society dimension and has more control over the Nature as Culture values. The approach for UUBG is to increase visitor numbers in the future by enhancing accessibility, while

still controlling the number of cultural activities taking place on the premises (which is lower than what participants desire).

Additionally, the Nature for Nature dimension has higher values, promoting biodiversity and its preservation, which are among the top priorities of UUBG. Figure 25b represents the position of Strategic Future for UUBG. The Plausible Future vision for UUBG, based on expert (the author based on input from previous Chapters) opinion and session inputs (and conceptually similar to SMG), are: 1. Increase in public and social use and a reduction in biodiversity levels (UPF1), 2. Increase cultural events and activities in harmony with nature (UPF2), and 3. Seasonal instability and reduced biodiversity (leading to reduced public use) (UPF3), 4. Development focused on biodiversity preservation (trade-off on lower public admission) (UPF4), and 5. Climate resilience approach with focus on public services (and surrounding areas) (UPF5). Figure 25c shows all the triangulations for the mentioned Plausible Futures.

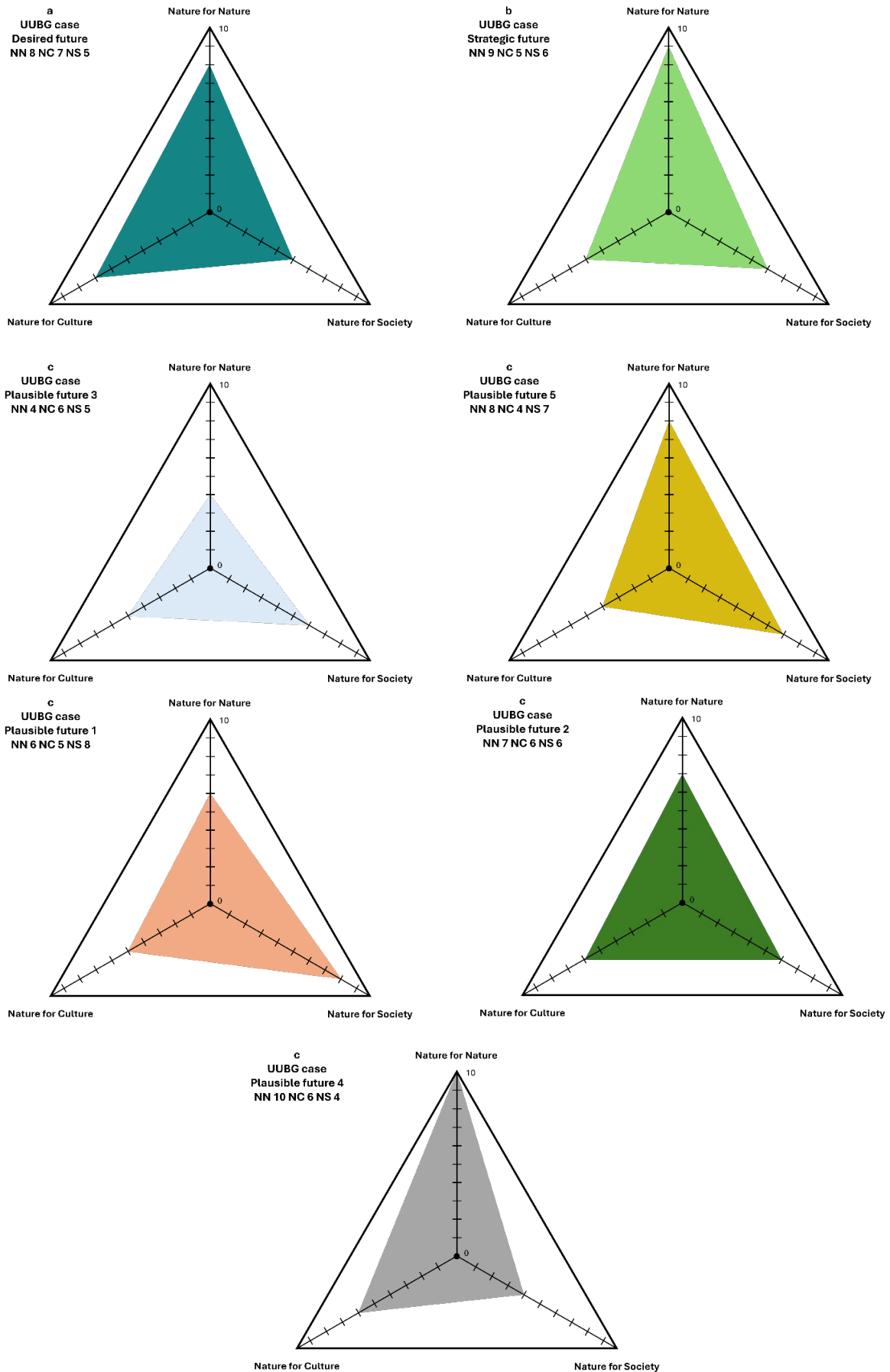


Figure 25: (a) Desired future, (b) Strategic future, (c) Plausible future scenarios at UUBG.

After defining Plausible Futures, Desired Future, and Strategic Future and optimizing them (for all calculations and processes see Supplementary Material 8), within non-dominated Plausible Futures, UPF4 has the highest utility value of 7.35, followed in order by Strategic Future (7.02), Desired Future (7.01), UPF5 (6.46), UPF2 (6.45), UPF1 (6.12). UPF3 is dominated by UPF2, with a utility value of 4.89, indicating the least alignment with vision, values, and indicators compared to other scenarios. All Plausible Futures, excluding UPF2, are on the Pareto front and represent sub-optimal trade-offs, as their outcomes could be improved without necessitating sacrifices in other dimensions.

5.4.2.4. Constructing possible strategies and policies

Focusing on the highest-ranked scenarios (UPF4, Strategic Future, Desired Future, UPF5), priorities are more concentrated on Nature for Nature and Nature as Culture dimensions, and subsequently, the strategies need to address this tendency. The suggested strategy at UUBG, which aligns with social input, prioritizes biodiversity preservation, even at the cost of a trade-off with sociocultural activities. Currently, specific locations at UUBG are unassailable and observable by the public; this strategy has the possibility of enforcement by this channel. Focusing on biodiversity in most scenarios often requires trade-offs between limiting public activities and achieving better performance. These trade-offs can be managed primarily through sociocultural activities with a focus on service areas in UUBG (rather than broad interventions) or designated pathways within the premises to minimize disruption to ecological systems. For promoting biodiversity in relation to social use, focusing on cultural activities and learning is an optimal strategy for continuation, considering social input and indicators. Policies need to focus more on limiting the overuse of social activities (NP dimension) and incentivizing activities that are in harmony with and respectful to nature. Furthermore, learning and immersive experiences through low-barrier activities are encouraged. Social use of nature is mostly preferred toward cultural activities rather than regulation issues, as participants mainly perceive the area as a place for relaxation, learning, and escape (break) from work or study. The current perception reflects that most uses of the park are within defined pathways around the waterbodies, and policies can encourage and highlight such activities by introducing local guiding elements.

5.4.2.5. Developing contingency plans

The main uncertainties and risks in the UUBG case are institutional and management policies, as well as social usage patterns. While the status of biodiversity in most scenarios is deemed to be stable or within an acceptable range (considering the baseline status of UUBG, which has a stable biodiversity status), changes in management policies or social interactions within the context of the Science Park are uncertain. For UPF4, in the case of institutional instability or financial constraints, the strategies and policies toward Strategic Future can be followed. Within this plan, the focus on ecological aspects has a higher priority, even if it means limiting costs for maintaining social activities. In case of limited social use and interactions in UPF4, Strategic

Future, and UPF5, policies defined by Desired Future are advised to follow to trigger community engagement at deeper levels. As Desired Future has a substantial focus on Nature for Nature and Nature as Culture dimensions, this path is the first alternative. In the case of extreme lack of engagement, policies of UPF1 offer more focus on social engagement at a cost, and less attention to the ecological aspect. Ultimately, in cases of excessive public use that threatens biodiversity preservation (UPF3 and 1), limiting policies and interventions from UPF4 and Desired Future are considered for contingency plans in UUBG. To see the trade-offs among all dimensions in each Plausible Future, see Supplementary Material 8.

5.5. Discussion

LNFF, based on established NFF advancements and variations, is designed to operationalize adaptive management of local urban social-ecological systems by integrating local actors' knowledge and priorities within the process of MCDA and optimization. LNFF aims to reduce uncertainty in the planning and decision-making processes by evaluating future scenarios and selecting optimal development scenarios while focusing on preserving and promoting the values of nature and biodiversity in urban areas. In this research, the proposed LNFF is operationalized and tested in two distinct urban green spaces. The analysis, based on social collaborative inputs, decision-makers' priorities, and contextual variables, successfully identifies desired, strategic, and optimal futures, alongside defining plausible future scenarios based on local values and insights. The findings reflect how social-ecological systems in each case study are uniquely defined, and counting differences and trade-offs can aid planners and policymakers in adapting to a state of deep uncertainty. Within this process, visions, objectives, values, indicators, and future scenarios are defined by the direct engagement of involved actors (Haase et al., 2017) at each context (e.g., see Morello et al., 2024), which showcases advancements from previous studies (Díaz et al., 2015; Sterling et al., 2017), especially at the local scale.

A principal finding of this innovative analysis is the clear demonstration that optimal future pathways for local urban green spaces are fundamentally context-dependent. LNFF identified distinctly different optimal futures and pathways for the two case studies, a result directly attributable to the unique priorities of stakeholders and decision-makers. In SMG, the analysis identified the Strategic Future as one of the most effective scenarios. This was due to a more balanced set of priorities where both Nature for Nature and Nature for Society were heavily weighted, rewarding the Strategic Future's strong, balanced performance across multiple dimensions. In contrast, at UUBG, the optimal path was UPF4, a future-focused program that almost exclusively focused on biodiversity preservation. This outcome was driven by the heavyweight local actors placed on the Nature for Nature dimension, reflecting the garden's core conservation and learning mission. These divergences highlight a critical conclusion that general and universal strategies for local green space management and planning are ineffective unless they contextualize their evaluation methods. The LNFF's ability to integrate local values (those that are primarily cultural and qualitative) through a structured weighting process (AHP) and

MCDA proves essential for tailoring strategic decisions to the specific social-ecological identity of a place.

While building on local social input, the application of a two-phase analytical method, combining Pareto optimization with a weighted sum model, is crucial for the robustness of the analysis and findings. By first applying Pareto optimization, planners can filter out such inefficient scenarios, ensuring that attention and priorities are given among a set of viable, efficient pathways. This two-step process adds a layer of objective, logical rigor that strengthens the credibility of the final recommendation, representing a key methodological strength of the LNFF in comparison to previous studies. Beyond identifying a single optimal future, this research provides a dynamic tool for adaptive management in the face of deep uncertainty (Bina et al., 2024). The use of the Pareto Front (Haga et al., 2023) serves as a viable strategic pivot for decision-makers. The contingency plans developed for each case illustrate practical application in situations where the future and change in variables are uncertain. Transforming the analysis from a static, one-time report into a live, flexible strategic guide, empowering planners (D'Alessio et al., 2025) to navigate an uncertain future by moving between known, efficient states rather than using limited data or biased data, while it covers both positive and negative (Oostvogels et al., 2024) futures of human-nature relations.

The learning and feedback step of LNFF makes this framework a live procedure that constantly monitors social and ecological status and adjusts the strategies and scenarios according to contextual changes (Frantzeskaki et al., 2024). The methodologies and indicators introduced in this research offer how the process of monitoring and learning can be conducted in collaboration with actors over time in a cost-effective manner. Monitoring and collaborative sessions can be adjusted based on the pace of changes in each case study and are flexible in response to changes in one or more sources of information over time. In contrast to previous NFF-based frameworks (e.g., H. Kim et al., 2023; Mansur et al., 2022; Mayer et al., 2023; Pereira et al., 2020; Shaikh & Hamel, 2023), LNFF is a continuous procedure that renders a picture of possibilities at the local scale, even in cases of data scarcity. LNFF is a step forward in contextualizing broad concepts of complex and uncertain human-nature relations (McPhearson et al., 2016; Nuno et al., 2014) at the local scale for sustainable and adaptive planning purposes.

Operationalizing LNFF faces several limitations. Firstly, the collection of social and ecological data may be limited due to a lack of participation or interest from actors, especially over a longer period of survey and monitoring. Additionally, a lack of diversity among participants might lead to biased perspectives and input. Similarly, collecting local ecological information relies on the use of precise indicators and expert elaboration, which faces administrative and scientific limitations. Secondly, the process of data interpretation and modeling, although structured, inherently carries subjectivity. The priority weights derived from the AHP and the performance scores assigned to each future scenario reflect the participants' values at a single point in time, whereas experts still determine these values. This means the identified "optimal" future is only optimal relative to this specific group and their current

priorities, which might be subject to bias. Future research on this topic should therefore focus not only on developing more effective low-barrier engagement methodologies for data collection but also on addressing the model's limitations. Constant re-evaluation and model update in the same case studies over time are essential as LNFF is a live framework. Furthermore, applying sensitivity analysis to the weights of the dimensions and indicators would test the robustness of the final rankings against changes in priorities. Finally, applying and testing the LNFF framework across a more exhaustive typology of urban green spaces is necessary to enhance the applicability of its findings and its utility as a local yet integrated planning tool. In an example from this research, both case studies are considered urban-scale botanic gardens, which are highly unique and exhibit an artificial form of nature, posing limitations and complicating the analysis of LNFF in each case. Future studies and analyses need to be explicit and placed in a wider context to support broader conclusions and examinations. For future research, it is recommended to apply this framework across multiple patches of green spaces with different typologies and participant structures to gather comparative information on the results.

Beyond operationalizing NFF at the local scale, NFF, as a framework, faces several criticisms and challenges, particularly in areas such as the lack of natural and biodiversity values inclusion, novelty in comparison to previous developments, such as Díaz et al. (2015), anthropocentrism, and a lack of multispecies thinking. Most importantly, concerning this research, the exclusion of time parameters is a key concern. In general, NFF limits its practical value for scenario analysis, ES management and planning, and governance at the scales where resilience, adaptation, and justice must be negotiated with local stakeholders. NFF evaluates the value of nature in relation to humans (as nature for society and nature as culture) while Nature for Nature offers an eco-centric perspective. In this case, one of its principal challenges is the limited inclusion and depth of Nature for Nature or intrinsic natural values. Despite its emphasis on plural value perspectives, NFF's organizational approach predominantly centers on nature's value through human lenses, which is either viewed as a resource for society or as tied to culture, while eco-centric, multispecies, or purely nature-centric logics are not robustly built into scenario methods or value mapping (Lazurko et al., 2025). Such conceptualization undermines nonhuman scenarios where nature plays a central role. To overcome this challenge, this research gives special attention to the intrinsic values of nature and biodiversity. Future research in this field should emphasize the intrinsic values of nature, independent of its social values and impacts, within the process of establishing visions, objectives, and indicators.

Another persistent critique is the lack of genuine conceptual novelty in the NFF compared to previous framings, such as Díaz et al. (2015). Additionally, the NFF's anthropocentrism and lack of multispecies thinking represent fundamental conceptual limitations. Coupled with critiques that the NFF largely rearranges existing paradigms without offering transformative innovation, these aspects underscore challenges in fully realizing its visionary potential. In fact, a recent study by Okayasu et al. (2025, p.1) emphasizes that *“while the framework is generally perceived as useful, challenges remain in integrating the NFF across multiple*

scales and fully incorporating plural values, particularly in measuring relational aspects and avoiding Western-centric biases.” To overcome such criticisms, recently, several developments have attempted to expand the perspective of NFF by considering both positive and negative values (Oostvogels et al., 2024), or tailoring it to a specific scale, like urban areas (Shaikh & Hamel, 2023), or elevating the discussion with the integration of narrative in the process of NFF (Durán et al., 2023). The most recent publications in this stream integrate NFF into the process of decision-making to aid planners in better mapping human-nature relations (e.g., Wolff et al., 2025). Based on the previous developments, this chapter broadens the conceptual structure of NFF as a process that, by incorporating local social-ecological values, supports decision-making through the provision of future scenarios. In this case, NFF is viewed as a dynamic and continuous framework that responds to social-ecological changes over time. Future studies in this case should focus on the comprehensive integration of local values, giving exceptional attention to community values, Aboriginal perspectives, and avoiding Western-centric biases (if applicable) throughout the process of establishing a continuous NFF.

Lastly, the exclusion of explicit temporal parameters constrains NFF’s ability to support dynamic, adaptive planning or scenario development aligned with ecological and social timescales relevant for urban and biodiversity futures. This limits the utility of NFF for transformative and adaptive decision-making. By treating social-ecological values as static states rather than dynamic and uncertain processes unfolding across multiple timescales, NFF limits its practical value for scenario analysis, planning, and governance at the scales where resilience, adaptation, and justice must be negotiated. These critical gaps highlight the need for refinements that link pluralistic value mapping to temporal realities, ensuring that frameworks like the NFF can effectively respond to the scientific and ethical complexities of urban futures. The proposed revision of NFF in this chapter provides a context for future studies to integrate time scales into the process of establishing a local framework and to explore pathways for structuring a usable NFF for short- to long-term planning, while focusing on both social and ecological values.

5.6. Conclusions

In a state of deep uncertainty, planning for urban social-ecological systems faces the challenge of navigating the future of human-nature relations amidst an accelerating loss of biodiversity. While adaptive planning through future-scenario making is a recognized approach, established frameworks are primarily designed for regional or city-wide scales and rely on quantitative data, leaving a gap at the local level where collaborative action often takes place, where social values and qualitative information are relied on. This research addresses that gap by introducing and testing LNFF as a novel approach tailored for adaptive planning of local green areas. The primary innovation of LNFF is its function as a live framework. Unlike other nature's future frameworks, it is designed to be iterative, continuously learning and adapting to new contextual information and stakeholder inputs. LNFF operationalizes this by structuring local knowledge into an MCDA procedure, creating a dynamic feedback loop between community values and scenario

optimization. The framework's effectiveness was validated by application in two distinct case studies (in Milan and Utrecht). In both contexts, the framework successfully translated qualitative social values and priorities into an evaluation model. Initially applying Pareto optimization principles to identify all efficient pathways (among Plausible Futures) and then using a weighted analysis based on local indicators within Nature for Nature, Nature as Culture, and Nature for Society dimensions to select the optimal scenarios, LNFF moves beyond prescribing a single, static pathway for the future. Instead, it enables planners with a spectrum of viable strategies, localized policies, actions, and contingency plans. This two-phase analysis, therefore, helps to reduce uncertainty not by predicting the future, but by clarifying the social-ecological trade-offs associated with each Plausible Future. LNFF provides a cost-effective, replicable, and inclusive decision-aiding framework for adaptive planning to investigate the future of social-ecological systems at the local scale in urban areas.

Chapter 6.

Developing Dynamic Adaptive Policy Pathways with Nature Future Framework for scenario-making at the local scale⁶

Abstract

The relationship between humans and nature in urban areas is in a condition of deep uncertainty, with factors such as climate change and biodiversity loss adding layers of complexity to decision-making. To tackle these challenges, adaptive planning provides a flexible context for guiding urban development, assuming multiple plausible futures based on social-ecological parameters. This research approaches adaptive planning in local urban areas by applying a Dynamic Adaptive Policy Pathways (DAPP) framework in combination with the Local Nature Futures Framework (LNFF) as a novel method. Through integration with local regulations, a co-creation process involving residents, stakeholders, and decision-makers systematically established visions, objectives, and preferences. The results initially identify plausible development pathways, each representing a unique scenario corresponding with locally defined visions. These pathways were evaluated against citizens' priorities and objectives, enabling the identification of preferred pathways that allow achieving the goal of multifunctionality and biodiversity in the case study. The analysis highlights the local policies and instruments that are most critical in directing transitions toward resilient and just urban futures, particularly those oriented towards Nature for Nature and nature for culture dimensions. This study demonstrates the potential application of DAPP at the local urban scale and a further possible, replicable, structured process for embedding citizen and decision-maker engagement in long-term shared or collaborative governance. By integrating adaptive planning with the Local Nature Futures Framework, this research provides decision-makers with an actionable framework to navigate deep uncertainty and data scarcity in evaluations and policy-making, offering pathways toward sustainable urban transformation.

6.1. Introduction

Cities are in a state of deep uncertainty due to the complexity of their social-ecological systems (Maier et al., 2016; Partelow, 2018). The deep uncertainty applies as we have limited knowledge of the dynamics of social-ecological components (E. Andersson et al., 2021; McPhearson et al.,

⁶ Chapter Six (citation below) is submitted to the Journal of Global Environmental Change in February 2026.

Ayatollahi, A., & Mahmoud, I. (forthcoming). Adaptive scenarios: Integrating dynamic adaptive policy pathways with local nature's future framework for decision-aiding at the urban scale. Case study from Milan, Italy.

2022; Partelow, 2018) and their context of interaction, and neither can we predict nor agree upon outcomes of interaction between humans and nature at the local scale over the long term, due to the variety of elements and factors (Haasnoot et al., 2013; Maier et al., 2016; Marchau et al., 2019b). Additionally, uncertainty also limits decision-makers' ability to make the best course of action over time (Marchau et al., 2019a). Challenges like climate change (R. Chapman et al., 2016; McCarthy et al., 2010; Pickett et al., 2024) and loss of urban biodiversity, which causes an imbalance in ecological systems (Ignatieva et al., 2023; Settele, 2022), are also adding layers of complexity to the state of uncertainty. To overcome challenges of deep uncertainty in the field of urban planning and ecology, adaptive planning and management for social-ecological systems planning came to attention as a shift from “predict-and-acts” paradigms (Malekpour & Newig, 2020) to “monitor and adapt” paradigm (Marchau et al., 2019b). In contrast to conventional approaches of planning, adaptive planning, in the condition of deep uncertainty, assumes multiple plausible futures (Haasnoot et al., 2013) that are adaptable (flexible) to changes over time. Assuming multiple futures allows planners to consider conditions of failure over time if plausible conditions of success are not met, planners adapt new pathways of development based on contextual realities (W. Walker et al., 2013; W. E. Walker et al., 2019). In an ideal and functional process of adaptive planning, with focus on uncertainty, three key elements of scenarios (multiple plausible futures), options (pathways for actions), and monitoring (to establish a tipping point) (Malekpour & Newig, 2020), are actively interacting with each other over time as a feedback loop to deal with uncertainty.

By considering the three key elements, the concept of adaptive planning has been applied in different fields, including urban or regional planning, through multiple approaches and methodologies, such as robust decision-making (Mousavi Janbehsarayi et al., 2024; Wester, 2022), dynamic adaptive planning (W. E. Walker et al., 2019), info-gap decision theory (Ben-Haim, 2019; Broitman & Ben-Haim, 2022), scenario planning (Cordova-Pozo & Rouwette, 2023; Liu & Wu, 2022), and dynamic adaptive policy pathways (DAPP) (Haasnoot et al., 2013; Lawrence et al., 2025; Rosello et al., 2022). Among various adaptive planning approaches and methods, DAPP stands out as an approach that combines adaptation pathways (Haasnoot et al., 2012) and adaptive policy making (Kwakkel et al., 2010) by use of a transient scenario with a constant monitoring perspective through time (Haasnoot et al., 2013, 2024) within a dynamic loop. DAPP was initially developed by Haasnoot et al. (2013) for application at the regional scale of water and flood management and later developed by contributions mostly at the same scale (e.g., Carstens et al., 2019; Rosello et al., 2022; Toimil et al., 2021) to deal with uncertainty. A demonstration of the DAPP approach and steps is presented in Figure 26.

The core feature of the DAPP methodology lies in constructing and identifying preferred pathways of development over time using adaptation tipping points (ATPs) (Werners et al., 2013) or the sell-by date of each action (Haasnoot et al., 2013). In DAPP, when reaching ATP, contingency plans are used to switch between pathways, offering flexibility in choice over time. Another advantage of DAPP for use at the urban scale is its ability to provide constant monitoring

and adaptation, which enables the involvement of actors and stakeholders across different time frames to optimize pathways based on contextual realities that address the challenges of stakeholder involvement (M. Chapman et al., 2023). Features such as constant monitoring capabilities, vulnerability and opportunity assessments, and the provision of contingency plans over time through the use of ATPs make DAPP a methodology with the capacity for adaptation at the urban scale, where planners are dealing with a wide range of social and ecological parameters (Haasnoot et al., 2024). As a result, this research specifically focuses on using DAPP for adaptive planning on the local urban scale, while also attempting to address its limitations for use at such a scale, which has significant differences compared to regional or national scales.

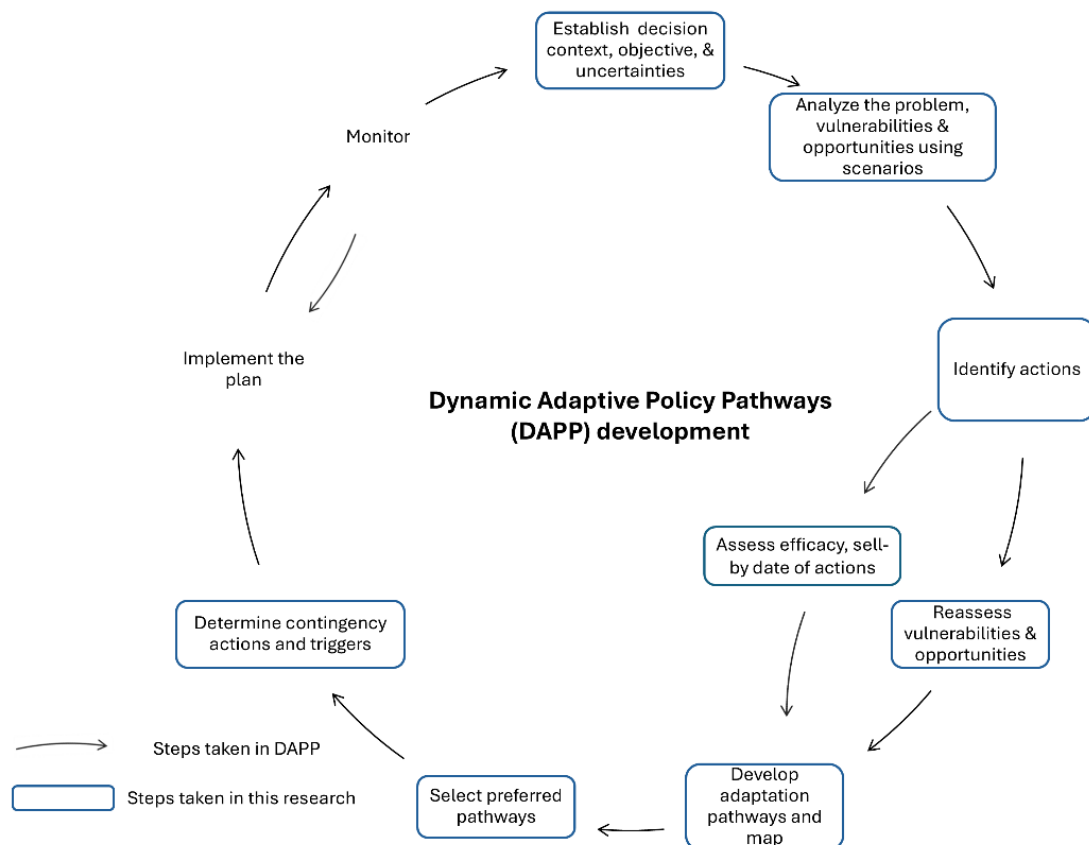


Figure 26: Adaptation of the DAPP development cycle for this research, adapted from Haasnoot et al. (2013).

As DAPP presents a unique capacity for use in adaptive planning at the urban scale, it also highlights the limitations and challenges associated with such adaptation. The primary challenge lies in integrating social-ecological system dynamics and parameters into the DAPP process. The relationship between humans and nature in cities is deeply uncertain due to the details and diversity in social perceptions and valuation of green spaces (Jim & Chen, 2006; Nóbrega-Carriquiry et al., 2023; Thiemann et al., 2022) and constant changes in ecological dynamics, especially with pressures like climate change and biodiversity loss (Kowarik, 2023; Rega-Brodsky et al., 2022; Schwarz et al., 2017; Visintin et al., 2025). While DAPP is an essential tool in scenario-making, its process might overlook or oversimplify essential social-ecological parameters in evaluations. To improve accuracy and coverage of future social-ecological dynamic evaluations,

several frameworks have been developed (Grêt-Regamey et al., 2015; McPhearson et al., 2022; Ostrom, 2009), while the most holistic and conventional one for such a purpose is the Nature Futures Framework (NFF) (Haga et al., 2023; Mayer et al., 2023; Pereira et al., 2020). As elaborated by (Pereira et al., 2020), NFF is a “*heuristic that captures diverse, positive values for human–nature relationships in a triangular space. We consider three main ways of valuing nature at each of the vertices (Nature for nature, nature for society, and nature as culture). The NFF builds on the three values of nature (intrinsic, instrumental, and relational values, respectively) identified by the IPBES and repurposes it to make it actionable for the modelling and scenarios community* (p. 1173).” By focusing on the local scale, local NFF (LNFF) serves as a flexible tool, allowing for the support and development of multiple scenarios based on local desires and perceptions, alongside decision-makers' valuation of the direct and indirect impacts of social systems on urban ecosystems, informed by both qualitative and quantitative information (Díaz et al., 2015). As LNFF addresses DAPP's social-ecological integration challenges, it also requires a methodology for gathering data at the local scale, where qualitative data are scarce due to limitations in indicators that address social perception (Ayatollahi & Morello, 2025).

The second challenge of DAPP adaptation is utilizing local information and data, which, in most cases, is centered on qualitative social information. As DAPP originally uses direct quantitative information (Haasnoot et al., 2013, 2019; W. Walker et al., 2013), incorporating qualitative local information into such an approach is deemed challenging (Haasnoot et al., 2019). This challenge is primarily addressed through the direct involvement of citizens in the data collection and interpretation process, aiming to increase the accuracy of local information (Mansur et al., 2022; Morello et al., 2024; Sterling et al., 2017). For this purpose, co-creation approaches (I. Andersson et al., 2023; Dumitru et al., 2020; Morello et al., 2024) are suitable methodologies as they establish a tested approach in direct involvement of local actors through the process of decision making to establish long-term visions (Mahmoud & Morello, 2021; C. M. Raymond et al., 2017). By gathering information through co-creation processes and relying on LNFF for framing and interpreting information for future scenarios, DAPP can be implemented to facilitate adaptive scenario making in urban areas, utilizing local information on social-ecological systems.

The novelty of using DAPP for decision-aiding in urban areas lies in its functionality as an approach to making more informed decisions and policies in line with a wide range of frameworks and regulations. While originally DAPP was used for proposing alternative future routes (Haasnoot et al., 2019). It can also explore the future of policy implementation in different social-ecological conditions. The policies have to be evaluated based on the given strategies and frameworks, while planners explore alternative pathways for sustainable future optimization (Haasnoot et al., 2013; W. Walker et al., 2013). Previous studies (Mahmoud, Morello, Vona, et al., 2021; Raymond et al., 2017; Sarabi et al., 2023) have explored how analyzing local social-ecological systems reveals essential information for decision makers, while they lack addressing how this information aids planners in finding optimal future scenarios of development

(Herrmann et al., 2021). Scenario making and modelling for future studies in the field of planning is evolving (see: Frantzeskaki et al., 2024; Rounsevell et al., 2021), while mainly quantitative large-scale models dominate the methodologies for scenario making in relevance to policies. Using DAPP in conjunction with LNFF and the co-creation process could shed light on utilizing qualitative social information to inform policies at the local scale, with the flexibility to explore different alternatives over time.

In this research, by focusing on the gap in literature and practice on adaptive planning methodologies at local urban areas in using social-ecological qualitative data for scenario making, we adapt, explore, and test the DAPP approach for policy making by integrating it with established frameworks such as NFF at the local scale and using co-creation approaches for data acquisition. In the context of addressing deep uncertainty in policy-making in urban areas, this research aims to explore adaptive scenario-making methodologies in urban areas and analyze future social-ecological systems to make flexible and informed policies in line with local priorities. The main question in this case is how adaptive decision-making can reduce deep uncertainty around local social-ecological systems for an informed course of policy-making by using DAPP methodology. To answer this question, as a novel approach, this research adapts and applies the DAPP framework in integration with LNFF in a local case study of Sorelle Mirabal Garden in Italy and combines qualitative (using the co-design process embedded in co-creation activities) and quantitative data for such purpose. Finally, by analyzing future scenarios and results, we explore the relevance of local policies and upper-hand strategies in relation to the outcomes, and propose future scenarios over time, considering different development possibilities. The results primarily establish a comprehensive methodology for adaptive planning at the local scale and contribute to the ongoing discourse on policy-making for urban green areas based on social values.

6.2. Conceptual framework

This section provides a brief introduction to the original DAPP framework in the first part, and the second part covers how DAPP is adapted for this research.

6.2.1. Dynamic Adaptive Policy Pathways (DAPP)

To address existing gaps in static planning under deep uncertainty conditions, DAPP is primarily established to reinforce and develop an adaptive planning process that can navigate changing conditions across short and long-term visions by emphasizing ATPs and flexible decision sequences through multiple future scenarios (Haasnoot et al., 2013, 2019; W. Walker et al., 2013). DAPP provides structured pathways for transitioning between policy options based on monitored trigger points and changes in the evaluation context's conditions. To achieve defined objectives under uncertainty, DAPP deploys a staged decision-making approach that combines near-term actions with multiple long-term options, each responsive to scenario-dependent threshold conditions and monitoring signals. These pathways outline how adaptive management

unfolds over time and what monitoring indicators must be prioritized to trigger appropriate policy transitions and avoid lock-ins or failures. DAPP provides a decision-support system firstly by engaging stakeholders in the process of monitoring and scenario-making, and secondly by aiding planners in identifying optimal pathways of development. Methodologically, DAPP follows a structured, vulnerability-based, bottom-up methodology that combines two complementary approaches of adaptive policymaking and adaptation pathways. The methodology systematically progresses through multiple analytical phases, from a qualitative, narrative-based assessment to a comprehensive, model-based evaluation, incorporating core components such as signposts (monitoring indicators), triggers (thresholds), pathway maps (visualization), and scorecards (performance summaries). DAPP is an established yet evolving methodology, and its rollout in real-world cases covers interrelated areas such as urban planning, coastal adaptation, ecosystem services, infrastructure development, and climate resilience planning across local to national scales. Despite this, most case studies in this context focus on water and flood management on a national or regional scale, with fewer studies focusing on smaller scales, such as urban areas.

6.2.2. Adapting Dynamic Adaptive Policy Pathways for use at the local scale

The process of adaptive scenario and policy making of this research is based on the original research of DAPP by (Haasnoot et al., 2013; W. Walker et al., 2013) and its later developments (Haasnoot et al., 2019, 2024; Kwakkel & Haasnoot, 2019; Muccione et al., 2024), and practices (e.g., Carstens et al., 2019; Lawrence et al., 2025; Toimil et al., 2021). The knowledge of DAPP applications beyond water management, specifically for urban areas, is quite limited, as scientific applications at the local scale are not observable in the literature. For an accurate adaptation in this research, the general concept and steps proposed in the DAPP methodology are explained and followed through this research. The use of LNFF and co-creation approaches is further explained in Section 3. Methodology.

As mentioned by Haasnoot et al. (2013, p. 489), DAPP approach includes: “transient scenarios representing a variety of relevant uncertainties and their development over time; different types of actions to handle vulnerabilities and opportunities; Adaptation Pathways describing sequences of promising actions; and a monitoring system with related contingency actions to keep the plan on the track of a preferred pathway.” The DAPP process revolves around step-by-step course which primarily explores and defines contextual status, its vulnerabilities, and opportunities to establish ATPs (“*an adaptation tipping point [ATP] is the point at which a particular action is no longer adequate for meeting the plan’s objectives. New action is therefore necessary. A trigger specifies the conditions under which a prespecified action to change the plan is to be taken* (p. 486).” (Haasnoot et al., 2013). The ATPs are necessary to define the timing of necessary actions to change the pathways by using transient scenarios for future development (Haasnoot et al., 2019). In the next step, by designing adaptive plans (with their contingency actions) through pathways, DAPP offers the possibility to switch between courses of action when ATPs are triggered. In the final steps, after implementation of the plan, the monitoring phase is initiated to evaluate the situation

and check if the pathway requires modification or if it needs to change between different policies, and in this case, the DAPP follows a cycle of acquiring feedback and learning to improve the accuracy of pathways by passing through the same process over time. A detailed step-by-step guideline for DAPP implementation is available in Supplementary Material 9.

In this research, for adaptations, the steps of structuring pathways are followed, established by Haasnoot et al. (2019), by using data input gathered from the co-creation process. A decision context and objectives for the case study are established through participatory problem framing with decision-makers and stakeholders. The uncertainties and disagreements are identified by an expert's (the author, in collaboration with the research team involved in the co-creation process) opinion based on input from various actors. Followingly, vulnerabilities, opportunities, and tipping points are identified and assessed by considering relevant policies and recommendations from local experts (the councilor of environment for the local municipality of the case study, a botanical expert, and the directorate of civic service of the local municipality). Pathways are designed and generated based on expert opinion and within LNFF, considering both short-term and long-term horizons, as well as the points of concern suggested by citizens. In this framework, the three primary future scenarios for nature —Nature for Nature (NN), Nature as Culture (NC), and Nature for Society (NS)—originating from LNFF, are employed to establish the main pathways. The remaining pathways, preferred connections, and preparatory actions are developed based on expert opinion, incorporating input from upper-level plans and strategies, as well as input from the municipality and stakeholders. The last steps regarding implementation and monitoring have not been completed for this research, as the case study was recently reopened, and there is insufficient information to establish a baseline for analysis.

6.3. Methodology

The adaptive scenarios for the Sorelle Mirabal Garden (SMG) case study in Italy were developed using the DAPP framework, which involved data input through a co-creation process and relied on LNFF for data interpretation. After defining the boundaries and evaluating SMG, a co-creation process with citizens was implemented to reopen the garden. LNFF interpreted the data input, and DAPP then used the information to create adaptive scenarios. In this section, the contextual status of SMG, the co-creation process for data acquisition, and the use of LNFF for integration with DAPP are elaborated.

6.3.1. Case study of Sorelle Mirabal Garden

The case study is a local urban park located in east Milan (Ortica neighborhood) and is bounded to the west by active railways, to the north and south by nursing homes, and to the east by streets and residential developments. The SMG, owned by the municipality, covers 17900 square meters of area and was closed to the public during the COVID pandemic. For reopening, the redesign aimed to preserve the garden's past identity while leveraging urban biodiversity (Morello et al., 2024). In this process, the preservation of biodiversity and nature, alongside sustainable public

use for recreation, were the primary priorities for reopening. The reopening process took place between May and June through three workshops and one session with stakeholders, including the municipality and experts (ibid). The garden reopened in May 2025 with a dedicated inaccessible biodiversity area, biodiversity monitoring equipment, and spaces for recreation and public use (ibid). Figure 27 showcases the status of the garden and surrounding areas.



Figure 27: Current status of SMG with the location of sensors and the biodiversity area.

6.3.2. Co-design and co-creation process

The co-design process (embedded in a co-creation process) consisted of direct engagement with citizens and stakeholders in open-discussion format sessions to develop analysis on SMG vulnerabilities and strengths (through SWOT analysis), mapping ecosystem services and prioritizing their benefits for the use of the SMG through a collective process, multi-species immersion activity by identifying species with citizens, defining vision, missions, and objectives, and finally evaluating and selection interventions and new measure for SMG (Ayatollahi & Morello, 2025; Morello et al., 2024). The inputs from the process are analyzed at both individual and collective levels. Both individual and collective responses are used for problem framing, establishing system boundaries, identification, and evaluation of development scenarios. Additionally, collective responses and elaborated information from the sessions are used for specifying objectives and outcome indicators, identifying uncertainties, developing transient

scenarios, assessing and adjusting timing of tipping points and horizons, exploring adaptation and development pathways, evaluating trade-offs, selecting preferred pathways based on public desire, and finally specifying short to long-term actions and preparatory options. In this process, through consultation with experts and decision-makers from the municipality, the compatibility of the outcomes with upper-hand plans and strategies is verified. It is necessary to mention that the data collected for this research are primarily extracted from co-design activities embedded in the co-creation process. Information gathered through activities such as inception, ideation, co-planning, and co-monitoring is largely excluded from the analysis.

6.3.3. Local Nature Futures Framework

The input from the co-creation process and analysis of the case study are interpreted through LNFF to fit into the DAPP framework. The LNFF suggests three visions of NN (Nature for Nature), NC (Nature as Culture), and NS (Nature for Society) regarding human-nature relations, specifically nature to humans (Pereira et al., 2020), in a defined time horizon (Díaz et al., 2015). The Nature for Nature vision represents a future mainly focused on the intrinsic values of nature, the Nature as Culture vision represents a living in harmony between humans and nature, mostly focusing on cultural values, and ultimately, the Nature for Society focuses on the benefits to people and the provision of ecosystem services (utility values) (Pereira et al., 2020). Each scenario (future) gains its values and attributes from inputs acquired through co-creation sessions or policies and strategies defined for the case study.

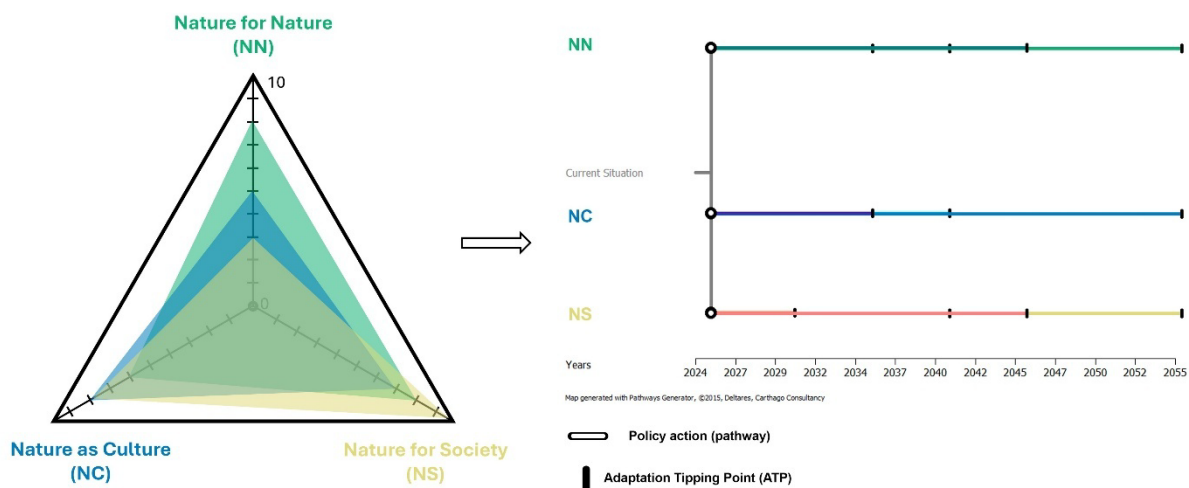


Figure 28: Establishing three main scenarios of DAPP based on LNFF dimensions.

In this research, three dimensions of Nature for Nature, Nature as Culture, and Nature for Society, are considered as main scenarios of development, and based on inputs from the co-creation process, transient scenarios, ATPs, and pathways are defined. This approach ensures that all possible interactions between humans and nature are covered through three general scenarios or the scenarios between them. The time horizons for each scenario are determined by the upper-hand plans' visions or expert interpretations (as defined in 6.2.2) from the context. The LNFF

integration in DAPP is through the third and fourth steps (identifying and designing pathways) by identifying and replacing primarily future scenarios with Nature for Nature, Nature as Culture, and Nature for Society. After establishing three main pathways, the secondary pathway can originate from the established scenarios by assigning different values to each future vision. For instance, in the Nature for Nature scenario, if, through time, public use and utility values of the SMG gain higher priority, a secondary scenario between Nature for Nature and Nature for Society (preparatory course of actions) takes place, which focuses on balancing the social use and restoring the green area while the intensity of nature preservation is lower than the original Nature for Nature scenario. Figure 28 illustrates how the co-creation process and LNFF are integrated to support the scenario-making process within the DAPP framework.

6.4. Results

The results present the progress of DAPP realization through the step-by-step guide provided by Haasnoot et al. (2019). The first section of the results focuses on problem framing, defining objectives, uncertainties, vulnerabilities, and opportunities, as well as assessing the timing of tipping points within the context of SMG, elaborated from co-creation sessions. The second section identifies and evaluates pathways and options for tipping points, which is followed by designing pathways and generating a pathways map to evaluate trade-offs between different options. The final section is dedicated to selecting preferred pathways and specifying short to long-term options. A comprehensive list of detailed elaborations for context evaluation within the DAPP framework, along with evaluations based on analysis, is available in Supplementary Material 10.

6.4.1. Evaluating the case study

By establishing the decision context of SMG as a local park planned for reopening with a focus on leveraging biodiversity along social use, in participation of citizens, stakeholders from local communities, experts from academia, and administrative units, problems and objectives are framed collectively. Initial constraints stated by participants are divided into ecological issues, such as decline in nature status and instability in biodiversity status, and social issues, such as concerns around public use and engagement with the Garden. Additionally, residents indicated noise issues from the railyard west of the Garden, and administrative stakeholders stated political limits of interventions, mainly concerning safety regulations. In this context, two main objectives of a multispecies and multifunctional garden for the future of SMG are agreed upon by participants. The multispecies garden mainly addresses future ecological challenges, aiming for a place where different species could have equal access to the Garden. Equally multifunctionality objectives indicate the aim for using the Garden not only as a public space for social use but also as a place for relaxation, learning, and interaction (both humans and other species). Secondary objectives that are indicated by participants are making the SMG a place for enjoyment and respect for citizens, creating a sense of belonging, and involving citizens in the process of the Garden's maintenance in the future. Through the process, the social and ecological future of

SMG had equal importance for the participants. To see a complete description of the vulnerabilities, opportunities, uncertainties, and disagreements, see Supplementary Material 9.

To meet the objectives, the established indicators, based on expert inputs, are divided into social and ecological sections. The ecological indicators are primarily quantitative biodiversity sustainability indicators (1. amount of pollinators per day, 2. air quality in the neighbor, 3. amount of tree canopy coverage at SMG, 4. temperature at SMG) which are measured by the installed indicators at SMG or through remote sensing information on daily (for local sensors) and monthly (for remote sensing) bases and changes over time (yearly bases) indicate improvement or decline in biodiversity status. Additionally, four qualitative indicators of 5. amount of animal observations in the SMG area, 6. local perception on greenery coverage, 7. perceived plant richness at SMG, and 8. plants' seasonal stability are established. These indicators are measured through anonymous online reports from citizens or by expert observations on a bimonthly basis. Qualitative indicators provide the opportunity to directly engage locals' opinions in the process of decision-making over time and enrich the calculations by integrating local perceptions in measurements. The social indicators are focused on public opinion, which are 9. perception of park multifunctionality (increase in visitors, diversity in age and activities), 10. perception and awareness of SMG functions (number of events and gatherings and their type) 11. Sense of belonging (local awareness of activities at SMG, changes in social gathering patterns, or social use). The information for social indicators is collected through public information gathered from a public online questionnaire constantly accessible to visitors and interviews conducted at SMG with users on a bimonthly basis.

Ultimately, after evaluating the decision context, three initial scenario types based on LNFF dimensions are established, which are elaborated upon in consideration of the stakeholders' objectives and inputs. The first scenario is the Nature for Nature, within which policies are dedicated to the preservation of nature and biodiversity at SMG, with limited public and social use of spaces. This scenario aims to raise awareness about the intrinsic natural values and mutual respect for nature. The second scenario involves Nature as Culture, characterized by moderate local social activities and gatherings in the park, the preservation of biodiverse areas, controlled use of space, and increased awareness of local values. This scenario focuses on cultural activities and limits intense public use of the garden, while maintaining less restrictive policies for cultural activities. The last scenario is Nature for Society, which focuses on policies that encourage formal social use of the park by local stakeholders. In this scenario, multifunctionality as a local park is prioritized over biodiversity preservation policies, with a focus on the utility value of SMG and on using nature for public benefits and activities. By considering these scenarios, the long-term success condition of the garden can be addressed through any of these three scenarios. A successful scenario generally has to 1. Meet minimum biodiversity status set by guidelines (as measured through ecological indicators) 2. Foster a positive public perception of the park's long-term functionality and its natural benefits. 3. Meet the minimum guidelines set by the municipality, the commune, and the upper hand in planning for both biodiversity and

functionality. In a condition that any of the scenarios do not meet or approach these conditions, an ATP can be triggered to explore new pathways.

6.4.2. Identifying and evaluating adaptive pathways

Establishing pathways based on assessments primarily requires determining ATPs and opportunity tipping points (OTPs). Based on the analysis of context status, there are a total of eight ATPs and four OTPs for all scenarios together. The ATPs for each scenario are as follows, and the full description of ATPs and OTPs is available in Supplementary Material 10. For the Nature for Nature scenario, 2 ATPs of biodiversity decay and increased social use of SMG with breaching of biodiversity area, and 1 OTP of connecting SMG with the green corridor of botanical gardens in the west. For the Nature as Culture scenario 3 ATPs of biodiversity decay (same as Nature for Nature with lower threshold over time), shifting Identity of Garden in public perceptions, and mono dimensionality or lack of public use with 1 OTP of enforcing local policy (based on meeting the neighborhood's plan), which the Garden functions as one of the neighborhood centers for the cultural activities. Lastly, for the Nature for Society scenario 3, ATPs of Biodiversity collapse (below the lowest ecological threshold or in public perceptions), the closure of the Garden due to failure in coordination between actors for management and maintenance, and a lack of positive perception of ecosystem service functionality in public opinion in the long term. This scenario features two OTPs of Local developments, a higher function of regulating ecosystem services, and a higher budget allocation for the Garden's development and maintenance, as well as social activities in the medium to long term. As it is observable, tipping points are mainly centered on the objectives of multifunctionality and biodiversity of the SMG.

To determine the timing of the tipping points and based on the upper hand plans' horizons, three-time horizons, ranging from short- to long-term, are established. Horizons consist of short-term (2025-2030, 5 years from the current situation), mid-term (2030 -2040, 15 years from the current situation), and long-term (2040-2050, 25 years from the current situation) periods. In this case, as with most urban and local planning development schemes, visions, and strategies, the year 2050 is established as the longest horizon for this research, given that most planning documents set their time horizons between 2030 and 2050. Exploring horizons beyond 25 years at the local scale has proven to be difficult, as it involves a wide variety of parameters for which there are insufficient upper-hand or guiding documents to support or calculate them. To consider each scenario successful over a long-term horizon, it must achieve both multifunctionality and biodiversity objectives. In this context, each scenario can, over time, reach three states for each objective (a total of six states per scenario and 12 states in total), each of which triggers at the tipping point (either a shift to other pathways or a success condition). The ecological states consist of biodiversity decay (B-), no change in biodiversity (B/), and biodiversity improvement (B+). The social states are characterized by no social use of SMG or mono-functionality (S-), no change over time in the social use of SMG functionality (S/), and SMG multifunctionality with respect to nature (S+). As 2050 is the most extensive horizon, successful scenarios have to pass (be effective

and in action within both objectives) until the 2050 horizon or afterwards. The timing of each tipping point, based on the objectives' states, is shown in Table 6.

Table 6: Tipping point timing of each LNFF dimension based on the status of biodiversity and multifunctionality objectives.

LNFF dimension	No BD change	Negative BD	Positive BD	No social change	Negative social use	Positive social use
NN	2045	2035	>2050	2045	2040	2045
NC	2040	2035	>2050	>2050	2040	>2050
NS	2040	2030	>2050	>2050	2045	>2050

Based on elaborated timelines and timings, we can now explore alternative pathways in case a tipping point is triggered in each scenario. For each scenario, several plausible pathways are possible. For instance, in the case of biodiversity decline in Nature for Society or Nature as Culture scenarios, a combination of policies with Nature for Nature is conceivable, as conservation policies on biodiversity can lead to new pathways that prolong the sell-by date of the initial scenarios. On the contrary, for instance, in the Nature for Nature scenario, if the social use and multifunctionality of the Garden are deemed to be insufficient (or stagnated), at different

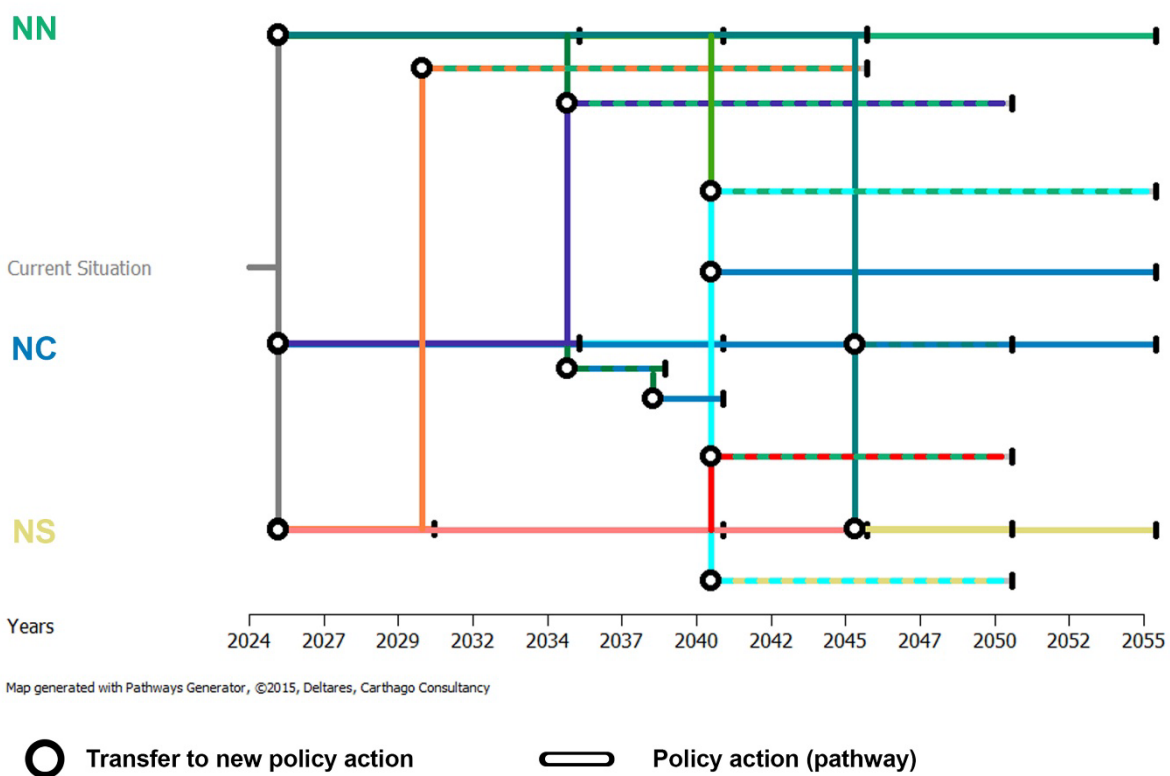


Figure 29: Pathways (scenarios) elaborated for the SMG based on LNFF dimensions.

time points, new combinations of pathways can be triggered which incentivize social activities through cultural (Nature as Culture) or daily activities (Nature for Society). There are several trade-offs between the three main scenarios due to the duality of objectives. Based on the severity of biodiversity decay or lack of social use, each of the main scenarios can adapt to new pathways in the short or long term. While most pathways are conceived to be successful beyond the horizon, pathways like biodiversity decay in Nature for Nature, with a sequence of focus on cultural policy, still lead to failure earlier than the horizon due to a lack of social functionality and biodiversity degradation. Considering all conceivable pathways with respect to ATPs results in the initial pathways map of all the scenarios and their connections, which is presented in Figure 29. In total, across three main LNFF scenarios, 22 pathways are conceivable, presenting overall future possibilities for meeting both objectives. To see a complete list of pathways, their connections, and types of pathways, see Supplementary 10.

6.4.3. Selecting the preferred based on the scores and finishing the results

The ultimate part is dedicated to evaluating the pathways for selecting the preferred pathways and establishing preparatory actions based on the results. Pathways are evaluated based on their societal impact (corresponding to the social objective), biodiversity conservation, and promotion of values (corresponding to the ecological objective), their co-benefits for citizens (corresponding to public perception on SMG), their provisional budget requirement (corresponding to maintenance and development limitations), policy alignment (corresponding to alignments with upper hand plans and policies at neighborhood and city level), and their resilience to external influence (corresponding to concerns such as climate change, extreme heat condition and unwanted social use). Each evaluation criterion consists of a range from +5 to -5, indicating optimal or weak performance for each criterion. Each criterion's performance can be measured through the indicators stated in Section 6.4.1, which, in complementary steps, such as regular evaluations in collaboration with the municipality, can further enrich. The evaluations are based on expert opinion derived from co-creation sessions, considering the local context and the results of indicators. The pathways are ranked and categorized based on their average score in calculations. A comprehensive evaluation list for each pathway, based on the aforementioned criteria, is available in Supplementary Material 10.

Initially, all three primary scenarios—Nature for Nature, Nature as Culture, and Nature for Society—are considered plausible and successful, with average scores of 8, 9, and 9, respectively. Despite their high score, assuming their success without changing to other pathways is less plausible, as there are uncertainties in both social and ecological aspects. As a result, among secondary scenarios, pathways that are based on a combination of Nature for Nature and Nature as Culture policies have higher scores (both with a score of 10). Following the Nature for Society scenario combined with the Nature for Nature scenario (in the case of biodiversity, no change in biodiversity status) has the highest total average of 7. Additionally, the sequence of scenarios from the social dimension decline in the Nature for Nature to the Nature as Culture pathway, and the combination of these scenarios in the case of no social change, both received an average score of

6. On the other side of the spectrum, the pathway of Nature for Nature social stagnation, sequenced with Nature for Society, gained the lowest score of 1 due to a considerable shift in policy focus (from ecological to social). A pathway map with preferred pathways is presented in Figure 30.

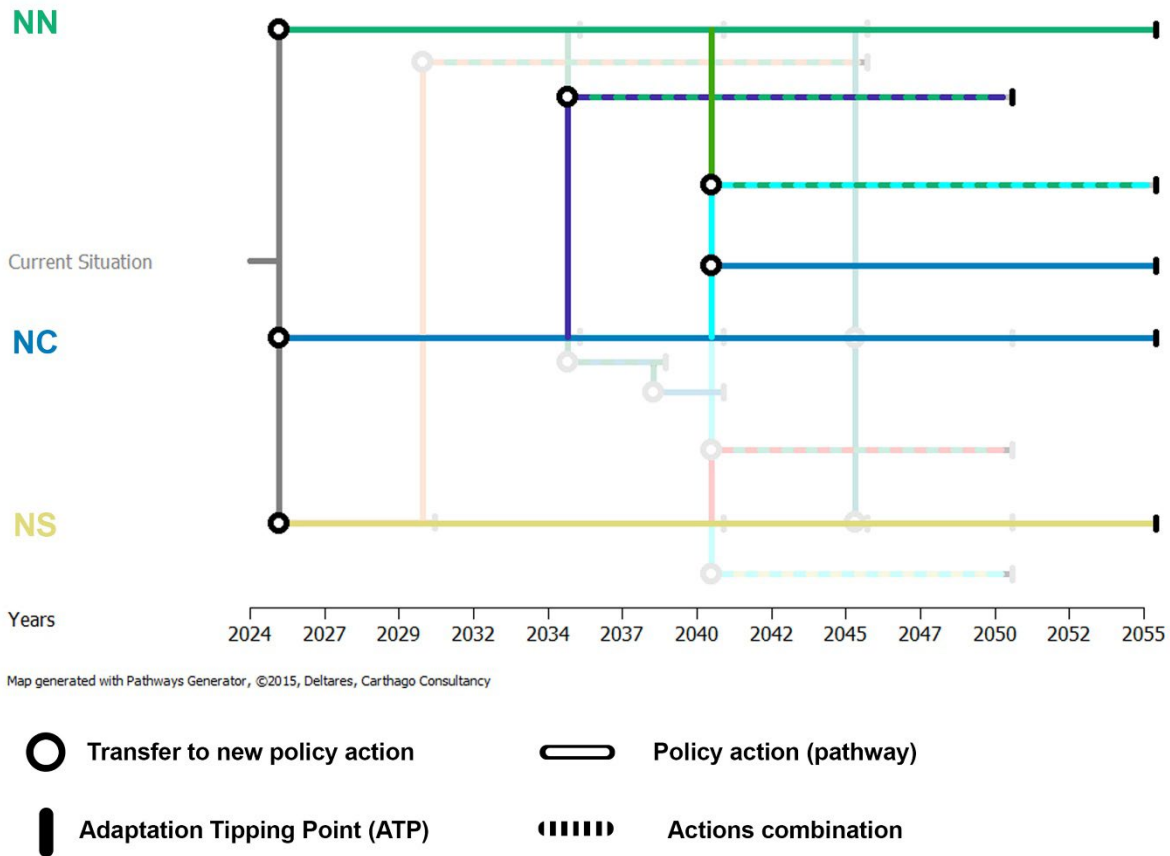


Figure 30: Preferred pathways based on SMG evaluations.

The results indicate that preferred pathways and policies should primarily focus on the Nature as Culture and Nature for Nature dimensions, with policies that maintain a respective social use by considering the intrinsic and cultural values of nature. In contrast, policies and pathways that focus on the Nature for Society dimension and give less attention to the Nature for Nature might perform poorly over a long-term horizon. This reflects a focus on the cultural function of SMG and on enforcing policies more oriented toward collective activities in harmony with nature. Respectively, preparatory policies and actions have to focus on nature conservation and restricting the sole social use of SMG. These results also align with the outputs from the co-creation sessions and priorities, such as living in harmony with nature, learning opportunities through collective action, and establishing biodiverse areas as ecological refuges.

6.5. Discussion

Adaptive planning utilizes scenarios through future pathways to cope with the uncertain conditions of urban areas, and as it employs a process of constant collaborative monitoring, it

offers flexibility to modify the scenarios as the future unfolds. The novelty of adaptive scenarios using DAPP at the local scale, in comparison to traditional predict-and-act approaches, lies primarily in the use of collaborative pathways for data collection, utilizing local input, and secondly in integrating LNFF for input interpretation in policy-making. Using co-creation at the local scale allows decision-makers to render a clear picture of the visions, objectives, and values of local actors (Kati & Jari, 2016; Morello et al., 2024; Nevens et al., 2013) based on their perception of the social-ecological systems (Morello et al., 2024; Villamor et al., 2014). Using the co-creation process for the evaluation and development of social-ecological systems, such as the case study of SMG, allows planners to engage stakeholders in the space planning and design process while raising citizens' awareness of the values of nature. As the embedding co-creation process in the field of planning evolves, one of the challenges remains in establishing a process that adaptively copes with local uncertainties through time (Oetken, 2025). In this research, utilizing the co-creation process is not limited only to the preliminary step of planning, but is also expanded to continuous monitoring and evaluation processes, in comparison to previous studies in this field (e.g., I. Andersson et al., 2023; Hazell et al., 2024; Mahmoud et al., 2021). The evaluation process of the changes is a collaboration with citizens. This process is primarily facilitated by using qualitative social and ecological indicators, which require descriptive input primarily from observations, thereby reducing the limitation of conducting periodic co-creation sessions with actors. While using co-creation for data collection and monitoring showcases an advancement in comparison to theoretical frameworks (Frantzeskaki et al., 2025), the main question remains how its input can contribute to the adaptive planning process.

Interpretation of co-creation inputs for adaptive policy making remains a challenge in planning (Leino & Puumala, 2021), as most of the collected data are gathered qualitatively and require comprehensive interpretation without biases to reflect local information directly (Díaz et al., 2018; Smith et al., 2024). In the context of scenario-making for social-ecological systems, LNFF provides a simple yet comprehensive framework for analyzing and preparing inputs for decision-making (Mayer et al., 2023; Pereira et al., 2020). Using NFF has previously been studied, both theoretically (Díaz et al., 2015; Pereira et al., 2020) and practically (Haga et al., 2023; Kim et al., 2023; Shaikh & Hamel, 2023), at global and regional scales, while few practices utilize such a framework at the local urban scale for framing social-ecological systems (Mansur et al., 2022). The advantage of utilizing LNFF lies in providing an overview of the orientation of information across the three dimensions of Nature for Nature, Nature as Culture, and Nature for Society, while also having the potential to incorporate both qualitative and quantitative information. Beyond utilizing LNFF at the local scale, its integration with DAPP represents a significant step forward in addressing the challenges of scenario-making. In conditions of deep uncertainty due to a variety of options, agreement among actors on future conditions is challenging (Marchau et al., 2019b; Stanton & Roelich, 2021). Additionally, establishing rigorous scenarios that address a range of plausible futures requires substantial information and data, which, in most local case studies, is limited (Oriol et al., 2024). In this research, using LNFF dimensions as the primary scenario, with flexibility in constructing scenarios between them, addresses prior challenges.

While LNFF limits the scope of uncertainty on social-ecological futures (by defining three comprehensive aspects for human-nature relations), it also provides a boundary to define the dynamics of the case study and social perception by using intrinsic, cultural, and utility values. Information collected during the co-creation and monitoring phases is interpretable in terms of values for each dimension.

To make adaptive scenarios, this research adapted the DAPP framework. As DAPP is dominantly utilized for water and flood management at the regional scale (Rosello et al., 2022; Toimil et al., 2021), its implementation for planning at the local urban scale is a step forward in dealing with the uncertainty of social-ecological systems. Previous studies reflect how adaptive planning in collaboration with citizens fosters the process of transformative governance (Chaffin et al., 2016; Frantzeskaki et al., 2024), while practical examples of such approaches were limited (Stanton & Roelich, 2021). Using a DAPP integrated with LNFF, based on the input from the co-creation process, provides a replicable approach to adaptive planning for planners and decision-makers. For instance, in research, this methodology helps planners identify which policies lead to more successful outcomes in contexts where social and ecological objectives are equally important. In the long term, focusing on Nature as Culture policies, such as incentivizing collective activities in harmony with nature (as opposed to individual daily use) and limiting extensive social use alongside extensive nature-protective actions, is better aligned with the objectives of multifunctionality and biodiversity. In contrast, minimizing policies and actions that correspond with the Nature for Society dimension (such as increasing furniture or making the entry more inviting to the public) provides a better chance for the sustainable use of the Garden for both humans and nature. Using DAPP, ATPs, and OTPs also provides compatibility with upper-hand plans and strategies, which allow decision-makers to monitor the development process in pathways and consider new strategies (pathways) in case of a major change in any of the social or ecological indicators. For instance, if by 2030 the SMG does not meet the objectives defined by the neighborhood's plan decision-makers, based on shortcomings in either social or ecological dimensions, it can shift to new pathways of development using policies corresponding to the LNFF dimensions. Defining adaptive scenarios through DAPP offers a novel yet replicable and flexible approach in local contexts that address a wide range of social and ecological variables, where public opinion takes priority in decision-making.

This research on adaptive scenario making and planning at the local scale faces several limitations. On a methodological and conceptual level, this research faced major limitations. Primarily, utilizing DAPP with elaborated qualitative information is subject to the expert's (planner's) bias regarding the context of the study. Additionally, several limitations imposed by decision-makers and administrative units restrict the options or pathways available for policymaking. For instance, regulation regarding the security and safety of green public areas limits the possibilities for designing entries based on public opinion. To avoid potential biases, this research primarily utilizes information from co-creation sessions in the analysis, without expert interpretation (e.g., established objectives, visions, and indicators suggested by citizens).

Despite this, the use of interpretation data for evaluating scenarios and selecting preferred pathways is subject to the researcher's preferences. In future research, to overcome this challenge, it is necessary to conduct evaluations in collaboration with stakeholders with a team of experts and planners. Secondly, this research faced limitations in engaging citizens broadly through the co-creation process. Such a limitation might narrow the scope of information input on a specific topic (such as prioritizing ecological objectives over social ones) and may exclude the majority's voice in the planning process. While studies indicate proficiency in the co-creation process, even with limited participants (Haase et al., 2017; Morello et al., 2024), authors suggest that broader engagement and communication with citizens, especially younger generations, is necessary in future studies, which can be facilitated through the use of online platforms. Ultimately, on a practical level, this research faces limitations in integrating local policies with upper-hand planned strategies. This is due to the broad scope of public opinion on the subject that administration units have strict policies on. Future studies in this topic should address communication challenges between locals and decision-makers and facilitate a feedback system that functions throughout the planning and monitoring process.

6.6. Conclusion

In urban areas at the local scale, overcoming deep uncertainty in decision-making requires adaptive planning. This study advances a novel integration of DAPP with the LNFF at a local public garden in Milan, using data collected through co-creation with residents, stakeholders, and decision-makers. The process identifies plausible development scenarios across LNFF value dimensions, each specifying short to long-term policies and actions. By matching these scenarios with local preferences and priorities, preferred pathways are revealed that guide policy sequencing and implementation over time, including ATP, OTP, and indicators for evaluation. Interpreting information through value dimensions and timed pathways enables decision-makers to monitor progress, evaluate outcomes, and shift to alternative pathways as contexts change, thereby identifying scenarios that align with the objectives established by citizens and the strategies defined in upper-level documents. The results indicate which local policies (e.g., biodiversity conservation, incentivizing collective cultural activities, and heat reduction by greenery) are most critical to deliver multifunctionality and biodiversity while sustaining cultural ecosystem services. The approach is actionable and replicable in local urban contexts when paired with transparent data (either qualitative or quantitative), facilitation capacity, and alignment with existing regulations and planning cycles, and it embeds equity by centering engagement in pathway design and evaluation. Limitations include the need for long-term monitoring, sustained citizen engagement, and potential biases in interpreting co-created data, which future studies should address. The implemented process of using DAPP in integration with LNFF provides local decision-makers with a replicable methodology for co-creating and adjusting nature-positive policies, utilizing clear indicators and ATP, thereby enabling decisions that deliver social-ecological benefits under deep uncertainty.

Chapter 7.

Conclusions, new perspectives in social impact assessment and scenario making of re-naturing measures in local urban areas

7.1. Introduction

This chapter concludes the research by summarizing the key findings regarding the process of social impact assessment (SIA) of re-naturing measures through the use of ecosystem services (ES) in urban areas. This study begins with a brief overview of the SIA framework as applied, comparing it to traditional approaches, followed by an integrated discussion of the results aligned with the research objectives and questions. Subsequently, the chapter explores the implications for urban policy and planning, outlines the study's limitations, and suggests pathways for future research. For this purpose, the results are interpreted in relation to the aims, objectives, and research questions, which is followed by a discussion on the implications for policy-making and planning. The results reveal new perspectives in SIA for urban areas, moving beyond traditional approaches, and aim to involve citizens and stakeholders in the assessment process. The new perspective establishes and evaluates short- to long-term development horizons to provide concise adaptive policies and action at the local scale. The outcomes as a package of SIA aid decision-makers in the course of planning for local social-ecological systems. This package takes a step forward from previous practices by introducing adaptive scenario-making approaches that are integrated with the Local Nature Futures Framework (LNFF) to reflect social values regarding nature.

This research proposes an SIA approach based on the constructivist paradigm for evaluating the social impact of re-naturing measures in cities. The process approaches social impacts by analyzing and evaluating local social-ecological systems with a focus on prioritizing biodiversity values. In this research, the SIA process is revised at the conceptual, methodological, and practical levels to establish a replicable process that collaboratively incorporates social-ecological values directly into the assessment process. The following sections provide detailed elaboration on the results, implications, innovations, and limitations of this new SIA perspective in urban areas. The results in this chapter are organized and interpreted to correspond with the research questions and steps taken (literature review, application to case study, and analysis), providing an overview of the research's progress toward its objectives and aims. For detailed results regarding each section of the research, please refer to the results and discussion section in chapters 2, 3, 4, 5, and 6. Before presenting the overall results and key findings, the following section outlines the scope, aim, objectives, and research question as established in Chapter 1.

7.2. Research approach

As established in the first chapter, the scope, aim, objectives, and research questions are as follows. The scope of the research is to aid the process of adaptive planning and decision-making in cities on a local scale. For this scope, the research aims to uncover social values regarding nature and re-naturing measures by using ES in a collaborative process at the local urban scale, providing contextual input for adaptive planning processes. Based on this aim, three main objectives were established as follows: 1. Integrating the use of ES in SIA and monitoring by using and analyzing their indicators, factors, impacts, and measurement methods (Objective 1), which was approached in Chapter Two; 2. Assessing the social impact of re-naturing measures through participatory processes to uncover social values in local social-ecological systems (Objective 2), which was explored through an investigation of case studies in Chapters Three and Four. Using local social inputs on the impact of re-naturing measures to aid the adaptive scenario and policy-making processes in short to long-term horizons (Objective 3), which was elaborated through Chapters Five and Six. To address these objectives, the main research question (RQ) is: How do ES and biodiversity values benefit the process of SIA of re-naturing measures to support the process of adaptive decision-making in cities? This question was elaborated throughout the thesis as it offers an SIA process of re-naturing measures at the local urban scale, which uses ES to aid adaptive planning processes. Additionally, three subsequent questions guided the research to answer the main question. These questions led the research into different phases and facilitated the navigation in each step of the research. These questions are as follows: 1. Which are the ES leading indicators and factors for SIA in urban areas? What are their value metrics, and to what extent are these issues related to urban biodiversity? (Q1 in relation to objective 1 in step 1); 2. How can these indicators be measured and localized in an urban context through participatory processes? What are the contextual influencing factors in the process of participatory SIA? (Q2 in relation to objective 2 in step 2); 3. How does the SIA of re-naturing measures, by analyzing local social-ecological systems, aid the process of adaptive decision-making and policy-making in cities? (Q3 in relation to objective 3 in step 3). The key findings regarding the RQ and three sub-research questions regarding the aim and objectives are presented in the following sections.

7.3. Summary of results, key findings, and research positioning

The key findings are divided into four sections, each addressing a specific research question and objective, following the research flow of review, application, and analysis. The first part is devoted to the results regarding the use and integration of ES variables and biodiversity values in SIA, which corresponds to Objectives 1 and Question 1 of the research, showcasing developments at both conceptual and methodological levels in comparison to previous studies. The second part is dedicated to results in engaging and collaborating with citizens and stakeholders in the SIA process by using ES to gain a clear picture of the social narrative of biodiversity and social values of re-naturing measures. This part corresponds to Objective 2 and Q2 of the research, showcasing advancements in the SIA process at both methodological and practical levels. The third part

presents analytical results on operationalizing LNFF for interpreting social values in scenario making and evaluations at the local scale. This section directly addresses Objective 3 and Q3, while also providing additional value for SIA at both conceptual and methodological levels. Ultimately, the fourth part is dedicated to adaptive scenario-making and future studies in SIA, utilizing the results from the previous section. This part shifts the SIA focus beyond the present status to explore future scenarios using the Dynamic Adaptive Policy Pathways (DAPP) methodology, and it utilizes SIA results in the policy-making process for adaptive urban planning. This final section presents results regarding Objective 3 and Q3, while introducing a new course of discussion in the SIA application at both methodological and practical levels. After presenting the results, the answer to the RQ and progress toward the aim of the research are presented in the final section.

In an overview, this research is conducted in the first steps by building upon established SIA frameworks (Arce-Gomez et al., 2015; H. A. Becker, 2001; H. A. Becker & Vanclay, 2003; Carley & Bustelo, 2019; Vanclay, 2003). While this research benefits from using such frameworks, the findings from the reviews in Chapters 1 and 2 indicate shortcomings in traditional approaches in their application at the urban scale, including their inability to capture social-ecological dynamics, conduct long-term assessment, account for socio-cultural qualitative values, and engage with participants continuously. In this context, in the first step, by elaborating on SIA participatory approaches for use in local urban areas for long-term SIA and monitoring, this research provided a complementary framework to traditional approaches. The findings of the literature review on SIA methodologies (Chapter 1) and the systematic literature review on social indicators, factors, and measurement methods in assessment (Chapter 2) position this study in contrast to the current stream of literature on SIA (Li et al., 2025; Peraki et al., 2025; Vanclay, 2024; Wan et al., 2024) and render SIA as a bottom-up continuous procedure that requires focusing on socio-cultural values of nature and biodiversity in the context of assessment of urban greenery. To overcome these limitations and in line with similar perspectives (Dumitru et al., 2020; Frantzeskaki et al., 2025; Haase & Dushkova, 2025; Leino & Puumala, 2021; C. M. Raymond et al., 2017; von Döhren & Haase, 2023), this study proposes a participatory approach in SIA that integrates multi-dimensional values of nature and urban green infrastructure and moves beyond pure quantification of information based on static indicators. In this approach, SIA in urban areas covers contextual background dynamics and integrates highly heterogeneous values of nature into assessment and processes a variety of perceptions and values through the use of ES as a connection point between humans and nature.

The proposed SIA approach is tested and validated in two distinct case studies in Chapters 3 and 4. For SIA implementation, this study focused on collaborative approaches of co-creation and co-monitoring with direct engagement of actors and stakeholders, with adaptation and expansion of established methodologies and processes in previous studies (I. Andersson et al., 2023; Frantzeskaki et al., 2025; Mahmoud et al., 2021; Mahmoud et al., 2021; Morello et al., 2024; Nevens et al., 2013; Oetken, 2025; C. M. Raymond et al., 2017). Co-creation and co-monitoring

methodologies were used in this step to facilitate public engagement during the sessions. In both cases, to better explore citizens' perceptions and values, special attention was given to the use of ES in the collective process. The results from both case studies, in line with previous research in this field (e.g., Gai et al., 2022; Kati & Jari, 2016; Nawrath et al., 2022; Nóbrega-Carriquiry et al., 2023; Thiemann et al., 2022), confirm that perceptions of nature and biodiversity differ based on citizens' experiences, urban context setting (temporal and permanent), nature conditions, norms, socio-cultural dynamics, and personal and collective values. The use of ES collective activity additionally shows beyond the focus of the mainstream literature on quantification of provisional and regulating ES (e.g., Babí Almenar et al., 2021; Belaire et al., 2022; Jorda-Capdevila et al., 2019; Liqueste et al., 2016; Ma & Yang, 2025; Nicholls et al., 2020; Pistón et al., 2022) qualitative values of ES, especially cultural and regulating categories play an important role shaping perceptions and social values and have to be highlighted with the special attention during co-creation and co-monitoring process. To this end, the proposed collective activities using ES cards and scenario-making, alongside analysis based on the provided indicators, impacts, factors, and measurement methods in this research, are proven to be crucial methods and approaches for such analysis, as an advancement on the literature.

To analyze and use SIA information for urban planning and policy making, in the third step, this research relied on two established frameworks of NFF (Díaz et al., 2015; Pereira et al., 2020), its later development with a focus on urban or larger scales (e.g., Durán et al., 2023; Haga et al., 2023; Mayer et al., 2023; Shaikh & Hamel, 2023) for framing the social value of nature and BD, and DAPP (Haasnoot et al., 2013, 2019, 2024; Kwakkel & Haasnoot, 2019; W. Walker et al., 2013) for developing and evaluating future scenarios. Regarding the use of NFF (Chapter 5), in preliminary analysis of this framework, this research argued that while NFF provides a comprehensive approach, its application to the urban context, especially at the local scale, is still limited, while it has shortcomings in covering intrinsic values of nature in calculations for human-nature relations in the short- and long-term. By expanding on previous studies, this research provided NFF with a focus on the local urban area, with special attention to urban greenery. This approach is in line with recent studies on NFF and complements the argument that NFF limitations provide a framework for values related to the human-nature relation (Lemes de Oliveira, 2019; Oostvogels et al., 2024), and emphasizes increasing the role of nature and BD values in such frameworks to enable operationalization.

Ultimately, regarding DAPP in Chapter 6, this research uses DAPP directly for urban areas and policy-making. DAPP is initially designed for water and flood management at the regional and national scales (Haasnoot et al., 2019; Lawrence et al., 2025; Rosello et al., 2022; Toimil et al., 2021). Using such a framework at the local scale or in urban areas posed several limitations, especially in identifying information sources, engaging with actors, and establishing timelines and scenarios that are compatible with the plurality of perspectives and desires of stakeholders. To overcome these limits, while this research positioned its contribution as complementary and an expansion of the DAPP framework, it proposed modifications and

methods to make DAPP a flexible framework that encompasses the plurality of local social-ecological dynamics in engagement with a diverse range of stakeholders. This advancement also supports the use of NFF in synchronization with DAPP to establish primary scenarios for investigating urban green areas. The following sections provide further elaboration on the results and on the positioning of this research within the literature.

7.3.1. Moving beyond quantification: The role of qualitative ES-based indicators in SIA

The relation between humans and nature is multidimensional, and the impacts of nature (and consequently re-naturing) on human lives involve multiple value systems as its impacts go beyond solely instrumental values (Pascual et al., 2023). Capturing the full extent of the social impacts of re-naturing requires indicators that not only address instrumental values through quantification but also encompass relational and intrinsic values through local elaborations. In response to objective of integrating ES in SIA by analyzing their indicators, factors, impacts, and measurement methods (Objective 1), as in Chapter Two, this research initially established that quantitative indicators such as physical health metrics, financial-related indicators, proxies, and quantification models are crucial for intermediary baseline SIA, but they are not sufficient for capturing the full spectrum of human-nature relations in urban context. Based on empirical evidence and a systematic review of ES categories, to answer Q1, this research identified that beyond quantitative indicators, SIA must incorporate qualitative social indicators, impacts, factors, and measurement methods that address values that are not translatable into numeric values. In this context, by using ES categories (as they cover different contributions of nature on human lives), this research establishes that effective ES indicators for urban SIA are those that, in addition to quantitative and qualitative values, focus on biodiversity values and qualitative measures, as these successfully capture the multidimensional human-nature both in instrumental, relational, and intrinsic dimensions. This evidence-based conclusion provides the foundation for moving SIA practice toward more inclusive and holistic evaluation frameworks that recognize both measurable outcomes and lived experiences of urban residents with re-naturing interventions. The assessment, based on qualitative values, directly integrates social perceptions, values, and concerns into evaluations, thereby avoiding the oversimplification of information that often occurs when quantifying social data.

This step of the research contributes to SIA knowledge at both the conceptual and methodological levels by systematically expanding the theoretical framework to recognize biodiversity values as integral components of human-nature relations in urban areas. Conceptually, this research addresses the lack of suitable indicators and measurement methods for direct and indirect SIA of re-naturing by positioning ES as a mediator between ecological processes and social outcomes. Using ES enables planners to scope ecological parameters within the SIA context and identify suitable indicators for assessing impacts. Additionally, this proposition represents a paradigmatic shift from viewing biodiversity as a purely environmental

variable to understanding it as an infrastructure that generates relational and intrinsic values for human well-being, which can be measured through qualitative outputs. Methodologically, this research introduces a novel six-category classification system for ES indicators that systematically integrates quantitative and qualitative information for use in SIA. Using information based on local perceptions about greenery or changes in human behavior related to nature and biodiversity are examples of this integration. This categorization contrasts with classic SIA perspectives by moving beyond quantifications and conventional binary approaches, providing a mixed-methods perspective. The provided categorization introduces sufficient versatility in indicators to be used in participatory and collaborative assessment processes, thereby engaging local actors in the evaluation process.

The integration of ES-based indicators (qualitative and quantitative) in the SIA of re-naturing, with an emphasis on biodiversity values, fundamentally transforms priorities in monitoring methods for shaping strategies and policies, moving beyond solely economic metrics. This research demonstrates that using qualitative ES indicators based on biodiversity values more accurately reflects community perspectives, perceptions, and visions, providing information that is not readily interpretable through numerical values. The practical application of this approach enables decision-makers to identify both intended and unintended consequences of re-naturing through direct engagement with local actors. By having a framework that contains flexible indicators, potential impacts of re-naturing, and factors involved in this process, planners can, based on contextual parameters (for instance, ecological challenges or social objectives), identify how interventions can affect local communities and social values. In contrast to previous approaches, local actors are at the center of decision-making, and their perceptions serve as the foundation for creating policies. This structure and categorization of indicators provide a replicable framework for planners to investigate social-ecological systems at the local scale, using tools to examine context-specific situations. Despite this advancement, integrating qualitative biodiversity indicators with existing quantitative planning tools requires fundamental changes to established frameworks. The framework's success depends heavily on mutual understanding, political commitment, and public prioritization of biodiversity values in the planning process. To successfully utilize the proposed indicators and measurement methods, municipalities must establish direct and constant communication channels (such as co-creation sessions or collective monitoring) with citizens and stakeholders and involve them in the monitoring process. In such processes, planners as facilitators can narrow down the priorities of investigation by using the impacts and factors provided in this research and identifying which aspects of re-naturing have the most social impacts on communities involved. This enables planners to anticipate local needs and desires for future developments, alongside the effects of re-naturing social impacts, in a bottom-up, collaborative manner, while considering priorities set by local decision-makers.

7.3.2. SIA for the future: a framework for interpreting SIA results to guide future studies

SIA, in its established and standard form, is viewed as a process that assesses the consequences of interventions, mainly through a one-time activity, a defined time period (before or after the intervention), and evaluates the social impacts of the interventions. In a constructivist perspective, SIA, and within this research, is viewed as a continuous process that not only examines the results of interventions but also evaluates their long-term impact on society. Understanding how the social consequences of re-naturing evolve over time requires an in-depth understanding of the components and dynamics of social-ecological systems. As this research focuses on the local urban scale, the process must examine the details of ecological dynamics and social values and evaluate how they change in each specific context in response to challenges and limitations. This research considered local participation in SIA as a critical component and measured the social-ecological relations by using collaborative approaches and utilizing the indicators and measurement methods identified in the first step. This research addressed the question of how ES indicators can be measured and localized in an urban context through participatory processes (Q2), by developing and testing participatory methodologies based on ES indicators and measurement methods in two case studies in Milan and Utrecht, analyzing the local perspective of social impacts of re-naturing for evaluating the present and future status. By offsetting from top-down approaches, the empirical application of participatory SIA techniques (such as collective ES benefits card selection, co-creation process, narrative making, and direct interviews) in both cases showcased the effectiveness of collaboratively defining, identifying, and validating the social impacts of re-naturing at the local scale.

This process, through gathering relevant and legitimate feedback from citizens and stakeholders, enriches the information available to decision-makers and integrates qualitative and quantitative data to evaluate local perceptions. It also utilizes a participatory process to gather suggestions and approaches for enhancing the future of each case study. As this methodology is tested under both pre- and post-intervention conditions, it has proven successful in reflecting social perceptions and values at different stages of local development. The ES indicators demonstrated sufficient flexibility to adapt to contextual differences and collectively measure social impacts. As social values might change over time, SIA should not be considered as a one-time process. SIA must occur through time in different stages of planning and development to ensure accurate and updated information. This allows planners to modify and adjust objectives, indicators, and policies based on the most recent social-ecological changes. To make SIA an approach that covers future scenarios, methodological and practical changes from classic approaches are necessary

This research, at the methodological level, developed a participatory SIA approach whose methodologies for gathering information are replicable at any stage of assessment, with low cost and direct engagement of actors. Direct interviews, observations, collaborative stakeholder

mapping, the gamification of priority selection using ES cards, and narrative making were examples tested in the two cases, demonstrating efficiency in data collection. These approaches enable context-specific data collection, allowing planners to utilize remote-sensing data and numerical values for ecological information that, in most cases, are proven to be challenging to gather over the long term through collective processes. These methodologies can address the challenges of data scarcity at the local level, even with engagement from a limited number of actors and experts. On a practical level, this research demonstrates how participatory processes can be operationalized through co-creation workshops, focus groups, and community engagement sessions that not only collect data but also build local capacity for ongoing monitoring and assessment activities, as well as raise awareness. This framework enables municipalities and planners to implement an SIA process without processing large amounts of information through quantitative approaches, but to create shared knowledge that is co-produced by all affected or interested parties. The provided process is adaptable and contextualized to the context of each social-ecological system, and it updates its information over time with the support of decision-makers or through local initiatives for monitoring.

For a future-oriented SIA and to operationalize assessment results in planning, it is necessary to interpret and analyze the social output of assessments in a framework that can provide potential pathways of future development. In this research, the Local Nature Futures Framework (LNFF) was adapted and utilized for data interpretation and analysis of future scenarios. Based on this framework, human-nature relations are mainly pluralistic and perceived through three value dimensions (intrinsic (Nature for Nature), cultural (nature as culture), and instrumental (nature for society)), which future scenarios are also an extension of this concept. Building on previous studies that utilized NFF at global, national, or city scales, this research takes an innovative approach, operationalizing LNFF at the local scale, and interprets social input through LNFF dimensions to build future scenarios. Through this practice, instead of assuming one definite possible pathway for the future, several plausible pathways are defined. In this case, planners can utilize benefits from co-creation sessions to gather information on constructing multiple plausible futures, a strategic future (based on local regulations and plans), and a desirable future (based on local objectives and vision). By constructing these pathways, planners can then evaluate the pathways and plausible futures using the indicators and measurement methods provided in the first step (or built in collaboration with actors) and realize which future is more aligned with local objectives and desires. This approach highlights two key implications for planning and policy-making.

Firstly, it offers resiliency and flexibility in the planning process, providing multiple plausible scenarios based on social information. Evaluating these scenarios can help decision-makers identify which pathways are more aligned with local context needs and have better compatibility in reaching defined objectives and goals. In contrast, the classic approach of SIA does not provide such an option for policy-making through time-based social information. Secondly, by transitioning from a linear assessment approach to locally developed multiple

future systems, planners can continually review the evaluation of each case study over time and track the progress of social-ecological systems toward their visions and objectives. This ability provides opportunities to gather input from stakeholders over time and optimize strategies and policies, or adjust them based on local development, while being prepared for adversity. In both aspects, evaluating the status of biodiversity is an essential component, as biodiversity serves as a fundamental indicator of social-ecological system health, functionality, and resilience, connecting all three value dimensions within the LNFF framework. Biodiversity monitoring enables planners to track changes in ecosystem functions that directly relate them to ES that each context depends on and evaluate those ES for measuring the effectiveness of pathways taken. The key conclusion in this case is the necessity of integrating adaptive perspectives approaches in course policy making. Planners must continually revise their policies and strategies in response to evolving ecological and social realities, adapting to new scenarios as the future unfolds.

7.3.3. SIA as an essential component for adaptive planning

The ultimate dimension of SIA that this research has explored is utilizing the SIA process as a component for adaptive planning and policy-making at the local scale. The process of adaptive planning is a continuous process over time; it requires a complementary approach to data collection and interpretation that provides information for its analysis on an ongoing basis. In this research, focusing on local urban social-ecological systems, SIA was tested and proven effective in elucidating the social impact of re-naturing measures to inform the course of adaptive planning and policy-making for urban greenery. Intending to utilize local social inputs to inform re-naturing measures that support adaptive scenario and policy-making processes, both in the short and long term, at the local scale, this part of the research addresses the question of how the SIA of re-naturing measures, by analyzing local social-ecological systems, aids the process of adaptive decision-making and policy-making in cities. Continuous participatory SIA processes can capture evolving community values, ecological conditions, and social-ecological interactions that inform adaptive management policies over multiple scenarios and pathways. Through empirical application in the Milan case study, the research demonstrated that establishing a continuous monitoring and feedback system can provide detailed, updated information on human-nature relations through continuous SIA. This approach, by interpreting outputs through LNFF, enables the development of initial scenarios. In the next step, Dynamic Adaptive Policy Pathways (DAPP) at the local scale (for which there are very limited practices for such a scale), it evaluates how each scenario might change or evolve over time based on input provided in the second step of the research, in addition to constant monitoring information. Using DAPP provides a means to evaluate plausible scenarios and develop contingency plans for planning in extreme conditions. Ultimately, this process informs policymakers about future possibilities under defined objectives and contextual input, providing a roadmap in conditions of deep uncertainty for both short- and long-term horizons.

Integrating the SIA and DAPP methodologically advances knowledge of adaptive planning by developing and establishing an adaptive planning framework using DAPP at the

local scale. In this structured approach, local social input primarily informs decision makers for immediate interventions or optimization, and provides a long-term policy evolution outlook that enables planners to respond to changing conditions of deep uncertainty. This adaptive methodology is a replicable structure tailored for the local scale, gathering context-specific information about the social impact of re-naturing measures and taking a step forward from the classical perspective in reactive planning. From a practical perspective, integrating SIA and DAPP operationalizes a continuous planning process that builds on local social input and generates information on future possibilities, aiding decision-makers. The innovation in this case is providing a structure that monitors the development process in a local case study, showcasing how it achieves the defined plans and objectives, and what measurements are necessary in the event of adversity. The required information for such a process in social systems is based on the output of SIA, while for ecological systems, it is based on changes in ecological status through monitoring biodiversity status.

The major contribution to integrating SIA and DAPP for adaptive planning and policy-making lies in providing decision-makers and municipalities with evidence-based methodologies for developing adaptive policies that can evolve in response to changing social and ecological conditions, while maintaining community support and ecological effectiveness. Such an approach and framework enable authorities to enjoy an adaptive monitoring and planning system, where the results of interventions can be mapped and evaluated to identify new pathways of development or adjusted based on local feedback for improved outcomes. The practical implementation supports both short-term adaptive capacity through feedback loops that enable real-time intervention modifications based on community response and ecological monitoring, and long-term adaptive governance through systematic learning processes that inform strategic policy evolution based on change in conditions or strategies. This approach enables urban governance systems to benefit from re-naturing measures, such as learning opportunities, and continuously gather feedback and information from local or ecological systems to optimize their interventions. In such a context, defined policies, strategies, and plans can be integrated into the DAPP pathways, and the efficiency of predetermined policies or strategies can be evaluated in comparison to locally defined objectives. By overcoming uncertainties in the planning process to identify optimal and plausible pathways, complex social or ecological challenges, such as climate change, biodiversity loss, or a lack of public participation, can be analyzed in collaboration with stakeholders through mapping in DAPP, enabling the identification of effective strategies and policies to address them locally.

7.4. Discussion

This research approached SIA to recast it from a static, top-down procedure to a participatory, bottom-up, tailored activity that assesses the impact of re-naturing in urban areas. By centering biodiversity as a proxy for ecosystem functionality, it integrates into adaptive planning and policy-making to provide concise information and inputs based on local values, facilitating

optimized policy-making for social-ecological systems. As this research is conducted to revise the SIA at multiple levels, it initially provides ES-based indicators, impacts, factors, and measurement methods that combine qualitative and quantitative information to assess the social impact of re-naturing measures, capturing the instrumental, relational, and intrinsic values of nature for humans. These findings prepare SIA as a decision-support system for planners by providing a range of indicators that measure social impact and center biodiversity as a key component, representing ecosystem functionality. The framework equips decision-makers to prioritize interventions where perceived benefits and ecological gains align, focusing on biodiversity values through measurements to address biodiversity loss at the local scale. While at higher scales of planning, quantification, and reliance on remote sensing information is becoming dominant, in contrast, at the local scale, it is essential to focus on contextual differences, perceptions, and social variables that make each study context a distinct case. The provided framework allows planners to shift their perspective from numbers toward in-depth information on human-nature relations.

Policy makers in this process must use social-ecological information alongside quantitative information to enrich the decision-making process (E. Andersson et al., 2022; Grêt-Regamey et al., 2015; Mayer et al., 2023). Policies that rely solely on quantitative proxies and indicators overlook relational and intrinsic values, leading to misaligned priorities and reduced social acceptance (Morrow, 2024; Nilgen et al., 2024). Integrating qualitative ES-based indicators and biodiversity-related measurements into assessments and policy making enhances the accuracy of this practice. Planners at the local scale must embed the interactions and dynamics of social-ecological systems into evaluation criteria, define context-specific biodiversity targets linked to social impact, and indicators that reflect social values and perceptions without requiring quantification (Bernardo et al., 2021). This approach bases the planning process on contextual realities, without compromising or oversimplifying information for policy-making. To implement this recommendation, direct engagement with stakeholders, experts, and decision makers is necessary to gather social and ecological information. In this case, the second revision phase of the SIA re-naturing process involves integrating these findings into the data collection process to inform policy development.

In contrast to established practices of SIA (Burdge & Vanclay, 1996; Imperiale & Vanclay, 2024; Vanclay, 2003, 2024), this research proposed and tested a collaborative and bottom-up perspective for SIA. Through this process of data collection, this research employed a bottom-up and collaborative approach, engaging with stakeholders. In this case, co-creation is the central approach for collecting information, utilizing various tools and methodologies tailored to the contextual needs and availability of participants (Frantzeskaki et al., 2025; Leino & Puumala, 2021; Nevens et al., 2013; Oetken, 2025). In this step of SIA, through co-creation sessions, a mixed-format of activities, such as collective ES selection, stakeholder mapping, narrative making, collective analysis, defining interests, visions, and objectives, are examples of tools that have been proven to be efficient in better understanding human-nature relations and local contexts (see: Ayatollahi et al., 2026). The co-creation activities can also be enriched with

interviews, field observations, and direct interactions with experts and administrative units relevant to the case study's context (I. Andersson et al., 2023; Leino & Puumala, 2021; Mahmoud et al., 2021; N. Smith et al., 2024). Data quality in the process is ensured through cross-checks between results from different methods and final elaborations with administrative units and experts, to ensure that the gathered information reflects contextual realities. To keep this process feasible and replicable in other case studies in urban areas, it is necessary to keep co-creation sessions and monitoring activities engaging (through low-barrier and lightweight activities) while enabling citizens and participants to contribute to the constant monitoring procedure actively. Continuous engagement of participants can occur beyond the co-creation sessions and can be facilitated by incentivizing an independent local monitoring and reporting system (for instance, by providing a questionnaire to be filled out anonymously during the post-intervention phase). In addition to qualitative measurements, integrating information from sensor trackers (both animals and plants) and remote sensing databases can enhance the quality of information, particularly when interpreting the ecological status and trends of the case study.

Embedding the SIA of a re-naturing data collection approach into policy-making requires establishing a complementary assessment procedure during the context evaluation phase at the local scale. As SIA is a continuous process over time (Parsons, 2020; Vanclay, 2024), the data collection procedure also takes place at different stages of the re-naturing intervention. A continuous monitoring procedure ensures changes in social and ecological values and parameters are adequately addressed and considered in decision-making and interventions. In this context, authorities and decision-makers must facilitate and support planners in executing co-creation sessions through public calls and invitations. This institutionalization should be achieved through interventions (from the pre-intervention phase, through planning and intervention, and ultimately post-intervention), by defining minimum methodological standards for co-creation and assessment (indicators, measurement approaches, and dedicated budget lines). In practice, SIA is often viewed as a one-time event; however, for better outcomes, it is necessary to establish a monitoring and feedback loop to gather information and revise policies as future events unfold. In such a procedure, planners act as facilitators and interpreters of information. The proposed and test data collection methodologies provide a feasible and replicable approach that planners can use in the assessment and monitoring process. By embedding SIA in the policy-making process, the ultimate step that requires attention is using the assessment output to inform the policy-making process and provide information on the current status and future possibilities of local social-ecological systems for adaptive planning.

The integration of SIA in adaptive planning processes at the local scale offers several advantages and benefits, including the use of social-ecological evidence in the decision-making process, reduction of uncertainty regarding contextual variables, and enhanced effectiveness and performance of policies and interventions. Re-naturing and greening interventions in the complex context of urban areas might lead to several multidimensional effects and impacts that require evaluation (Babí Almenar et al., 2021; Díaz et al., 2018; Hobbie & Grimm, 2020). By

grounding priorities in local objectives and preferences, planners can align policies with the targets set by stakeholders and identify the social impacts that decision-makers need to focus on. In this research, LNFF provides a means for interpreting SIA information into scenarios for the future, which serve as a basis for future analysis and decision-making (Okayasu et al., 2025; Remme et al., 2024; Shaikh & Hamel, 2023). Using LNFF can aid planners in translating the information gathered into value-explicit scenarios and narratives that each offer a traceable link to stakeholders' input. These scenarios are adjustable based on the visions and objectives of experts, decision-makers, and citizens, which are ready to be evaluated by a multi-criteria analysis system using ES-based indicators and measurements provided in the first step. The LNFF-derived scenarios then feed into an adaptive methodology (DAPP) that decomposes all gathered information into pathways rolled out over time, spanning short- to long-term horizons. The analysis of information provides a roadmap for planners and decision-makers to gain an overview of possible future scenarios and track courses of interventions through different pathways (Carstens et al., 2019; Lawrence et al., 2025; Rosello et al., 2022). In this context, by providing adaptation tipping points, probable timelines of interventions and policies, and plausible scenarios in each context, planners are enabled to adapt to new scenarios and pathways based on contextual changes over time, rather than relying on a single predefined plan (Haasnoot et al., 2019; Toimil et al., 2021; W. E. Walker et al., 2019).

Local policy-making processes have to shift from one-time assessments to continuous, adaptive cycles of SIA that incorporate data interpretation through scenario-making and analysis methods like LNFF and DAPP. Local authorities should use the collected information for adaptive decision-making and compare evidence across stages to develop a clear understanding of changes, modifying their strategies or policies as needed. Direct engagement with citizens and ongoing social and ecological monitoring are key components of a successful adaptive planning process. Furthermore, local authorities need to develop contingency plans for adverse events in collaboration with experts and planners. While establishing indicators in the DAPP procedure and setting thresholds through measurement methods are important, maintaining an open dialogue among stakeholders facilitates the generation of community-based knowledge and the early identification of weaknesses and changes. Contingency plans can also be co-developed with active involvement from local communities, non-profit organizations, and volunteers, who serve as key stakeholders for each case study. Ultimately, in adaptive planning for social-ecological systems, managing biodiversity variables and integrating their data into analysis have been proven to be effective. In this context, SIA must focus on presenting a clear picture of the relationship between humans and nature, identifying which values—instrumental, relational, or intrinsic—should be prioritized, and guiding strategies accordingly. This information helps planners navigate the pathways based on local perceptions. It is also essential to communicate this process to authorities and decision-makers to ensure expectations align with the goals outlined in higher-level plans and strategies.

This research faced several overall limitations, which serve as a basis for future studies in the field of SIA of re-naturing in urban areas (see specific limitations in each chapter's discussion). The first major limitation is establishing a continuous SIA process that maintains a minimum level of public engagement over time. Public engagement with participants is a crucial part of SIA, and at the local level, engaging with different actors and stakeholders can be difficult. In a continuous SIA process, the number of participants and their interest in monitoring tend to decline over time. Especially during post-intervention stages, participants are less likely to share their opinions about the changes. Along with limited engagement, participants' input may be biased due to their specific age or work conditions. For example, in both case studies, participants in co-creation sessions belonged to a particular age group. In Milan, participants were primarily elderly individuals who engaged in open interactions with active non-profit organizations in the neighborhood. In Utrecht, participants were mainly younger individuals affiliated with one of the local academic institutions. While these limitations do not necessarily invalidate the results, they may introduce bias in data collection or limit the range of perspectives that can be gathered. To address these issues, future studies should explore approaches that increase public engagement in the SIA process. Possible strategies include incentivizing public activities with monetary rewards, gamifying participation in the co-creation process, promoting extensive social media outreach targeting younger populations, and organizing local biodiversity monitoring groups (such as bird or reptile watching) in partnership with local schools.

Another overarching limitation is the gap in the literature on SIA at the local urban scale. While knowledge in this field is evolving, recent studies have given more attention to SIA in urban areas. However, there are still a limited number of studies (and practices) that evaluate the social impact of re-naturing on the local scale. Initially, this limitation is due to the natural structure of SIA, which is designed to assess specific interventions (for instance, the social impact of a new private textile company on neighboring blocks), thereby limiting the scope and approach of SIA to a narrower focus. Secondly, SIA in urban planning is dominantly viewed as an optional byproduct of research activities that can be conducted through various methodologies. At the same time, there is no standard or established framework for SIA in urban areas. Lastly, SIA of re-naturing requires tools and methods that can be replicated in different contexts at low cost, for which there is limited consensus. To overcome this limitation, for SIA of re-naturing in urban areas, this research proposes using a common framework based on public engagement that incorporates ES and biodiversity values, providing a context-adaptive planning approach based on its outputs. Future research in this context should focus on enriching the indices and measurement methods based on ES and centralizing biodiversity as a central part of analyzing social-ecological systems.

Another important limitation concerns the full integration of the social values of biodiversity in SIA, ensuring both positive and negative impacts are considered within the SIA. The assessment framework developed and applied in this research systematically addresses both positive and negative impacts of biodiversity, incorporating both ecosystem services and

disservices. In line with the indicator categories outlined (see Chapter 2), potential disservices such as pest issues, nuisance mediation, and security risks are explicitly considered. However, it is important to note that across both case studies, positive impacts of biodiversity were reported more frequently and dominated the stakeholder responses. Despite the main emphasis on positive outcomes, several negative aspects were identified through stakeholder engagement and have been integrated into the analysis. For example, security concerns related to dense green areas, particularly at night, were expressed by local administration in the Milan case study. In both Milan and Utrecht, participants mentioned pest issues as a challenge related to increased biodiversity, and in Milan, administrative actors also highlighted health concerns regarding interactions with wild animals in the introduction area with high biodiversity (for more details, see sections 3.4.2 and 4.3.2). Overall, the analysis shows that positive effects are more commonly observed and cited, especially in the Utrecht case study, where a more controlled environment and management approach appear to mitigate many potential negative impacts. While the research covers both positive and negative aspects of biodiversity, the findings from both case studies tend to lean towards positive impacts due to the values and experiences expressed by participants. While the negative aspects of biodiversity are a critical component of SIA, in this research, it was expected to observe more positive results, given its particular focus on re-naturing urban areas. Future research should go further by actively introducing participants to and familiarizing them with the full spectrum of biodiversity's potential negative impacts, rather than focusing only on its positive impacts. This could involve presenting examples of ecosystem disservices and facilitating collective activities that address both benefits and drawbacks. Alternatively, facilitators can present hypothetical or real scenarios that outline possible negative impacts of biodiversity (e.g., pest infestations, reduced safety in dense green areas) and invite participants to discuss or prioritize these alongside positive outcomes to explore different scenarios regarding biodiversity impacts. With such approaches, researchers can foster more balanced stakeholder input and enhance SIA's critical capacity to inform planning and decision-making.

Ultimately, implementing or replicating a continuous, long-term SIA process faces limitations due to data scarcity and limited institutional capacity. While quantitative information, especially on provisional and regulating ES such as temperature and air quality regulation, is available through public databases, qualitative information on social values and cultural ES remains limited. Despite recent advancements in evaluating cultural and intrinsic values of nature at a local urban scale, most available data are based on quantifications that omit crucial information in calculations. Acquiring socio-cultural information requires direct engagement with citizens and stakeholders, as well as indicators that reflect qualitative social values. Additionally, limited support from authorities and public actors challenges the process of data collection and SIA implementation. Since SIA is an adaptive process, it requires ongoing collaboration with authorities and decision-makers, as well as policy adjustments or updates. In contrast, during the implementation and monitoring phases of SIA, especially the feedback stage, there tends to be institutional resistance to change or amendments. Meanwhile, the tendency for

collaboration often diminishes over time. These challenges restrict the long-term applicability of SIA, and to address them, future studies should focus on feasibility assessments of SIA processes and on establishing practical timelines with authorities.

7.5. Final remarks

In conclusion, this research underscores the importance of evaluating human-nature relations in urban areas by developing a framework for SIA of re-naturing at the local urban scale with a dedicated focus on ES and biodiversity values to support adaptive planning. This research demonstrates SIA has to be a continuous, inclusive, engaging, and evidence-based process that can uncover social values of re-naturing, interpret social-ecological dynamics by using ES and biodiversity values, support scenario-based planning for future studies, and guide decision-makers in conditions of deep uncertainty. This research advances and recasts the process of SIA at conceptual, methodological, and practical levels, bridging theory and practice within a practical and replicable framework of SIA. Ultimately, this research lays the groundwork for orienting planners and policymakers toward the inclusion of social values in the policy-making process for urban green areas through continuous monitoring and evaluation. As cities worldwide face challenges such as climate change and biodiversity decline, this framework provides an inclusive, adaptive, and comprehensive approach to monitoring and evaluation, thereby enhancing the planning and policy-making process. By doing so, this research contributes to a shift toward a more inclusive, responsive, and adaptive approach to urban governance, which can navigate the complex social-ecological challenges in uncertain conditions.

Chapter 8.

Policy Outline

8.1. Summary

Urban re-naturing and nature-based solutions show clear potential to address biodiversity loss, climate risks, and social well-being. Despite the influence of re-naturing measures on human lives, their social impacts are not systematically assessed over time, resulting in a limited understanding of their effectiveness, overlooked community priorities, and challenges in demonstrating social value alongside ecological gains. Current social impact assessment (SIA) practices are largely static and lack continuous, participatory monitoring, resulting in misalignment between local objectives and implementation, and reduced adaptability in complex conditions. The proposed SIA process mandates a continuous, phase-gate SIA across all project stages, with an adaptive decision process that integrates ecosystem services (ES)- based indicators into the monitoring procedure, tracking both social and ecological change. This process institutionalize clear engagement approach with inclusive methods (collective ES benefit cards selection, narrative-building, short interviews); establish policy review and tracking cycles informed by community input and remote-sensing data; reinforce biodiverse living conditions through paired human–nature monitoring and biodiversity triggers; implement Local Nature Futures Framework scenarios and Dynamic Adaptive Policy Pathways for planning; deploy constant monitoring tools (digital ES cards, citizen science, pathway sessions); and apply case-specific recommendations validated in Milan and Utrecht.

8.2. Problem Statement

Urban re-naturing and greening actions, such as nature-based solutions (NbS), have garnered a comprehensive amount of attention as approaches to locally tackle and mitigate the challenges of urban biodiversity loss, climate change, and improve societal conditions at different city scales. While these interventions show substantial promise in delivering co-benefits (e.g., improving biodiversity status, regulating local temperatures, controlling air quality, promoting immersive cultural activities, and enhancing social well-being), their social impacts in the short and long term are less systematically studied. This gap in monitoring and assessment leads to a lack of clear understanding of the efficiency of re-naturing interventions and their changes over time in relation to social values. These shortcomings limit the knowledge capacity of planners and policymakers in providing effective and targeted policies and managing current interventions for improved efficiency and adaptability. Additionally, these gaps result in urban re-naturing projects often overlooking community priorities and preferences, which shows struggles in demonstrating social value alongside ecological benefits. On the other hand, Social Impact Assessment (SIA) approaches and methodologies often fail to adequately address social values

and exhibit inefficiencies in engaging local actors and stakeholders in the assessment process, as well as in navigating the complex and uncertain conditions of human-nature relations. Without an inclusive and comprehensive framework for SIA of re-naturing, projects may fail to achieve the intended social outcomes of their interventions, leading to misalignment between project objectives and implementation.

Scope: Implementation-focused recommendations for embedding SIA in the evaluation process of urban greenery and re-naturing with emphasis on using ecosystem services (ES) and biodiversity values in adaptive policy-making that evolves and responds to changes in social-ecological conditions.

Purpose: This chapter translates research findings on SIA of re-naturing in urban areas into actionable policy guidelines and key policy messages. This chapter highlights how the SIA of re-naturing needs to be operationalized, using methodologies and analysis results to guide decision-makers and planners.

Target audience: Local planning authorities, urban planners and policy-makers, and greening assessors.

8.3. From research to policy practice (general recommendations)

This section serves as a how-to guide for implementing plans at various levels and scales.

8.3.1. Regulatory Framework Changes

- **Mandating a phase-gate process:** Mandating a continuous collaborative SIA for all project phases (pre- and post-intervention). Moving beyond one-off evaluations with adaptive decision gates.
- **ES-based indicators framework:** Establishing a list of ES-based indicators based on common categories and classifications (e.g., CICES or TEEB) following ES that are active or perceivable in the area of intervention. These indicators can be acquired through existing literature or reports or built in collaboration with experts and stakeholders for monitoring purposes. The indicators have to address and monitor both social and ecological changes.
- **Institutionalize engagement timetables:** Providing a clear timetable on collaborative activities within the timeline of intervention (from preparation to post-monitoring). Mapping initial actors and stakeholders for engagement in collaborative activities in consultation with experts. Collaborative activities are part of the continuous monitoring process.
- **Organize indicators and policy review cycles:** Defining checkpoints during and after interventions to review the suitability of established indicators and policies

with contextual changes. Reviews are conducted based on input from collaborative activities (changes in perceptions and objectives) and remote-sensing information.

- **Reinforce biodiverse living conditions:** Granting equal rights, considerations, and priorities between humans and nature (across all species) in monitoring activities. Amending local planning codes to define biodiversity targets and promoting better living conditions.
 - Integrating monitoring protocols for both humans and nature and shifting by focusing on sensitive or symbolic species.
 - Incorporating the biodiversity tipping point in adaptive plans based on local monitoring information.
 - Visioning equitable living conditions for different species in public areas with a focus on living facilitation for native species (e.g., providing shelters, monitoring soil conditions).
 - Revision and amendment of safety policies on contact with wild species in urban areas to facilitate access of fauna species to protected biodiversity areas in urban green spaces.

8.3.2. Collaborative activities and engagement mechanisms

- **Gamify the process:** Participants in small groups (4 to 6 people) can use ES benefits cards to explore and prioritize what benefits they want to see in the area of the intervention. The cards are modifiable based on the contextual status, and benefits can change depending on the existing ES at the site. Participants must prioritize five benefits, and they can also play the game to select the disservices they are observing. Introduce basic concepts with examples at the beginning of the activity to familiarize the participants with definitions.
- **Narrative-building and storytelling:** Building narratives based on individual or collective discussions (with actors and stakeholders) through co-design or co-monitoring sessions. Planners can extract information like the problems, visions, objectives, and suggestions for improvement. In this process, facilitators and planners have to avoid commenting or guiding the answers.
- **Conduct short interviews:** Interviews have to be structured semi-structured in a short duration (5 to 15 minutes) with diversity in gender and age through different time frames (morning, noon, and evening) and seasons. Questions should focus on definitions, perceptions, and values of nature or specific interventions, without guiding participants in their answers.

8.3.3. Analytical procedures and decision-support tools

- **Value elicitation:** Besides quantitative information, use output from co-design activities, narrative and scenario making, ES benefits selection, and direct engagement for value elicitation. Categorize values of nature, biodiversity, and re-naturing based on intrinsic, cultural, and instrumental value categories. Connect values with ES classes and categories to interpret them and avoid quantifying socio-cultural values.
- **Scenario making by local nature futures framework:** Code community priorities, objectives, and visions into local nature future framework values dimensions (Nature for Nature, Nature as Culture, Nature for Society). Utilize multi-criteria ranking tools that incorporate both social and ecological indicators to evaluate scenarios against predefined criteria.
- **Adaptive planning using the Dynamic Adaptive Policy Pathways framework:** Map decision sequences for built scenarios from short (5 years) to long-term (15-20 years) based on the criteria defined by participants and visions defined in upper-hand plans. Identify tipping points, timelines, and signposts (early warning indicators) based on input from collaborative sessions in conjunction with experts and authorities. Establish thresholds and triggers based on local policy and requirements defined in local plans.

8.3.4. Tools for constant monitoring

- **Digital ES cards and online surveys:** Provide a digital survey open to the public and distribute it among residents with a focus on actors that were not previously involved in the assessment procedure. A set of digital ES cards can be integrated into questionnaires. The survey has to focus on changes in perception regarding interventions.
- **Engage communities:** For ecological monitoring alongside sensors, activate community activities such as bird or reptile watching. Provide a platform for residents of the area to submit reports regarding sightings or observations of species. If applicable, dedicate an isolated area as an animal refuge to facilitate comparative analysis.
- **Pathway management systems:** Besides the digital tools, organize local sessions with actors in a period of 6 months to 1 year to reassess the changes as the case study evolves.

8.4. Recommendations for case studies

8.4.1. Milan case study – Sorelle Mirabal Garden

- Installing a covered and shaded green structure to reduce heat effects in the north of the Garden alongside a paved path and in the center, using the shade provided by the tree canopy.
- Reopen the inaccessible biodiverse area west of the garden and replace the fence with small animal shelters to provide better access for fauna species. The shelters must be equipped with signs to prevent direct contact and disturbance by humans.
- Promote weekly cultural activities (for instance, on community insect discovery) at the center of the Garden (natural theater), organized by volunteers or NGOs, targeting engaging younger generations to be present in the Garden.
- Providing insect hotels in the north and west (near the pond) of the Garden in more dense green areas to promote the presence of pollinators.
- Installing green noise barriers on the west side alongside the railway and providing a small-sized access point to the Garden from the railway to facilitate access of existing fauna species.

8.4.2. Utrecht case study – Utrecht University Botanical Gardens

- Providing green barriers between the Gardens and the sports complex in the north and the main road in the south to mitigate incoming noise.
- Improve accessibility of the Gardens to pedestrians by opening a new entry in the south to increase visitor presence and visibility.
- Introduce maintenance activities operated by communities and volunteers to increase awareness and familiarity of participants with different flora species.
- Promote low-barrier activities in open areas east of the Gardens, like open theaters or nature education activities for youth.

8.5. Implementation roadmap

The proposed SIA process is rolled out in four continuous phases, or specific phases can be adapted based on contextual status or stage of development for implementation.

- **Phase 1, Pre-interventions**
 - **When:** From 2 months before the beginning of interventions.

- **What:** Baseline data collection, stakeholder mapping, scenarios development, and values elicitation.
- **Who:** Planners, decision-makers, citizens, stakeholders, and experts.
- **How:** ES benefits card game, co-creation and co-design activities, narrative making, interviews, and online surveys.
- **Phase 2, During interventions**
 - **When:** Throughout the intervention implementation period (ongoing monitoring).
 - **What:** Real-time monitoring of established indicators, community feedback collection, and data validation.
 - **Who:** Planners, decision-makers, and stakeholders.
 - **How:** Co-creation and co-design activities, sessions with experts, online survey, and remote data collection.
- **Phase 3, Post-intervention (short-term)**
 - **When:** From 3 to 18 months after intervention.
 - **What:** Evaluation based on established indicators, community validation through co-monitoring sessions, policy refinements, tracking scenarios and analysis, and establishing feedback loops.
 - **Who:** Planners, stakeholders, NGOs and communities, experts, and decision-makers.
 - **How:** Comparative analysis between stages of intervention, co-monitoring sessions, online survey, and monitoring tools.
- **Phase 4, Post-intervention (long-term)**
 - **When:** From 2 to 5 years after interventions.
 - **What:** Data validation and tracking pathways and scenarios, strategy and policy refinements, and adapting new pathways based on contextual realities.
 - **Who:** Planners, decision-makers, experts, citizens.
 - **How:** Pathways monitoring through the dynamic adaptive policy pathways framework, comparative analysis with similar case studies, online survey, and monitoring tools.

8.6. Conclusion and next steps

The transformation of SIA from a static, one-off approach to dynamic, participatory decision-support systems represents a critical opportunity for cities to better understand and analyze local social-ecological systems. The framework presented in this outline (based on the research presented in previous chapters) integrates ES indicators, community co-creation, and co-design methods, and adaptive planning and policy making to provide local authorities and planners with the tools needed to navigate uncertainty while ensuring interventions serve both human and nature. The evidence from the Milan and Utrecht case studies demonstrates that cities can successfully replicate and implement continuous SIA processes that enhance intervention accuracy and efficiency in addressing local objectives, while maintaining ecological integrity with a focus on biodiversity values. However, realizing these benefits requires immediate action: regulatory frameworks must be updated to mandate phase-gate assessments, institutional capacity must be utilized to engage with local actors and stakeholders, and new methodological approaches must be deployed to enable ongoing community engagement. Cities that embed participatory SIA into their adaptive planning systems will be better positioned to deliver re-naturing interventions that are both effective and inclusive.

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Annex I Handbook for Collaborative Social Impact Assessment of Urban Re-Naturing Projects

1.0 Introduction: A New Paradigm for Social Impact Assessment (SIA)

As cities worldwide confront the accelerating effects of climate change and biodiversity loss, re-naturing urban areas has become an essential strategy for building resilience against changes related to biodiversity decay. Re-naturing, which aims to create nature-positive cities by reconnecting human-nature relations, offers a pathway to restore ecological functions and enhance human well-being. However, the social impacts of these projects are complex, deeply contextual, and often misunderstood by traditional, top-down assessment methods. Standard technocratic approaches, which focus on quantifiable data and general indicators, often fail to capture the intricate social-ecological dynamics within urban or local scales. This handbook provides a strategic guide to a more participatory, adaptive, and effective methodology for Social Impact Assessment (SIA), transforming it from a static reporting exercise into a collaborative planning process.

SIA is the interdisciplinary process of monitoring and analyzing the **positive and negative** intended and unintended social consequences of interventions (in this case, re-naturing) over time. Traditionally, SIA has been a top-down, expert-driven process, primarily operating within a technocratic paradigm that prioritizes quantifiable data. However, this classic approach is proving inadequate for the complex social-ecological challenges of urban re-naturing. In response, a new "constructivist" paradigm has emerged, which this handbook champions. This approach sees SIA as a bottom-up, socially constructed process that acknowledges multiple, equally valid value systems. It reframes assessment as a collaborative deliberation of local values, where information is gathered from, analyzed with, and elaborated upon through engagement with the community to sustainably enhance their quality of life.

Classic SIA Paradigm	Constructivist SIA Paradigm
Top-down, expert-driven	Bottom-up, socially constructed
Technocratic approach	Multi-value system
Focus on quantifiable data	Oriented around deliberating local values
Linear, static process	Collaborative and participatory

At the heart of this methodology is the concept of **Ecosystem Services (ES)**, which serves as the conceptual and practical bridge for evaluating the social impacts of re-naturing. ES are defined as the benefits people obtain through ecosystems and natural processes that contribute directly or indirectly to sustaining their health and well-being. By framing the discussion around ES, practitioners can utilize the relationships between benefits, impacts, factors, and measurement

methods related to different ES classes to facilitate a more transparent dialogue about the tangible and intangible benefits that nature provides to communities. These services are typically grouped into three main categories (based on European Environmental Agency classification biotic categories):

- **Provisioning services:** such as food and water or biomass.
- **Regulating services:** such as air quality regulation, noise attenuation, and heat control.
- **Cultural services:** such as recreation, aesthetic enjoyment, and spiritual fulfillment.

The methodological approach presented in this handbook unfolds across three primary phases, designed to integrate local knowledge and values with rigorous analysis and adaptive planning:

1. Scoping & Preparation for indicators and measurement methods: This initial phase involves a systematic review of existing literature (and a non-systematic on report and frameworks) to develop a robust toolkit of context-appropriate indicators and assessment tools, ensuring the process is grounded in scientific evidence. This step provides indicators, factors, possible impacts and measurement methods for evaluation and assessment.

2. Collaborative Engagement: This core phase implements bottom-up participatory methods, including workshops, collective activities, interviews, and field observations to uncover and prioritize the social values, local knowledge, and community desires that quantitative data cannot capture.

3. Analysis & Adaptive Planning: The final phase uses the in-depth qualitative data collected to develop future scenarios based on Local Nature Futures Framework and build dynamic, adaptive policy pathways that enable decision-makers to navigate long-term deep uncertainty effectively.

This handbook guides you through each of these phases, providing the conceptual frameworks and practical tools needed to move from theory to implementation. We begin with the foundational work of scoping and preparation, the critical first step in building a legitimate and effective assessment toolkit.

2.0 Phase 1: Scoping and Preparation - Building Your Assessment Toolkit

Your first strategic decision is to ground your assessment in evidence, not assumptions. This phase is non-negotiable for building credibility and ensuring your participatory efforts are focused and effective. The goal here is to systematically construct a robust assessment toolkit—a collection of indicators, metrics, and measurement methods tailored to the specific context of urban re-naturing. By grounding your tools in a systematic review of the existing knowledge landscape, you ensure that your subsequent engagement with the community is both efficient and credible, creating a legitimate basis for collaborative decision-making.

Practitioner's Tip: Your literature review isn't just about finding indicators; it's about building a defensible "menu" of options (the ES Benefit Cards) that is pre-validated by science. This gives your community engagement process immediate legitimacy. These options can contain also measurement method, impacts, and factors regarding the social impacts of re-naturing.

Systematic Literature Review: Identifying Key Indicators

The first step in building your toolkit is to conduct a systematic literature review to identify relevant indicators of social impact. This process moves beyond ad-hoc searches to create a comprehensive and defensible list of potential metrics. Structure your review using a transparent framework like **PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)** to guide the identification, screening, and selection of relevant academic and grey literature.

To organize the findings, use the **Common International Classification of Ecosystem Services (CICES) V5.1** (or later versions). This hierarchical classification system provides a detailed and comprehensive structure for categorizing different ES, ensuring that your review covers the full spectrum of potential social impacts—from noise attenuation to pest control. The goal is to extract indicators, impact factors, and measurement methods that can be adapted for your local assessment.

Six Categories of Social Impact Indicators

The literature review reveals that indicators for the social impact of re-naturing can be grouped into six emergent categories. Understanding these types is crucial for selecting a balanced set of tools that capture a project's multifaceted effects. While the other five categories represent established approaches, the systematic review reveals the emergence of **Biodiversity-related indicators** as a powerful new lens for SIA. This category is the critical link that connects abstract ecological health directly to tangible social outcomes and lived experiences.

Human-based

This category includes indicators that measure the direct effects of environmental changes on citizens' lives, health, and well-being. These are often observable but may not be quantifiable in purely monetary terms.

- **Example:** The level of noise annoyance or irritation experienced by residents living near a busy road, which can be mitigated by green barriers.

Biodiversity-related

These indicators use plant or animal factors to measure social impacts, directly linking ecological health to human experience. They are instrumental in demonstrating how biodiversity contributes to quality of life.

- *Example:* The effect of tree canopy abundance and species richness on citizens' physical and mental well-being.

Proxies

Proxy indicators measure indirect effects through a causal chain of events. They are useful when a direct link between a re-naturing action and a social outcome is complex or difficult to measure.

- *Example:* Improved mental health as an indirect result of a reduction in pests within urban green spaces, which in turn encourages more recreational use of those spaces.

Financial-related

This category encompasses indicators with market-oriented values or explicit monetary components. These are useful for communicating economic benefits but should not be the sole focus of an assessment.

- *Example:* Citizens' willingness-to-pay for the conservation of a local green space, which indicates its perceived economic value to the community.

Models

Models are used to calculate and quantify secondary or indirect effects, often translating complex ecological processes into understandable metrics.

- *Example:* Calculating the annual reduction of airborne dust and sand by a new shelterbelt of trees, which directly relates to improved public health outcomes.

Perception-based

These qualitative parameters require direct engagement with citizens and stakeholders to capture their perceptions, feelings, and subjective experiences.

- *Example:* Public perception of the effectiveness of tree coverage for noise cancellation, gathered through surveys or focus groups.

The Emerging Importance of Biodiversity-Related Indicators

Among these categories, **biodiversity-related indicators** represent an emerging and highly versatile tool for modern SIA. These indicators serve as a powerful bridge, connecting abstract ecological functions (like species richness or habitat quality) to the tangible well-being of citizens. Their flexibility is a key strength; they can be measured both quantitatively (e.g., counting pollinator species) and qualitatively (e.g., assessing residents' appreciation for birdsong). This adaptability makes them particularly well-suited for the participatory, mixed-methods approach championed in this handbook, as they provide a common language for ecologists, planners, and community members to discuss the value of nature.

Having systematically built this evidence-based toolkit, your next step is to take these indicators and methods into the field and use them to facilitate a rich, collaborative dialogue with the community.

3.0 Phase 2: Collaborative Engagement and Data Collection

This is the phase where your project gains its social license to operate. Moving beyond the toolkit, direct engagement is where you unearth the nuanced values and local knowledge that will make or break your project's long-term success. It transforms residents from passive recipients into active co-creators. This section outlines key methods for facilitating this deep engagement, moving beyond the theoretical toolkit to capture the rich, qualitative priorities that quantitative data alone can never capture.

Practitioner's Tip: The ES Benefit Cards are your most powerful tool for translation. They transform abstract ecological concepts into tangible community desires. The magic happens not in the final selection, but in the group *discussions* about trade-offs. Your primary role as facilitator is to listen to the 'why' behind their choices.

Conducting Co-Creation Workshops

Co-creation workshops are structured, facilitated sessions designed to bring together residents, local experts, and other stakeholders to collaboratively define problems and solutions. Your objective is to move beyond simple consultation and actively involve participants in shaping the future of their environment. Based on the Milan case study, a typical workshop sequence includes:

- 1. Opening Dialogue:** Begin with open discussions to collectively define what "urban biodiversity" means to the community. Ask participants to share personal experiences and observations of nature in their neighborhood.
- 2. Identifying Benefits & Values:** Facilitate a conversation about the benefits that local nature provides. Use probing questions to distinguish between instrumental benefits (e.g., shade from trees) and intrinsic or cultural values (e.g., a sense of peace or community identity tied to a garden).
- 3. Gamified Prioritization:** Introduce an interactive activity, like the ES Benefit Cards, to help the group collaboratively prioritize their desires for the re-naturing project.

Gamified Prioritization: The ES Benefit Cards

The "Ecosystem Services (ES) Benefit Cards" are a gamified tool designed to make the abstract concept of ES tangible and accessible. This activity facilitates a structured yet engaging conversation about community priorities.

- **Card Design:** Each card represents a specific benefit derived from nature.

- **Front:** Features a clear description of the benefit (e.g., "Reduction in depression and anxiety disorders") and a compelling, AI-generated image that visually represents that benefit in a relatable urban context.

- **Back:** Contains corresponding technical information, such as the relevant CICES classification, to link the community-facing benefit to the formal ES framework.

- **Card Content:** The benefits featured on the cards must be carefully selected from the systematic literature review conducted in Phase 1 and tailored to the specific ecological and social context of the project area. The deck should include a mix of provisioning, regulating, and cultural services.

- **Facilitation:**

1. Divide participants into small groups of 4-6 people.

2. Provide each group with a full deck of ES Benefit Cards.

3. Instruct the groups to discuss the benefits among themselves and collaboratively select their top five most desired benefits for the project.

4. Ask each group to present their top five choices to the wider audience, explaining the reasoning behind their prioritization. This final step is crucial for uncovering the underlying values and narratives that drive community preferences.

Collaborative Stakeholder Mapping

To ensure inclusive governance and follow-up, it is vital to understand the full network of actors who have a stake in the project. Use collaborative stakeholder mapping as a simple yet powerful way to leverage the collective knowledge of the community. As demonstrated in the Milan case, ask workshop participants to brainstorm a list of all potential actors—individuals, groups, and institutions—who might be affected by or have an influence on the project.

Guide the group to categorize these actors (e.g., public, private, administrative, NGOs, local communities). This process not only identifies key players you may have overlooked but also helps reveal the complex relationships and power dynamics within the community, providing a crucial foundation for equitable and effective governance.

Complementary Methods: Interviews and Field Observations

While workshops are excellent for capturing collective values, you must complement them with methods that capture individual perspectives and real-world behaviors. As utilized in the Utrecht case study:

- **Semi-Structured Interviews:** Conduct one-on-one interviews with a diverse range of users and residents. These allow for deeper exploration of personal experiences, experiential narratives, and nuanced opinions that may not surface in a group setting.

- **Field Observations:** Spend time in the project area observing how people actually use the space. Note patterns of activity, informal social interactions, and physical traces of use. This provides an essential reality check, grounding the stated preferences from workshops and interviews in observable behavior.

After collecting this rich body of qualitative data, the focus shifts to the final phase: analyzing this information and translating it into coherent, future-oriented, and adaptive strategies.

4.0 Phase 3: Analysis, Scenario Development, and Adaptive Planning

This analytical phase is where you will structure the rich, qualitative data gathered through collaborative engagement into coherent future visions. Its purpose is to translate community values and priorities into robust, adaptive plans that can effectively navigate long-term uncertainty. Instead of producing a static final report, this phase creates a dynamic decision-support framework that empowers planners and communities to make informed choices over time. The primary tools for this are the Local Nature Futures Framework (LNFF) and Dynamic Adaptive Policy Pathways (DAPP).

Practitioner's Tip: Pareto Optimization can sound difficult, but think of it as a "common sense filter." It quickly eliminates scenarios that are objectively worse than others, allowing you to focus community and stakeholder deliberation on the most viable and efficient options where real trade-offs exist.

Interpreting Social Values: The Local Nature Futures Framework (LNFF)

The Local Nature Futures Framework (LNFF) is a tool for understanding and structuring the different ways people value their relationship with nature. It helps translate the diverse perspectives from workshops and interviews into a clear, analytical model based on three core value dimensions:

- **Nature for Nature (NN):** This dimension emphasizes the intrinsic value of nature. It prioritizes the preservation of biodiversity and ecological processes for their own sake, independent of any direct human benefit.
- **Nature as Culture (NC):** This dimension focuses on the relational values between people and nature. It centers on living in harmony with nature, cultural identity, stewardship, and the spiritual or aesthetic enrichment derived from human-nature connections.
- **Nature for Society (NS):** This dimension centers on the instrumental and utilitarian benefits that people obtain from nature. It highlights the direct ecosystem services that support human well-being, such as air purification, food production, and flood control.

Applying the LNFF: From Data to Scenarios

The application of LNFF is a structured, step-by-step process that transforms raw data into ranked, plausible futures.

1. **Define Futures:** Collaboratively define multiple future scenarios. This must include a *Desired Future*, synthesized directly from citizen input and prioritized ES benefits. It should also include a *Strategic Future*, which is grounded in existing policies, budget constraints, and administrative realities. Finally, brainstorm a range of other *Plausible Futures* that could emerge based on different drivers or priorities.

2. **Score Scenarios:** Evaluate and score each future scenario against the three LNFF dimensions. Using a consistent scale (e.g., 0-10), assess how well each scenario performs in promoting the values of Nature for Nature (NN), Nature as Culture (NC), and Nature for Society (NS).

3. **Identify Optimal Pathways:** Use a two-phase optimization process to identify the most effective and efficient future.

- **Phase 1: Pareto Optimization:** Before conducting a detailed ranking, first apply Pareto Optimization. **Think of this as a strategic filter to remove the 'no-brainer' bad options.** It identifies the "Pareto Front"—the subset of scenarios that represent the most efficient trade-offs. Any scenario that is objectively worse than another across all dimensions is considered "dominated" and is set aside, allowing you to focus the final analysis on the strongest contenders.

- **Phase 2: Weighted Analysis:** The remaining efficient scenarios are ranked using a weighted analysis, where **the weights are derived directly from the community priorities identified during the Phase 2 ES Benefit Card activity.** This critical step ensures the final "optimal" future is a direct reflection of local values, not just expert opinion. The scenario with the highest final score is identified as the optimal future.

Long-Term Planning: Dynamic Adaptive Policy Pathways (DAPP)

While LNFF helps identify an optimal near-term future, the Dynamic Adaptive Policy Pathways (DAPP) framework provides a method for long-term (e.g., 25-year) strategic planning under conditions of deep uncertainty. It moves away from a single, rigid plan and instead creates a flexible roadmap of actions.

The key DAPP concepts include:

1. **Pathways:** These are sequences of actions and policies designed to achieve the goals of a specific future scenario (derived from the LNFF analysis). Multiple pathways can be pursued.

2. **Adaptation Tipping Points (ATPs):** An ATP is the point at which a current policy or action is no longer effective due to changing conditions (e.g., climate impacts, social preferences). Reaching an ATP signals that a change in strategy is required.

3. Contingency Plans: These are pre-defined actions designed to switch from one pathway to another when an ATP is reached. This ensures that the overall plan remains flexible and can adapt to unforeseen changes without starting from scratch.

Constructing a DAPP Map

A DAPP map visually lays out the different pathways, their tipping points, and the planned shifts between them. The following table, based on the conceptual model from the Milan case study, illustrates a basic structure for a DAPP map.

Pathway (Scenario)	Key Actions/Policies	Potential Tipping Point (ATP)	Contingency Action (Switch to...)
NN: Biodiversity Focus	- Expand inaccessible habitat zones. Strict limits on public access. Monitor sensitive species.	Biodiversity indicators show decline despite protection.	Switch to NC Pathway to increase stewardship and community monitoring.
NC: Harmony & Culture	- Promote community gardening & stewardship. Develop educational nature trails. Host low-impact cultural events.	Social participation drops below a critical threshold.	Switch to NS Pathway to introduce more recreational amenities.
NS: Societal Benefit	- Install recreational facilities (playgrounds). Maximize shaded areas for heat relief. Focus on high-utility re-naturing.	Overuse leads to soil compaction and ecological damage.	Switch to NN Pathway to implement restorative actions and limit access.

This analytical framework provides a powerful toolkit for translating rich, participatory data into concrete, adaptive, and future-proofed strategies. The next section explores how this methodology has been applied in two distinct real-world contexts, offering practical lessons for implementation.

5.0 Application in Practice: Lessons from the Milan and Utrecht Case Studies

This section distills practical lessons from the application of this methodology in two distinct European urban contexts to guide your strategic implementation. The case studies—the Sorelle Mirabal Garden in Milan and the Utrecht University Botanical Gardens—highlight the framework's adaptability across a project's lifecycle. Milan serves as an example of an *ex-ante* assessment, conducted before a major re-naturing intervention, while Utrecht represents an *ex-post* evaluation of an established, functional green space. Together, they offer invaluable insights into how to tailor the approach to your project's specific stage and challenges.

Sorelle Mirabal Garden, Milan (Ex-Ante Assessment)

- **Core Objective:** The primary goal was to plan the reopening of a public garden that had been closed during the COVID-19 pandemic. The vision, co-developed with the community, was to create a "**multifunctional and multispecies**" space that served both people and nature.
- **Key Findings from the Participatory Process:** Through co-creation workshops and the ES Benefit Cards activity, the community prioritized a clear set of social benefits. The most desired outcomes were **regulating services**, such as urban heat reduction, and **cultural services**, including the enhancement of local biodiversity for aesthetic and educational purposes and the creation of spaces that foster social cohesion and neighborhood identity.
- **Outcome of the LNFF/DAPP Analysis:** The analysis of future scenarios revealed that the community's preferred pathways were those that struck a careful balance between the **Nature for Nature (NN)** and **Nature as Culture (NC)** dimensions. The optimal future focused on preserving and enhancing biodiversity through dedicated, protected zones while simultaneously enabling respectful socio-cultural activities that allowed residents to connect with and learn from nature. The instrumental, high-impact recreational uses associated with the Nature for Society (NS) dimension were seen as a lower priority.

Utrecht University Botanical Gardens (Ex-Post Evaluation)

- **Core Objective:** The goal here was to evaluate an existing, highly functional botanical garden with a strong, pre-existing mission centered on scientific research, species conservation, and education. The assessment aimed to understand its social value to users and identify opportunities for improvement.
- **Key Findings from the Participatory Process:** The engagement process, which included interviews and workshops, identified three distinct "**Narratives of Urban Biodiversity**" among users: *Fauna and Flora* (valuing specific species), *Controlled Wilderness* (valuing the aesthetic of maintained wildness), and *Supporting Living Systems* (valuing ecological functions). The primary social benefits that users derived from the garden were mental **well-being**, opportunities for **recreation** and reflection, and its role as an important **educational** resource.
- **Outcome of the LNFF Analysis:** Reflecting the garden's core mission and the values of its primary users, the optimal future scenario (identified as UPF4) heavily prioritized the **Nature for Nature (NN)** dimension. This outcome affirmed that the garden's primary value lies in its scientific and conservation work. While social and cultural benefits are important by-products, the analysis showed that stakeholders were willing to accept trade-offs—such as limitations in integrity.

Comparative Lessons for Practitioners

The two case studies offer a valuable comparative lens for practitioners, highlighting how the methodology adapts to different contexts and project stages.

Aspect	Milan (SMG) - Ex-Ante	Utrecht (UUBG) - Ex-Post
Primary Challenge	Defining a new, shared vision for a closed space.	Aligning social benefits with an existing, strong institutional mission.
Key Engagement Tool	Gamified "ES Benefit Cards" to prioritize future desires.	Semi-structured interviews and narrative analysis to uncover existing values.
Dominant LNFF Value	A strategic balance favoring Nature as Culture (NC) while safeguarding Nature for Nature (NN) .	A clear prioritization of Nature for Nature (NN) .
Primary Policy Implication	Design interventions that foster both biodiversity and respectful social interaction.	Strengthen policies that protect the core scientific mission, even if it means managing social use.

These real-world applications demonstrate that the participatory SIA framework is not a rigid template but a flexible and powerful methodology. It successfully uncovers the unique social-ecological identity of a place and translates that identity into targeted, context-appropriate, and adaptive strategies for urban greening.

6.0 Conclusion: Towards an Adaptive and Participatory Future for Urban Greening

This handbook has outlined a replicable, engaging, and cost-effective package for conducting Social Impact Assessments of urban re-naturing projects. By integrating the concepts of Ecosystem Services, participatory engagement, and adaptive planning, this methodology moves beyond the limitations of traditional, expert-driven assessments. It transforms the SIA from a static, retrospective report into a live, forward-looking planning process. This approach empowers both decision-makers and communities to navigate uncertainty and co-create urban green spaces that are not only ecologically resilient but also deeply valued by the people who use them.

By systematically linking biodiversity to social well-being, framing impacts through the accessible lens of Ecosystem Services, and structuring local knowledge into adaptive pathways, this framework provides the tools needed to build a stronger, evidence-based case for nature in our cities. Ultimately, its adoption can foster more just, resilient, and sustainable human-nature relationships, helping to shape urban futures where both people and biodiversity can thrive.

7.0 Appendix: Glossary of Key Terms

- **Social Impact Assessment (SIA):** An interdisciplinary process of monitoring and analyzing the positive and negative intended and unintended social consequences of interventions over time.

- **Ecosystem Services (ES):** Benefits people obtain through ecosystems and natural processes that contribute directly or indirectly to sustaining their health and wellbeing.
- **Re-naturing:** Attempts to create nature-positive cities by restoring human-nature relations, where nature is deliberately reintegrated into built environments to address social-ecological challenges.
- **Nature-Based Solutions (NbS):** Actions that address environmental, social, and economic challenges simultaneously by maximizing the benefits provided by nature and inspired by, supported by, or copied from nature.
- **Local Nature Futures Framework (LNFF):** A heuristic framework that captures diverse, positive values for human-nature relationships, used to develop and analyze future scenarios.
- **Nature for Nature (NN):** A dimension of the LNFF that emphasizes the intrinsic value of nature.
- **Nature as Culture (NC):** A dimension of the LNFF that focuses on relational values and living in harmony with nature.
- **Nature for Society (NS):** A dimension of the LNFF that centers on the instrumental and utilitarian benefits people obtain from nature.
- **Dynamic Adaptive Policy Pathways (DAPP):** A method for crafting robust decisions for the long term by developing sequences of actions (pathways) that can be adapted over time in response to changing conditions.
- **Adaptation Tipping Point (ATP):** The point at which a particular action or policy is no longer adequate for meeting a plan's objectives, triggering the need for a new action or a switch to a different pathway.

Supplementary Material I (Chapter 2)

ES Class Final string used	Results (base query/+BD/+U/+Limits/ Final	Indicators Extracted	Social Impact Indicators	Type	Secondary Type	Tertiary Type	Interaction related	Outcome related	Contextual
Bio-remediation by micro-organisms, algae, plants, and animals Base query AND TITLE-ABS-KEY ("bio-remediat*" OR "bioremediat*" OR "remediat*") AND TITLE-ABS-KEY ("biodiversit*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re"))	36/15/2/3/9/7	8	Amount of Payment for sustaining ES (PES) by governing bodies (Quilliam et al., 2015)	Monetary/ Financial	-	-	ES	Economic systems	-
			Amount of participation in harvesting or managing the bio-remediation by society or governing bodies (Quilliam et al., 2015)	Human-based / Health related	-	-	-	Users	-
			Public perception on: quality of life during the intervention, public benefits, governing actor	Perception/ Questioners	Indirect/ Proxies	-	Biophysical	Users	-

		image in public, workers' safety, and resulted cultural heritage values (Harclerode et al., 2015)						
		Level of concern to the government versus the level of concern to stakeholders for each intervention (Harclerode et al., 2015)	Indirect/ Proxies	-	-	-	Governance system	-
		Changes in human health and risk before and after remediation (residents and workers) (risk of accidental injury, avoid secondary contamination, and prevent exposure	Human-based / Health related	-	-	Biophysical	Users	-

		pathways) (Harclerode et al., 2015)						
		Level of acceptance by stakeholder participation, information disclosure, considering remedial related effects on local residents, and preservation of cultural heritage (Harclerode et al., 2015)	Perception/Questioners	Human-based / Health related	-	Biophysical	Users	-
		Common social perception on related effect such amount of noise, odor, and vibration (Harclerode et al., 2015)	Human-based / Health related	-	-	Biophysical	Users	-
		1. Changes in the safety level of the site for	Perception/Questioners	Monetary/Financial	Models	Biophysical	Users	Sociocultural

			humans 2. changes in the ratio between economic and benefits costs of intervention 3. community involvement and employment amount; 4. flexibility and lifespan of the project (Harclerode et al., 2015)						
Filtration/sequestration /storage/accumulation by micro-organisms, algae, plants, and animals Base query AND TITLE-ABS-KEY (("filtra*" OR "sequestra*" OR "storage*" OR "accumulation*" OR "purific*" OR "treatment*") AND ("animal*" OR "plant*" OR "algae*" OR "micro-organism*" OR "micro organism*" OR "fungi*" OR "bacter*")) AND TITLE-ABS-KEY ("biodiversit*")	153/53/5/4/3	2	1. Value of tree richness and number of native tree species in the area (direct relation with carbon sequestration) 2. Bee and wasp species richness (positive correlation with carbon	Biodiversity index	Indirect/ Proxies	–	Biodiversity	–	Related ecosystems

<p>AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))</p>			<p>sequestration (r = 0.61)) 3. local vegetation density and leaves (direct relation with carbon storage) (Belaire et al., 2022)</p>						
<p>Smell reduction</p> <p>Base query AND TITLE-ABS-KEY (("smell*" OR "odor*" OR "odour*" OR "scent*") AND ("reduc*" OR "contro*" OR "attenu*")) OR TITLE-ABS-KEY ("smell reduc*" OR "smell control" OR "odor reduc*" OR</p>	<p>3/2/0/2/0</p>	<p>0</p>	<p>–</p>	<p>–</p>	<p>–</p>	<p>–</p>	<p>–</p>	<p>–</p>	<p>–</p>
			<p>Amount of green spaces in urban areas (e.g, due to shrinkage or land use change)(direct relation with carbon sequestration)(Haase et al., 2014)</p>	<p>Models</p>	<p>Human-based / Health related</p>	<p>–</p>	<p>Biophysical</p>	<p>Governance system</p>	<p>Socio-cultural</p>

"odor reduc*") AND TITLE-ABS-KEY ("biodiversit*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))									
Noise attenuation Base query AND TITLE-ABS-KEY ("nois*") OR (("noise control*") OR ("noise attenu*") OR ("low nois*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))	19/11/5/5/8	4	Amount of noise annoyance , irritation, and anger (van den Bosch & Ode Sang, 2017) Pereception of greenery and its coverage for noise attenuation (Dzhambov &Dimitrova, 2014) Pleasantness of space and tree canopy (pleasant sound cover or living barriers from roads) (Bautista et al., 2020)	Hum an-based / Healt h relate d Perce ption/ Quest ioners Biodi versit y index	- Hum an-based / Healt h relate d Perce ption/ Quest ioners	- - Hum an-based / Healt h relate d	Bioph ysical ES Biodi versit y	Users Users Users	Relat ed ecosy stems - -

			Quietness level of space for humans (Wang et al., 2014)	Human-based / Health related	-	-	-	Users	-
			Neighbors with a lower Social Development Index (SDI) have higher identification of noise attenuation (indirect relation)(Pistón et al., 2022)	Monetary/ Financial	Models	Human-based / Health related	Biophysical	Economic systems	Socio-cultural
Visual screening TITLE-ABS-KEY ("social*" AND "impact*" OR "social impact*") AND TITLE-ABS-KEY ("ecosystem servic* " OR ecosystem-servic*) AND TITLE-ABS-KEY (("visual*" OR "sight*") AND ("screen*" OR "nusianc*" OR "amenit*" OR "impact*") OR ("visual screen*" OR "visual nusianc*" OR "visual amenit*" OR "sight screen*" OR "sight nuisanc*" OR	89/16/5/4/0	0	-	-	-	-	-	-	-

"sight amenit*" OR "visual impact*" OR "sight impact*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*") AND (LIMIT-TO (LANGUAGE , "english")) AND (LIMIT-TO (DOCTYPE , "ar"))									
Control of erosion rates Base query AND TITLE-ABS-KEY ("erosi*" OR "erosion control*") AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))	205/62/11/10/4	3	Areas dedicated to urban agricultural activities (or for soil safety) (Jorda-Capdevila et al., 2019)	Indirect/ Proxies	Human-based / Health related	-	-	Users	Related ecosystems
			Resident willingness to pay for the conservation of greeneries that help to prevent erosion within a 50 km radius of the case study (Jakarta) (Vollmer et al., 2016)	Monetary/ Financial	Models	-	-	Economic systems	-
			Amount of food productio	Indirect/	-	-	ES	-	Related

			n in agricultural or agroforestry areas in urban areas (Balzan et al., 2020)	Proxies						ecosystems
Buffering and attenuation of mass movement										
Base query AND TITLE-ABS-KEY (("buffer*" OR "attenu*" OR "stoppi*" OR "control*") AND ("mass move*" OR "mass flow*" OR "erosi*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))	79/24/5/5/0	0	-	-	-	-	-	-	-	-

<p>Hydrological cycle and water flow regulation (Including flood control, and coastal protection)</p> <p>Base query AND TITLE-ABS-KEY ("hydrological cycle*" OR ("water" AND "flow*" AND "regulat*") OR ("flood control*") OR ("coastal protection*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	<p>145/53/15/1 1/7</p>	<p>1</p>	<p>Primary industry output value, secondary industry output value, tertiary industry output value, GDP, population, and volume of diverted water are the main anthropogenic factors (Cai et al., 2023)</p>	<p>Monetary/ Financial</p>	<p>Models</p>	<p>–</p>	<p>–</p>	<p>Economic systems</p>	<p>Socio-cultural</p>
<p>Wind protection</p> <p>Base query AND TITLE-ABS-KEY (("wind*" AND "protect*") OR ("storm*" AND "protect*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar"))</p>	<p>57/12/3/3/1</p>	<p>4</p>	<p>Public perception on ES functionality (through semi-systematic assessment) (Missall et al., 2018)</p>	<p>Perception/ Questioners</p>	<p>–</p>	<p>–</p>	<p>–</p>	<p>Users</p>	<p>–</p>
			<p>Amount of annual airborne dust and/or</p>	<p>Models</p>	<p>Human-based / Health</p>	<p>–</p>	<p>Biophysical</p>	<p>Users</p>	<p>Related ecosystems</p>

AND (LIMIT-TO (LANGUAGE , "english"))		sand which (results in improvement in public health and decrease in lung diseases) (Missall et al., 2018)		h related				
		Amount of water used by protective vegetation in comparison with actual water provided (efficiency) (Missall et al., 2018)	Indirect/ Proxies	Models	-	Biophysical	Users	-
		Enhanced perception of living conditions . (Missall et al., 2018)	Perception/ Questioners	Human-based / Health related	-	-	Users	Socio-cultural

<p>Fire protection</p> <p>Base query AND TITLE-ABS-KEY (("fire*" OR "wildfire*") AND ("protect*" OR "prevent*")) OR TITLE-ABS-KEY ("fire protect*" OR "wildfire protect*" OR "fire prevent*" OR "wildfire protect*") AND TITLE-ABS-KEY ("biodiversit*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	44/16/1/10/2	1	<p>Positive changes in habitat maintenance standards (as a co-benefit) (effectiveness measurement) (McElwee et al., 2020)</p>	Indirect/ Proxies	Biodiversity index	-	Biodiversity	-	Related ecosystems
<p>Pollination (or 'gamete' dispersal in a marine context)</p> <p>Base query AND TITLE-ABS-KEY ("pollinat*") AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	80/46/10/8/5	3	<p>Amount of area provided to pollinator vectors in urban areas (by green spaces and urban density) (Jansson & Polasky, 2010)</p>	Models	Indirect/ Proxies	-	Biophysical	-	-
			<p>1. Functional diversity of arable plant communities</p>	Biodiversity index	Indirect/ Proxies	Models	Biodiversity	-	Related ecosystems

		<p>provided (Rao's quadratic entropy), 2. Weed species abundance (%), 3. Butterfly species richness, 4. Butterfly species abundance , 5. Wheat flowering onset, Pollinator visitation probability, 6. Richness and abundance of wild plants, 7. Bees' abundance , 8. Non-bee flower visitor abundance (Balzan et al., 2020).</p>						
		<p>Willingness-to-pay of local residents and tourists for ES (Balzan et al., 2020)</p>	<p>Monetary/ Financial</p>	<p>Human-based / Health related</p>	<p>–</p>	<p>–</p>	<p>Users</p>	<p>Socio-cultural</p>

<p>Seed dispersal</p> <p>Base query AND TITLE-ABS-KEY (("seed*") AND ("dispers*" OR "spread*")) AND TITLE-ABS-KEY ("biodiversit*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	9/6/0/5/2	0	-	-	-	-	-	-	-
<p>Maintaining nursery populations and habitats (Including gene pool protection)</p> <p>Base query AND TITLE-ABS-KEY (("habitat*" OR "population*") AND ("nursery*" OR "maintain*" OR "support*")) OR TITLE-ABS-KEY ("nursery habitat*" OR "nursery population*" OR "habitat maintain*" OR "population maintain*" OR "habitat support*") AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND (LIMIT-TO (DOCTYPE , "ar") OR</p>	392/159/38/30/9	6	<p>1. Functional dominance of Mediterranean arable plants (Community weighted mean), 2. Abundance and occurrence of a bird species, 3. Cattle beef variable costs, 4. subsidies (euro/cow) , 5. Gross Margin of beef cattle (euro/cow) , 6. Sheep</p>	Biodiversity index	Monetary/ Financial	Models	Biodiversity	Economic systems	-

LIMIT-TO (DOCTYPE , "re") AND (LIMIT-TO (LANGUAGE , "english"))		meat variable costs, 7. subsidies (euro/ewe) , 8. Number of cattle and sheep holdings, 9. Gross Margin of sheep meat (euro/ewe) , 10. Number of cattle and sheep head, 11. Drainage in wetlands (Balzan et al., 2020)						
		Value of commercial species in the market and conservation value (Liquete et al., 2016).	Models	Monetary/ Financial	-	-	Economic systems	-
		Habitat's amount of food delivery and/or recreational value (Liquete et al., 2016).	Models	Monetary/ Financial	Human-based / Health related	ES	Users	Related ecosystems

		<p>1. Biodiversity value (species diversity or abundance, endemics or red list species), 2. Oxygen concentration (%), 3. Turbidity (%), 4. Ecological status (high to bad), 5. Hydromorphological status (high, good, other)(Liquete et al., 2016).</p>	Biodiversity index	Models	–	Biodiversity	–	Related ecosystems
		<p>ES flow function indicators: 1. Annual production of each fish species attributable to seagrass (g/m²), 2. Change in the recruitment of adults (%), 3. Catch-</p>	Biodiversity index	Monetary/Financial	Models	Biodiversity	Economic systems	–

		per-unit-effort (kg/day) distribution against wetland connectivity index (%), 4. Catch-per-unit-effort (kg/day) distribution against wetland patch density (ha) (Liquete et al., 2016).						
		1. Annual value of the services provided to the fishery (USD/km of mangrove) 2. Economic production along the productive mangrove fringe (USD/ha/year), 3. Marginal value of a change in mangrove area	Monetary/Financial	Biodiversity index	Human-based / Health related	ES Biodiversity	Economic systems Users	Related ecosystems

		<p>(USD/ha), Estimated welfare losses associated with annual mangrove deforestation (USD), 4. Annual economic enhancement of commercial fish by seagrass (kg/m², AUD/ha), 5. Commercial fishery landings linked to seagrass-associated species (EUR/yr, %), 6. Expenditure of recreational fishers pursuing seagrass-associated species (EUR/yr, %), 7. The benefit of protecting fish habitat testing changes in</p>					
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			<p>habitat quality (CAD/ha, CAD/km), 8. Willingness to participate in mangrove reforestation projects for the nursery benefits (%), 9. Willingness-to-pay for mangrove reforestation project (Rs/yr), 10. Value of commercial fish in seagrass meadows (EUR/ha), 11. Benefits from cultivated shrimp over benefits from wild shrimp (%) (Liquete et al., 2016).</p>						
Pest control (including invasive species)	95/55/7/4/8	3	The increase of biodiversity	Biodiversity	Indirect/	–	Biodiversity	Users	Related

<p>Base query AND TITLE-ABS-KEY (("pest*" OR ("invasive*" AND "specie*")) AND ("control*")) OR TITLE-ABS-KEY ("pest control*" OR "invasive species control*") AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))</p>			<p>y and species richness in urban areas through agricultural activities (direct relation)(Nicholls et al., 2020)</p>	<p>y index</p>	<p>Proxies</p>				<p>ecosystems</p>
			<p>Urban development leading to habitat fragmentation (direct relation)(Shennan, 2007)</p>	<p>Indirect/ Proxies</p>	<p>Models</p>	<p>Human-based / Health related</p>	<p>Biophysical</p>	<p>–</p>	<p>Socio-cultural</p>
			<p>Payment amount to landowners for environmental and pest control (Alix-Garcia et al., 2018)</p>	<p>Monetary/ Financial</p>	<p>Indirect/ Proxies</p>	<p>–</p>	<p>–</p>	<p>Economic systems</p>	<p>Socio-cultural</p>
<p>Disease control</p> <p>Base query AND TITLE-ABS-KEY (("disease*") AND ("control*" OR "regul*")) OR TITLE-ABS-KEY ("disease*") AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY (</p>	<p>101/40/10/6/4</p>	<p>8</p>	<p>Lower urban environmental characters (air and noise pollution) (Nawrath et al., 2022)</p>	<p>Indirect/ Proxies</p>	<p>Human-based / Health related</p>	<p>–</p>	<p>Biophysical</p>	<p>Users</p>	<p>Related ecosystems</p>

<p>"urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	Level of social participation in cultural activities and increase in cultural ES indicators (Nawrath et al., 2022)	Indirect/ Proxies	Human-based / Health related	-	-	Users	Related ecosystems
	Amount of pests in green spaces in urban areas (indirect relation)(Nawrath et al., 2022)	Indirect/ Proxies	-	-	Biophysical	-	-
	Functional perception of cultural ES increase mental health safety (Nawrath et al., 2022)	Indirect/ Proxies	Human-based / Health related	Biodiversity index	-	-	Related ecosystems
	Perception of functionality of provisioning (negative) and	Indirect/ Proxies	Human-based / Health related	-	Biophysical	Users	-

		cultural (positive) ES at the local scale (Nawrath et al., 2022)				
		Air quality improves over time, as vegetation contributes to the removal of pollutants and the release of oxygen. Clean air is essential (Elendu et al., 2024)	Indirect/ Proxies	Biodiversity index	-	
		Level of Access to green spaces in relation to Coronary artery disease (Quantitative data from a study on green environments and CAD risk indicated a statistically significant	Models	Human-based / Health related	-	

		<p>decrease in systolic blood pressure (SBP) after spending time in natural, green surroundings ($P < .01$). Additionally, heart rate variability (HRV) measurements improved significantly ($P < .05$) in the green environment group compared to controls. These quantitative findings underscore the benefits of environmental stress reduction) (Elendu et al., 2024).</p>						
		<p>Increase in amount of income in neighbours</p>	<p>Models</p>	<p>Human-based / Health</p>	<p>–</p>	<p>–</p>	<p>–</p>	<p>Socio-cultural</p>

			(Nawrath et al., 2022)		h relate d				
Weathering processes and their effect on soil quality									
Base query AND TITLE-ABS-KEY ("weathering*" OR "weathering process*" OR "decomposi*") AND ("soil*") AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))	12/5/1/1/0	0	-	-	-	-	-	-	-

<p>Decomposition and fixing processes and their effect on soil quality</p> <p>Base query AND TITLE-ABS-KEY ("decompos*" OR "fix*" OR "maintain*") AND ("soil*") AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	222/81/16/13/2	0	-	-	-	-	-	-	-
<p>Regulation of the chemical condition of freshwaters by living processes</p> <p>Base query AND TITLE-ABS-KEY (("chemic*") AND ("condition*" OR "qualit*" OR "regulat*") AND ("freshwater*" OR "fresh water*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar"))</p>	12/5/1/1/0	2	Changes in water salinity risk levels and increase in drinking water supply (Balzan et al., 2020)	Indirect/ Proxies	Human-based / Health related	-	Biophysical	-	-
			Change in water use efficiency (Tamburini et al., 2020)	Indirect/ Proxies	Human-based / Health related	-	-	Users	-

AND (LIMIT-TO (LANGUAGE , "english"))									
<p>Regulation of the chemical condition of salt waters by living processes</p> <p>Base query AND TITLE-ABS-KEY (("chemic*") AND ("condition*" OR "qualit*" OR "regulat*") AND ("saltwater*" OR "salt water*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	1/1/1/1/0	0	-	-	-	-	-	-	-

<p>Regulation of chemical composition of atmosphere and oceans</p> <p>Base query AND TITLE-ABS-KEY (("chemic*") AND ("condition*" OR "qualit*" OR "regulat*") AND ("climate*" OR "atmosphere*" OR "ocean*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY ("urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "english"))</p>	23/11/3/1/0	0	-	-	-	-	-	-	-
<p>Regulation of temperature and humidity, including ventilation and transpiration</p> <p>Base query AND TITLE-ABS-KEY (("humid*" OR "temperat*") AND ("condition*" OR "qualit*" OR "regulat*") AND ("climate*" OR "ventilat*" OR "transpir*" OR "air*") OR ("heat island*" OR "thermal comfort*" OR "air qualit*")) AND TITLE-ABS-KEY ("biodiversit*") AND TITLE-ABS-KEY (</p>	103/23/11/8/3	4	Amount of curbside planting (unit per km2) and temperature reduction in pedestrian areas (Rosenzweig et al., 2006)	Indirect/ Proxies	Biodiversity index	-	Biophysical	-	-
<p>TITLE-ABS-KEY (</p>			Increase in tree canopy cover percentage reduces	Models	Indirect/ Proxies	-	Biophysical	Users	-

"urban*" OR "city" OR "cities*") AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "english"))		temperatu re (Pandey & Ghosh, 2023)						
		Number planted tress or greeneries in heat- exposed areas (Pandey & Ghosh, 2023)	Mode ls	Indire ct/ Proxi es	-	Bioph ysical	-	-
		Amount of tree shading and surface temperatu re reduction (Pandey & Ghosh, 2023)	Mode ls	Indire ct/ Proxi es	-	Bioph ysical	Users	-

Supplementary Material 2 (Chapter 2)

Category			Type						
Type	ES Class	Code	Indicators	Factors	Impacts	Questions	Quantifications	Location	Process
Provisioning (Biotic)	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	1.1.1	_Wheat production yield (t/ha), Food production, Number of spikes (per m ²), Downscaled crop production (t/km ²), Number of seeds per spike, Number of hives (per km ²), Beekeepers' habitat preference (Frequency of	_Rainfed agricultural land (Fodder production potential)(Balzan et al., 2020) _Intensity of farming/food type production/energy demand (Artmann & Sartison, 2018)	_Proximity to market / fresh product consumption / Increased social cohesion _Increase in income / Improvement in diet / Pollination and microclimate improvement / Efficient water harvesting form allotments/Improve urban regeneration process / Increasing health of	-	_Willingness-to-pay of local residents and tourists (Balzan et al., 2020)	_(Artmann & Sartison, 2018) N/A	_(Artmann & Sartison, 2018) SLR and analysis

			<p>responses) kernel weight (g), Number of quality products available for consumers (Balzan et al., 2020)</p>	<p>vulnerable population groups / Restorative and recreational contribution / cultural effects (learning) / job creations / increase in sense of belonging / cultural nature experience / increase in carbon storage / increase in environmental awareness (Artmann & Sartison, 2018)</p>				
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Provisioning (Biotic)	Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)	1.1.1.2		_ownership and gardens ownership status /household income (positive relation) (Philpott et al., 2023)	-	-	-	_(Philpott et al., 2023) California central coast, USA	_(Philpott et al., 2023) Survey and assessment by indicators
Provisioning (Biotic)	Cultivated plants (including fungi, algae) grown as a source of energy	1.1.1.3		-	-	-	-	-	-
Provisioning (Biotic)	Plants cultivated by in-situ aquaculture grown for nutritional purposes	1.1.2.1		-	-	-	-	-	-
Provisioning (Biotic)	Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2		-	-	-	-	-	-
Provisioning (Biotic)	Plants cultivated by in-situ aquaculture grown as an energy source	1.1.2.3		-	-	-	-	-	-
Provisioning	Animals reared for nutritional purposes	1.1.3.1	_Livestock (number of Cattle,	-	-	-	-	-	-

(Bio tic)			Sheep, Goats and Pigs)/k m2 (Balzan et al., 2020)						
Provisioning (Bio tic)	Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)	1. 1. 3. 2		-	-	-	-	-	-
Provisioning (Bio tic)	Animals reared to provide energy (including mechanical)	1. 1. 3. 3		-	-	-	-	-	-
Provisioning (Bio tic)	Animals reared by in-situ aquaculture for nutritional purposes	1. 1. 4. 1		_Status of invasive species (negative relation) / recreational and activity, and fishing pollution	-	-	-	-	-
Provisioning (Bio tic)	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding	1. 1. 4. 2		-	-	-	-	-	-

	genetic materials)								
Provisioning (Biotic)	Animals reared by in-situ aquaculture as an energy source	1.1.4.3		-	-	-	-	-	-
Provisioning (Biotic)	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	1.1.5.1		-	-	-	-	-	-
Provisioning (Biotic)	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2		-	-	-	-	-	-
Provisioning (Biotic)	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	1.1.5.3		_Yield/production per year (Mishra et al., 2019)	_minimizing soil erosion, soil carbon sequestration, water quality improvement, and landscape wildlife value enhancement)	_enhanced hunting and fishing opportunities, freshwater recreation, and wildlife viewing, are of benefit to local economies	_Payment for ES amount / benefit transfer and explored the integration of the benefits (Mishra et al., 2019)	_(Mishra et al., 2019) Vermilion River Basin, USA	_(Mishra et al., 2019) Indicator based analysis

					(Mishra et al., 2019) _enhanced quality of cultural and recreational activities (Mishra et al., 2019) _Local and regional increase in revenue (Mishra et al., 2019)	(Mishra et al., 2019)			
Provisioning (Biotic)	Wild animals (terrestrial and aquatic) used for nutritional purposes	1.1.6.1		-	-	-	-	-	-
Provisioning (Biotic)	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	1.1.6.2		-	-	-	-	-	-
Provisioning (Biotic)	Wild animals (terrestrial and aquatic) used as a source of energy	1.1.6.3		-	-	-	-	-	-

Provisioning (Biotic)	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	_Amount of physical activity in the area	-	_Improvement in microclimates/Increase urban food production/ Increase in vegetation / Increase aesthetic values/ Improvement of pollination / Improve human and nature interactions / Increase communications between community members (Cruz-Piedrahita et al., 2020)	-	-	_(Cruz-Piedrahita et al., 2020) N/A	_(Cruz-Piedrahita et al., 2020) Urban Horticulture SLR
Provisioning (Biotic)	Higher and lower plants (whole organisms) used to breed new	1.2.1.2		-	-	-	-	-	-

	strains or varieties								
Provisioning (Biotic)	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1. 2. 1. 3		-	-	-	-	-	-
Provisioning (Biotic)	Animal material collected for the purposes of maintaining or establishing a population	1. 2. 2. 1		-	-	-	-	-	-
Provisioning (Biotic)	Wild animals (whole organisms) used to breed new strains or varieties	1. 2. 2. 2		-	-	-	-	-	-
Provisioning (Biotic)	Individual genes extracted from organisms for the design and construction of new biological entities	1. 2. 2. 3	_Population of bearded vultures (Balzan et al., 2020)	-	-	-	-	-	-
Provisioning (Biotic)	Other	1. 3. X. X							

Regulation & Maintenance (Biotic)	Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1	<p>– Use of aquatic plants for waterbodies pollution removal. (Quilliam et al., 2015)</p> <p>– Payment for ecosystem services (PES) for recycling and reuse of APB by governing bodies (possibly the amount and participation in harvest)</p> <p>(Quilliam et al., 2015)</p>	<p>– “Raising stakeholder awareness about the full spectrum of remediation options available is still needed to highlight the toolbox of catchment management approaches available to help deliver more immediate environmental improvements.” (Quilliam et al., 2015)</p> <p>– Sustainable management of contami-</p>	<p>– Several impacts for implementation of aquatic plant biomass (APB) are predictable: water toxicity concerns and nuisances in lakes and waterscapes in one impact. The other impact is the use of high concentration of APB for direct animal feed. This impact should be regulated under health consider</p>	<p>– Techniques for sustainability assessment to evaluate socioeconomic indicators or are scoring/ranking systems, best available techniques, cost-benefit analysis, cost effectiveness, financial risk, and quality of life assessment. (Harclo et al., 2015)</p> <p>– Human risk assessment</p>	<p>– “Cost-effectiveness indicates the tools’ ability to ascertain whether remediation and restoration options ‘have value for money’, and whether internal rate of return or net present value is reasonably high based on a monetary comparison of costs and benefits of applying alternative options.” (Okpara et al., 2020)</p> <p>– Cost-Benefit Analysis (CBA) has been conducted based on the evaluated importance of remediation methods on economic consequences (Volchko et al., 2020)</p> <p>– The economic benefits associated with improved health at the</p>	<p>– (Quilliam et al., 2015) no case study (Iglesias, 2020) no case study (Harclo et al., 2015) no case study (Caputo et al., 2016) Easterlin North America – (Volchko et al., 2020) Sundesvall, Sweden – (Okpara et al., 2020) Euro</p>	<p>– (Quilliam et al., 2015) Scientific review in sources and evaluation of multiple aspects (Iglesias, 2020) Lit.Rev. (Harclo et al., 2015) Lit.Rev. review on policies (Caputo et al., 2016) long-term ecosystem capacity research – (Volchko et</p>

			<p>Increase of salinization in fresh water can decrease aquatic biodiversity, which can be prevented bio-remediation applications (Iglesias, 2020) – Plant-based bioremediation used in conjunction with storm water management may also be effective for treating some metals</p>	<p>nated sites is based on collaboration of stakeholders, policymakers, authorities, and institutional processes. (Harclerode et al., 2015) – “The framework lists five overarching social categories to evaluate during a sustainability assessment of remediation options: (1) human health and safety; (2) ethics and equality;</p>	<p>ations. Thirdly, APB can be recycled into agricultural lands under ecological hazard avoidance considerations. (Quilliam et al., 2015) – “societal effect of remediation: (1) socio-environmental, (2) socio-individual, (3) socio-institutional, and (4) socio-economic. (Harclerode et al., 2015) – Revitaliz</p>	<p>with concern of risk for local residents with general aim of human health and safety. (Harclerode et al., 2015) – “The SuRF ANZ guidance suggests conducting a semi-quantitative assessment of the core dimensions along with evaluating the effectiveness and practicability of</p>	<p>site a result of decreased non-acute health risks posed by contaminants in the soil (B2b) (Volchko et al., 2020)</p>	<p>pe (Allan, 2013) USA</p>	<p>al., 2020) ecological risk assessment for cost-benefit analysis (Allan, 2013) Joint analysis of stressors and ES</p>
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			<p>in select soil strata (Iglesias, 2020) – “The SDST is both quantitative and qualitative, with the following social indicators: cultural heritage, public and worker safety, project duration, quality of life during the project, public benefits, and the federal govern</p>	<p>(3) neighborhoods and locality; (4) communities and community involvement; and (5) uncertainty and evidence (CL:AIRE, 2011).” (Harclerode et al., 2015) – [possible connection with other ES] Ten main factors of societal impacts are observable: 1. Health and safety 2. Economic vitality 3. Stakeholder</p>	<p>ation of urban environments with public gathering places, housing developments, transit infrastructure, providing jobs and skills training through the remediation project ...Protection of human health, including incidentals from site activities (e.g., contributing to local safety risks and air pollution). (Harclerode et</p>	<p>proposed remedial technologies. The semi-quantitative assessment ranks, scores, and weighs each core dimension based on their advantages and disadvantages” . (Harclerode et al., 2015) – [Explanation of each is in the paper] For assessment methods</p>		
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		<p>ment's image. The tool uses a scoring and rating system to evaluate each social indicator in relation to the "level of concern to the federal government" versus the "level of concern to stakeholders," for each proposed remedial alternative (Klassen, 2012)."</p>	<p>collaboration 4. Benefits community at large 5. Alleviate undesirable community impact 6. Social justice 7. Value of ES 8. Risk-based land management and remedial solutions 9. Regional and global societal impacts 10. Contribution to local and regional sustainability. (Harclode et al., 2015)</p>	<p>al., 2015) – Factors considered in CBA are: 1. Increased property values on site and other internal project benefits (increase of property value) 2. Increase provision of ES (increase in recreational opportunities in site and surroundings) 3. Improve in human health (reduction of acute health risks) 4. Remediation</p>	<p>several approaches are considerable: 1. Rating and scoring system evaluations 2. Social sustainability evaluation matrix 3. Envision rating system 4. Enhanced cost-benefit analysis 5. Social science methodologies 6. Social network analysis 7. Multicriteria decision analysis</p>			
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		<p>(Harcle rode et al., 2015) _ In case of Taiwan social dimension has 2 critical indicators: “The first core dimension, human health and safety, is comprised of the following principles: human health and risk before remediation, human health risk during remediation (consid</p>		<p>costs (design, capital, action, and monitoring) 5. Negative health effects 6. Decrease provision of ES 6. Other negative impacts (Volchko et al., 2020) _ “The procedure includes five steps: (1) screening a gross list of ES to identify the ES present at the site before and after remediation; (2) assigning a degree of importance to</p>	<p>. (Harcle rode et al., 2015)</p>			
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		<p>ering both local residents and cleanup employees), risk of accidental injury, avoid secondary contamination, and prevent exposure pathways. The second core dimension, social justice and acceptance, is comprised of the following principles: stakeholder partici</p>	<p>each ES based on current demand; (3) assigning a score between 1 and 5 (very good to very limited, respectively) which reflects the capacity of the site to deliver a particular ES, while also specifying a level of uncertainty for the provision of this ES (low, medium, high); (4) evaluation of the effects of the two alternatives on</p>				
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		<p>pation, information disclosure, considering remedial related effects on local residents, and preserve cultural heritage.” (Harcrode et al., 2015)</p> <p>– “Common social indicators evaluated include worker operation and traffic accidental risks, and site activity</p>		<p>each ES relative to the reference alternative; and (5) summing the effects on ES while accounting for the demand for each ES.” (Volchko et al., 2020)</p>				
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		<p>related effects including noise, odor, and vibration.” (Harclo rode et al., 2015)</p> <p>_ For quantification of remediation effect in water bodies authors used Remediation of nutrient pollution (PRM) which is “Ratio of eutrophication potential of stream water to</p>						
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			eutrophication potential of precipitation” without threshold. (Caputo et al., 2016)					
Regulation & Maintenance (Biotic)	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	<p>_ Land use change or conversion related to urban shrinkage provides great potential for urban green space development resulting in carbon sequestration and preservation of urban biodiversity</p> <p>_ Vacant buildings have more effect in air filtration in comparison with bare or vegetated soil (Haase et al., 2014)</p> <p>_ “Urban habitats with greater vegetation coverage and density are also likely to provide more carbon</p>	<p>_ “water purification is the retention of total nitrogen (TN) and total phosphorus (TP) contained in freshwater, which avoids eutrophication and improves drinking water and fisheries” (Jordacapdevi</p>	<p>_ For carbon sequestration tree diameter at breast height (DBH) and species data and then land standardization (Belaire et al., 2022)</p>	<p>_ To estimate carbon sequestration rates, we used tree diameter at breast height (DBH) and species data (described above) and uploaded this into the _ Tree Eco v.6.0.10 software to calculate tons of carbon sequestration per year within each study site.(Belaire et al., 2022)</p> <p>-The ecosystem service water purification was assessed as total nitrogen (TN) and total phosphorus (TP) retention in terrestrial and fresh water</p>	<p>_ (Belaire et al., 2022) Austin, Texas, USA (Haase et al., 2014) Leipzig, Germany</p>	<p>_ (Belaire et al., 2022) Watershed scale monitoring of biodiversity and environmental factors with trade-offs analysis (Haase et al., 2014) Nexus of urban shrinkage and</p>

		<p>rsity. (Haase et al., 2014)</p> <p>_ Local increase in vegetation density and leaf area associated with higher level of carbon storage and sequestration. (Belair et al., 2022)</p> <p>_ “The percent native trees and tree species richness were positively related to carbon sequestration (r = 0.65 and r = 0.72)”</p>	<p>storage and sequestration” (Belaire et al., 2022)</p> <p>_ Carbon sequestration as an index for ESS condition (Belaire et al., 2022)</p> <p>_ Crop diversification enhanced carbon sequestration (lnRR = 0.11; 95% CI = -0.01 to 0.23) (Tamburini et al., 2020)</p>	<p>la et al., 2019)</p>	<p>ecosystems (Jorda-Capdevila et al., 2019)</p> <p>_ Soil organic carbon (%), Willingness-to-pay of local residents and tourist, Carbon sequestration (t/ha), Habitat index (%) (Balzan et al., 2020)</p>	<p>urban ecosystem services</p>
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			(Belair et al., 2022) _ “Bee and wasp species richness was positively correlated with carbon sequestration (r = 0.61)” (Belair et al., 2022) _ “Greater tree species richness and a greater percent native trees also had higher carbon sequestration values” (Belair et al., 2022) _ non-native tree					
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			species are often fast-growing and can thus be important carbon sinks (Belaire et al., 2022) – “Our study indicates that areas with higher tree species richnesses have cooler temperatures and that carbon sequestration increased with tree species richnesses and percent native tree						
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			species ” (Belair e et al., 2022) _ For total N load, Vegeta tion filterin g value for total nitroge n 0 (urban) with percent unit (Jorda- Capde vila et al., 2019)						
Reg ulati on & Mai nten ance (Bio tic)	Smell reduction	2. 1. 2. 1	-	-	-	-	-	-	-

Regulation & Maintenance (Biotic)	Noise attenuation	2.1.2	– Noise annoyance, irritation, anger (van den Bosch & Ode Sang, 2017)	– Road traffic (Dzhambov & Dimitrova, 2014)	– Mental health & well-being (Dzhambov & Dimitrova, 2014)	– Survey-based valuation (citizens' willingness to pay (Wang et al., 2014)	– (van den Bosch & Ode Sang, 2017)	– (van den Bosch & Ode Sang, 2017)
			– Vegetation reduce negative perception of noise (Dzhambov & Dimitrova, 2014)	– Availability/accessibility of green spaces (Dzhambov & Dimitrova, 2014)	– Noise attenuation affects health and human behavior positively (Wang et al., 2014)	– In neighbors with a lower Social Development Index (SDI), respondents identify ES for noise reduction (Pistón et al., 2022)	– (Dzhambov & Dimitrova, 2014)	– (Wang et al., 2014)

			<p>ment (Wang et al., 2014)</p> <p>_ Park size and tree canopy amount (Wang et al., 2014)</p> <p>_ Road vegetation as a living barrier (Bautista et al., 2020)</p> <p>_ In neighbors with lower SDI respondents identify ES for noise reduction (Pistón et al., 2022)</p>	<p>h & Maksym iuk, 2017)</p> <p>_ Water decontamination by vegetation (Bautista et al., 2020)</p>			<p>s (e.g. heat reduction) – or defined health outcomes (e.g. cardiovascular mortality)</p> <p>_ (Dzhambov & Dimitrova, 2014) systematically evaluate whether there is conclusive scientific evidence for the effectiveness of urban green spaces as a psychological</p>
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								<p>buffer for the negative impact of noise pollution on human health (Wang et al., 2014) systematic overview of the relationship, in terms of so-called 'ecosystem services', between urban green infrastructure and the indoor environment through a literature review</p>
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Reg ulati on & Mai nten ance (Bio tic)	Visual screening	2. 1. 2. 3	-	-	-	-	-	-	-	-

Regulation & Maintenance (Biotic)	Control of erosion rates	2.1.1	<p>– Soil bio-engineering provides living plant parts for soil reinforcement and prevents erosion. (Moreau et al., 2022)</p> <p>– Decrease in potential sediment erosion, which is driven by precipitation.</p> <p>– Agricultural activities (urban and non-urban) can decrease</p>	<p>– Erosion control is still considered as a technical problem with a low level of citizens and stakeholders' involvement. (Moreau et al., 2022)</p> <p>– Agricultural practices allow improvements in erosion control (Jordana et al., 2019)</p> <p>– Sediment retention as a factor for erosion control measure (Jordana</p>	<p>– Soil bio-engineering reduces costs and creates a variety of ES and restores biodiversity. (Moreau et al., 2022)</p> <p>– Vegetated riverbanks provide impacts for humans such as erosion and flood control, heat island limitation, carbon storage, water quality improvement, aesthetic, and recreational</p>	<p>– “the performance of soil bioengineering structures is low at the beginning but increases over time.” Which means most assessment for this case is in long term implementation. (Moreau et al., 2022)</p> <p>– Inclusion of stakeholders in selection of bioengineering technique for erosion control</p>	<p>– Retention model (in Invest program) (Jordana-Capdevila et al., 2019)</p> <p>– The ecosystem service erosion control was assessed as sediment retention in terrestrial ecosystems. Results are expressed as mass of sediments per unit of area, in tons (Jordana-Capdevila et al., 2019)</p> <p>– Erosion control: Annual soil loss: Losing >300 T soil/yr (Vollmer et al., 2016)</p> <p>– Swing weighting: “where stakeholders evaluate the potential “swing” in each criterion based on its extreme values, rank them according to preference, and then assign a weight to indicate the relative</p>	<p>– (Vollmer et al., 2016)</p> <p>– Jakarta a metropolitan area, Indonesia (Jordana-Capdevila et al., 2019)</p> <p>– Ebro river basin, adige river basin, Sava river basin, Southern Europe</p>	<p>– (Vollmer et al., 2016)</p> <p>– Multi-criteria analytical methods by using GIS by swing-weighting analysis and prioritizing ES in case study (Jordana-Capdevila et al., 2019)</p> <p>– Assess future trends of service provision with and without mitigation policies based on 2</p>
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			<p>e or increase the erosion rate if they do or do not implement safety measures in this regard. (Jordana-Capdevila et al., 2019b) – Resident willingness to pay for conservation of greenery that helps to prevent erosion within a 50 km radius of the case study (Jakarta).</p>	<p>Capdevila et al., 2019) – Pest control has less synergy with other ES as it might be less studied (Balzana et al., 2020). – Microfauna diversity (nematode trophic group), Nitrogen and Phosphorus recycling by waterbird species in rice fields, Fauna abundance (%), N leaching (kg/ha/year), Mesofauna diversity (enchytraeids</p>	<p>values. (Moreau et al., 2022) – The impact of bio-soil engineering techniques is in wider area than implementation and performance should be assessed in bigger area than artificial ones. (Moreau et al., 2022) – “regarding the objective of erosion control, soil bioengineering might appear to show</p>	<p>to reduce potential risks and increase acceptance. (Moreau et al., 2022) – A quantitative survey on perception of vegetated or artificial riverbanks is useful. (Moreau et al., 2022) – Direct questioning the stakeholders and residents in integration with spatial modeling of</p>	<p>strength of preferences.” (Vollmer et al., 2016) – Erosion control assessment method: “Future potential, in terms of t/ha/yr avoided when subtracting current erosion rates from SI scenario for 2030. Values are then normalized on a 0 to 100 scale.” (Vollmer et al., 2016) – Monetization with Degrading Costs Avoided (Vollmer et al., 2016) – Plant species richness, Soil agronomic qualification index, Risk of soil salinization (Shannon index) (Balzana et al., 2020)</p>	<p>scenarios.</p>
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			(Vollmer et al., 2016) _Agroforestry systems were associated with improved erosion control (Balzan et al., 2020) _Direct synergy with the amount of food production in agricultural or agroforestry areas in different landscapes (Balzan et al., 2020). _Soil physical indicat	and Collembola species), Nitrification, Soil run yield (mm) (Balzan et al., 2020) _Plant species richness (Shannon index), Collembola species richness (Shannon index), Floor litter dry matter (t/ha), Waterbird abundance, Diet composition of waterbirds foraging in rice fields, Food consumption from waterbird	less performance locally and over short-time scales, but offers many advantages if the scales being considered are expanded.” (Moreau et al., 2022) – “Riverbanks may well have been previously considered as marginal spaces with undesirable or illegal uses (e.g., drug or alcohol abuse, waste	floods and controls (Vollmer et al., 2016)		
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		<p>ors, Soil chemic al indicat ors, Soil biologi cal indicat ors, Nemat ode ecologi cal indicat ors, Plant species richnes s, Microb ial diversit y, Microb ial functio n (nitrifi cation, extrace llular enzym es, multip le substra te induce d respirat ion), soil loss</p>	<p>ds (kJ/bird/ day) in rice fields, Microbia l abundan ce (%), Bacteria species richness, Fungi species richness, Mite species classifica tion, and quantific ation, Molecul ar microbia l biomass, Soil erosion (t/ha/yea r), Soil loss (t/ha/yea r)(Balza n et al., 2020).</p>	<p>dumpin g), and may then become more socially valuable after bioengi neering works” (Moreau et al., 2022) _ Soil bioengi neering may provide aesthetic values for society (Moreau et al., 2022) – Erosion control and biodiver sity will improve under the Strong Interven tion scenario in which reforesta tion happens , and</p>				
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		<p>(mg/ha), sediment (kg/m³), Mineralizable Nitrogen, Earthworms abundance (%), Microbial respiration (Balzan et al., 2020)</p>	<p>urbanization is limited. While by the casual growth of urbanization (BAU scenario), erosion control will be marginally affected. (Vollmer et al., 2016)</p> <p>– “Erosion rates overall were estimated to decrease slightly under the BAU scenario because the large amount of agricultural land converted to urban land</p>				
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					would offset the smaller amount of agricultural land that shifts to even steeper slopes, though certain sub catchments would be expected to experience greater erosion rates when comparing the BAU scenario to current rates.” (Vollmer et al., 2016)				
Regulation & Maintenance	Buffering and attenuation of mass movement	2.2.1.2	-	-	-	-	-	-	-

ance (Bio tic)									
Regulation & Maintenance (Bio tic)	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2. 2. 1. 3	<p>_Rainfall volume is a primary driver of contaminant loading and water quality (Ward & Winter, 2016)</p> <p>_All water quality parameters examined in this study were significantly influenced by the duration of the antecedent dry weather</p>	<p>_Water quality parameters would be variably influenced by rainfall, antecedent dry period, location, and season (Ward & Winter, 2016).</p> <p>_Residential activities can directly influence water chemistry, especially in spring and dry weather (Ward & Winter, 2016)</p> <p>_Flow regulation (i.e., flood protection</p>	<p>_Interconnection of impacts and stressors which may lead to services causing disservices or harms in the same ES (Sabater et al., 2021)</p> <p>_Trampling on coastal ground has a great negative impact on macrofauna abundance and BD (Afghan et al., 2020)</p> <p>_Coastal protection has direct impact</p>	<p>_Shared Socio-Economic Pathways (SSP) (Sabater et al., 2021)</p> <p>_Willingness to pay for Ecosystem service Value (Cai et al., 2023)</p> <p>_look at formulation in paper]</p> <p>net primary productivity (NPP, t/ha) of natural vegetation (Cai et al., 2023)</p>	<p>_Aikake's and Bayesian Information Criteria (AIC and BIC, respectively)(Ward & Winter, 2016)</p> <p>_ [BD on wetlands] Shanon biodiversity index (Cai et al., 2023)</p> <p>_Using coefficient factors for ES values which are done by Chinese frameworks (Cai et al., 2023)</p>	<p>_(Sabater et al., 2021)</p> <p>None, river and basin networks in Lit. (Afghan et al., 2020)</p> <p>SLR, coastal line and beaches (Cai et al., 2023)</p> <p>Baiyandian wetland, Xiongba (Mou et al., 2022)</p> <p>Rhonde</p>	<p>_(Sabater et al., 2021)</p> <p>Identifying stressors for river and basin network on literature and classifying them (Afghan et al., 2020)</p> <p>SLR on stressors of coastal line and sandy beaches for macrofauna (Cai et al., 2023)</p> <p>Using Coefficients</p>

			<p>period (Ward & Winter, 2016). The amount of rainfall has a direct influence on soil chemical concentrations (Ward & Winter, 2016). Role of stressor, their scale, impact, and legacy and connections (Sabater et al., 2021). Tracking the effect of stressors and their network</p>	<p>n) is enhanced by increases in community and habitat area (Liquete et al., 2016). Urbanization, forestry, damming, water abstraction, and ground water exploitation are among stressors on the hydrological cycle (Sabater et al., 2021). Longitudinal connectivity within the river network; lateral and vertical connectivity (Sabater</p>	<p>on life cycle and abundance [connection with other ES] (Afghan et al., 2020). Physical activity such as beach mechanical cleaning or visiting has a negative impact on microfauna presence (Afghan et al., 2020). Hydrophytes and water may provide cultural ES such as tourism and historical value (Cai et</p>			<p>Alps basin, France</p>	<p>of ecosystem service value (ESV) for evaluation of water diversion projects quantitatively to assess socio-economical values (Moreau et al., 2022). Qualitative method using questionnaire from experts on effectiveness and paradigm shift in riverbank soil bioeng</p>
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			<p>k actors (Sabate r et al., 2021) _prima ry industr y output value, second ary industr y output value, tertiary industr y output value, GDP, popula tion and volum e of diverte d water as main anthro pogeni c factors (Cai et al., 2023)</p>	<p>et al., 2021)</p>	<p>al., 2023) _control in river banks cause: Erosion control, increase in water quality, heat island limitatio n, carbon storage, cultural ES *aestheti c, recreatio nal), provisio n ES ((plant producti on) (Moreau et al., 2022) _[riverb ank bioengi neering] They have positive to neutral impacts, may refine social issues</p>				<p>ineerin g techni ques</p>
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					and reduce drug use and increase security and be more socially valuable places (Moreau et al., 2022) _[soil bioengineering tech.]Restoration and maintaining natural river dynamics (Moreau et al., 2022).				
Regulation & Maintenance (Biotic)	Wind protection	2. 2. 1. 4	_ The amount of water uses by vegetation (Missall et al., 2018) _ Public perception (through	_ Economic productivity per unit of water consumed in comparison with comparable activities (Missall et al.,	_ Improve human health and wellbeing by generating ecosystem using green belts. (Missall et al., 2018)	_ Methods that were used to assess the Kökyar Protection Forest included a water use calculat	_ It is better to refrain from monetizing social and environmental costs and benefits comparing them against each other. (Missall et al., 2018) _ Economic sustainability is evaluated along the criterion of	_ (Missall et al., 2018) Cities in Taklimakan desert in NW China	_ (Missall et al., 2018) Sustainability assessment of plantations by evapotranspiration calcula

		<p>semi-systematic assessment) (Missall et al., 2018)</p> <p>– Amount of annual airborne dust and/or sand which might result in improvement in public health (decrease in lung diseases) (Missall et al., 2018)</p> <p>– Amount of water use in comparison with actual water provided (for</p>	<p>2018)</p> <p>– Economic losses due to storms (such as traffic or commuting difficulties. (Missall et al., 2018)</p> <p>– Enhanced perception of living conditions. (Missall et al., 2018)</p> <p>– Plantation requires native species, low water consumption, and potential for self-regulatory processes. (Missall et al.,</p>	<p>– Plantation of greeneries can result to dust and sand fixation, air purification and humidification. (Missall et al., 2018)</p> <p>– Planting fruitful vegetation and tree might increase rural income (Missall et al., 2018)</p> <p>– Increase in employment rate for planting and keeping activities (Missall et al., 2018)</p> <p>– Increasi</p>	<p>ion, a literature review, a household survey, semi-structured interviews, field trips and stakeholder dialogues with relevant actors. (Missall et al., 2018)</p> <p>– Comparing the water consumption of the Kökyar Protection Forest at Aksu with the water consumption of the</p>	<p>the project's net present value being greater or smaller than zero. Social sustainability is evaluated along the criterion of the project contributing to or impairing human wellbeing in terms of individual quality of life and social stability. Environmental sustainability is evaluated along the criterion of the project contributing to nature conservation or degrading the natural environment. (Missall et al., 2018)</p>	<p>tions, interviews, a socioeconomic household survey, stakeholder dialogues, and literature research</p>
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			<p>efficiency) (Missall et al., 2018)</p> <p>_Erosion control function (Moreau et al., 2022)</p>	<p>2018)</p> <p>_ solar radiance, temperature, relative humidity and wind speed, and the so-called crop coefficient (Missall et al., 2018)</p>	<p>ng the gross income of local activities (jobs and harvest) (Missall et al., 2018)</p> <p>_ Indirect monetary effect due to reduction of exposure to storms (Missall et al., 2018)</p> <p>- Decrease of dust-related lung disease (Missall et al., 2018)</p>	<p>natural Tugai forests at the middle and lower reaches of the Tarim River (Missall et al., 2018)</p> <p>_ Penman-Monteith calculation based on 5 climate parameters: solar radiance, temperature, relative humidity, wind speed, and the so-called crop coefficient. (Missall et al., 2018)</p>		
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Regulation & Maintenance (Biotic)	Fire protection	2. 2. 1. 5	<p>– Special effect of grazing and silviculture in agroecosystems for agriculture (Bernués et al., 2022)</p> <p>– in agroecosystems "maintaining grasslands, retaining water points, grazing in remote and abandoned areas, and managing forests actively through forestry</p>	<p>– Factors are mainly for agricultural activities, but related ones in Mediterranean Mont. are: 1. Maintaining semi-natural vegetation 2. Maintaining grasslands 3. Managing land in small plots 4. Retention of water points 5. Retention of drove roads 6. Forestry (active management of forest). (Bernués et al., 2022)</p> <p>– Fire</p>	<p>– [For BD] reducing agrochemical inputs positively impacts preservation of BD (Bernués et al., 2022)</p> <p>– On global measurement from literature, Fire protection has a medium positive impact on habitat creation and maintenance, small positive impact on pollination and seed dispersal, medium positive</p>	<p>– “Payments for ecosystem services (PES) have been long proposed as an effective instrument to promote synergies between agriculture development and nature conservation objectives” (Bernués et al., 2022)</p> <p>– Their willingness to pay for ES as an evaluat</p>	<p>– (Bernués et al., 2022) [Agro Forest, Mountain, non-urban] Aragon, Spain / Vestland and Inlander, Norway. (maps and climate classification universal) – (McElwee et al., 2020) globally measured in different</p>	<p>– (Bernués et al., 2022) SLR, Survey from experts and technicians, Combination for linking ES to Area and Values with use of lit. Survey for level of importance of ES and level of attribute with WTP for ES divided to general WTP with scenario making based on</p>
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			<p>y silviculture activities." (Bernués et al., 2022)</p> <p>_Fire management has 12 positive counted co-benefits for NCPs and 5 positive co-benefits for SDGs, while it doesn't have adverse effects (McElwee et al., 2020)</p> <p>_Fire management has positive co-benefit and impact</p>	<p>management in integration with other factors has large positive impact on SDG3 (well-being & good health) and SDG 13 and SDG 15 life on land (increase in soil carbon, water management, and avoid post-harvest losses) (McElwee et al., 2020)</p> <p>_ Sites with high carbon sequestration also support pollinators (Belaire</p>	<p>regulation of air quality, large positive impact on regulation of climate and acidification of oceans, and small positive impacts on freshwater regulation and coastal waters and soil protection and large positive impacts on regulation of hazards and small positive impact on regulation of organisms detri-</p>	<p>ion of importance (Bernués et al., 2022)</p> <p>_ Indirect impacts and tradeoffs are not considered as they are hard to measure or not nature related (McElwee et al., 2020)</p>	<p>climates based on the literature</p>	<p>evaluation. (Create category of proc)</p> <p>_ (McElwee et al., 2020)</p> <p>Corelating the SDGs and NCP (type view on ES which covers broader economical and social aspects) to 6 types of integrated response to land management which fire management is one</p>
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			<p>on habitat maintenance ES (a way of measurement for effectiveness perhaps) (McElwee et al., 2020)</p> <p>_Number of fire events (Balzan et al., 2020)</p>	<p>et al., 2022)</p>	<p>ntal to humans and small positive impact on physical and psychological experience, and large positive impact on well-being (good health), and small positive on water sanitation (McElwee et al., 2020)</p> <p>_ Fire management has an adverse impact on NCP (McElwee et al., 2020)</p>			<p>of them with the use of lit (non-systematic), which considers the relation and benefits for humans and gradient of the impact</p>
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Regulation & Maintenance (Biotic)	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	– Increase in plant and animal diversity of urban areas from agricultural increase provision of pollination and pest control (Nicholls et al., 2020)	– Allotments and residential gardens are hotspot for pollinators (Nicholls et al., 2020)	– Increase in food production (Nicholls et al., 2020)	– The amount of savings due to local harvest by insect-pollinated crops (Nicholls et al., 2020)	– The cost of production related to insect pollinated crops (Nicholls et al., 2020)	– (Nicholls et al., 2020)	– (Nicholls et al., 2020)
			– Urban land use likely will have large effect on terrestrial ecosystem due to pollination ES (Jansson & Polasky, 2010)	– Urban land use likely will have large effect on terrestrial ecosystem due to pollination ES (Jansson & Polasky, 2010)	– Increase of urban agriculture and local revenue (Nicholls et al., 2020)	– The cost of production related to insect pollinated crops by insects (Nicholls et al., 2020)	– (Nicholls et al., 2020)	– Direct citizen survey of use of pollinators dependent crop (Nicholls et al., 2020)	– Cost efficiency of pollinated crops by insects (Nicholls et al., 2020)

			(Nicholls et al., 2020)	– Reduction (with small effect) of pollination potential due to urban development (Jansson & Polasky, 2010)	urban residents (Jansson & Polasky, 2010)	pollination due to urban development (Jansson & Polasky, 2010)		2918)	Polasky,
			– Urban development in the area and density and amount of landscapes available for nesting especially for bees (Jansson & Polasky, 2010)	– It is possible to increase quality of urban habitats for pollinators due to synergy between bee and wasp richness and carbon sequestration, and human visitation (eg, increase no mow zones for flowers) (Belair	– Increase food security (Jansson & Polasky, 2010)	– The value of pollinators for urban agriculture and how much food is produced in urban allotments (Nicholls et al., 2020)		working cattle ranch in the oak woodland-annual grassland and interior coastal range of Northern Napa County, California, USA (Mediterranean climate)	Impact assessment of pollination potential by scenario making with the use of wild bees data collection for crop generation and output by considering price change and output of crop.
			– Solitary bees react more than working bees to reduction of semi-natural habitats (Jansson &	– Enhancing habitat for pollinators can provide secondary BD & ES benefits such as reduced pest densities and improve landscape aesthetics (Belair	– Record weight of each insect-pollinated crop (Nicholls et al., 2020)			– (Belair et al., 2022)	Watershed scale monitoring network

			Polasky, 2010) _Insite birds survey in breeding season can also capture the richness of birds and pollinators (Belair et al., 2022) _Functional diversity of arable plant communities (Rao's quadratic entropy), Weed species abundance (%), Butterfly species richness	et al., 2022) _Seeding practices based on climate might be an enhancing strategy for pollinators and seeding improve pollinators' forage (Eastburn et al., 2018) _Crop and noncrop diversification increased the provisioning of pest control and pollination (Tamburini et al., 2020) _Pollen grain deposition (species/	et al., 2022) _Human visits increase by initiatives which enhance the quantity of pollinators via restoration planting (Belaire et al., 2022) _Willingness-to-pay of local residents and tourists (Balzan et al., 2020)			k in 10 sites with green spaces adjacent and quantification of biodiversity with 7 indicators in synergy with four ES _ (Eastburn et al., 2018) 5 treatment sites with 5 seeding blocks and sampling the cover for comparison for invasive prevention.
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			s, Butterfly species abundance, Wheat flowering onset, Pollinator visitation probability, Richness and abundance of wild plants, Bees abundance, Non- bee flower visitor abundance (Balzan et al., 2020).	site), Crop pollinator dependence (Balzan et al., 2020)					
Regulation & Maintenance (Biotic)	Seed dispersal	2. 2. 2. 2	–	_Presence of alien species and disruption is the seed dispersal process (van	_Aesthetic and production values in short and long terms (Hougn er et al., 2006)	– Production Function (PF) and Replacement Cost (RC) approa	_Trade-offs people are willing to make for sake of this service (Hougner et al., 2006)	_(Hougner et al., 2006) Stockholm national urban park, Swed	– (Hougner et al., 2006) RC analysis to acquire the cost of

			Wilgen et al., 2022)	_Possible effects on cultural ES, health, safety, and material and immaterial assets due to the spread of alien species (van Wilgen et al., 2022)	ches for economic valuation (Hougnier et al., 2006) _Revealed preference by trade-off and stated preference method for the service (eg by interview) (Hougnier et al., 2006)		en (van Wilgen et al., 2022) South Africa	oak replacement (van Wilgen et al., 2022) SLR on invasive processes and their impact following habitat and species
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Regulation & Maintenance (Biotic)	Maintaining nursery populations and habitats (Including gene pool protection)	2. 2. 2. 3	_Functional dominance of Mediterranean rare plants (Community weighted mean), Abundance and occurrence of a bird species, Cattle beef variable costs, subsidies (euro/cow), Weed species traits (%), Gross Margin of beef cattle (euro/cow), Floristic composition of herbal	_There is no consensus on indicators or assessment method (Liquete et al., 2016). _The main factors that facilitate the reproduction and recruitment are density, growth and survival of juveniles, movement to adult habitats, or a combination of those (Liquete et al., 2016). _Economic benefits are mainly	_For example, the ecosystem services that improve water quality (i.e. water purification) and flow regulation (i.e. flood protection) are enhanced by increases in community and habitat area (Harrison et al., 2014)(Liquete et al., 2016) _Direct effect on recreational purposes (eg fishing), ecotourism, agricultural	_Estimated by valuing the additional benefits for commercial and recreational fisheries (Liquete et al., 2016) _In the presence of species recreational values, use of choice experiment or revealed preferences approaches, such as travel cost (Liquete et al., 2016) _Questionnaire	_Willingness-to-pay of local residents and tourists (Balzan et al., 2020) _Based on BD strategy, it can be quantified with proxies such as conservation investments, habitat-landscape protection, biodiversity value, ecological status of habitats diversity that can be considered as indicators of ecosystem condition (Liquete et al., 2016) _Surrogate market price, production functions, contingent or conjoint values, value transfer to pay, financial value using standard market price of production (Liquete et al., 2016) _Costs estimated applying the	– (Liquete et al., 2016) No specific location _(Pistón et al., 2022). Rio de Janeiro, Brazil _(O’Keefe et al., 2022) Thames water front development area, UK _(Tang et al., 2021) China _(Richards & Friess,	– (Liquete et al., 2016) Lit. review and conclusion based on perspectives for nursery population ES and proving if this ES can be treated as ES (in comparison to BD component) _(Pistón et al., 2022) Direct questionnaire and rating ES and ED based on
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			layer, Sheep meat variable costs, subsidies (euro/e we), Number of cattle and sheep holdings, Gross Margin of sheep meat (euro/e we), Number of cattle and sheep head, Drainage in wetland (Balzan et al., 2020) _Value of commercial species in the market and conser	indirect use values coming from support to production (Liquete et al., 2016) _Direct link with values give to nature and wildlife for direct or non-direct use (Liquete et al., 2016) _Quality of green spaces directly affect land price around the area (O’Keeffe et al., 2022). +Cropland expansion has direct	production and biodiversity (Liquete et al., 2016). +Direct connection with carbon storage and sandstorm prevention (Tang et al., 2021) _Green spaces within urban areas can positively impact residents’ physical and mental health, strengthen social bonds, and contribute to crime reduction (Archicinski et	e among participants considering: gender, age, level of perception of the greener and safety, and disservice (Pistón et al., 2022). _ [Regarding synanthropic habitats, there has been a longstanding belief that residents negatively assess these areas in terms of	replacement cost method (Liquete et al., 2016) _Biodiversity units from 0 to 1 describing condition of habitat in natural area is Area*Distinctiveness*Condition*Strategic Location*Connectivity euqals to Biodiversity Units (O’Keeffe et al., 2022) +Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) Habitat Quality model (Tang et al., 2021)	2017) Singa pore mangrove coastal area	answer in areas _ (O’Keeffe et al., 2022) Evaluation based on SD modeling and identifying stakeholders and quantification based on models _ (Tang et al., 2021) Using GIS and InVest Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) Habita
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		<p>vation value (Liquete et al., 2016). _Most of the examples found in the literature link the nursery function of certain habitats with the delivery of food provision or recreation (Liquete et al., 2016). _[BD related indicators] Biodiversity value (species diversity or abundance,</p>	<p>impact on natural habitat preservation (Tang et al., 2021) +Cropland expansion has considerably higher impact than urban expansion on natural habitats (Tang et al., 2021) +[regarding mangrove habitats indicators] Vegetation of carbon storage, mangrove charcoal production, recreational accessibility, fish producti</p>	<p>al., 2024). _Such approaches lead to residents having frequent contact with nature, which can engage people in conservation efforts, increase ecological awareness, and enhance the sense of belonging in their local area (Archicini et al., 2024) Synanthropic habitats provide numerous ecosystem</p>	<p>aesthetics and their usefulness as urban green spaces (Nasser 1995). (Archicini et al., 2024)</p>			<p>t Quality model in comparison between urban and cropland expansion _ (Richards & Friess, 2017) Characterizing trade-offs between urban development and mangroves using indicators and scenarios making</p>
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		<p>endem ics or red list species) Oxyge n concen tration (%), Turbid ity (%), Ecolog ical status (high to bad), ,Hydro morph ologica l status (high, good, other). (Liquet e et al., 2016). _[ES functio n indicat ors] Habita t nursery functio n (spp/ha bitat), Canop y height (cm),</p>	<p>on, habitat quality (biodiver sity) (Richard s & Friess, 2017) _Anothe r factor is the role of forests in maintain ing biodiver sity and protecti ng natural resource s, making them key to city ecologic al sustaina bility. Spatial planning often prioritiz es the protectio n and integrati on of forested areas into the urban fabric</p>	<p>services in the urban fabric, such as air purificat ion, water manage ment or recreatio n, and their value is relativel y high (Luo & Patuano 2023).(A rchicińs ki et al., 2024)</p>				
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			<p>Canopy cover (%), Residence time in seagrass at each life stage of the fishery species (yr), Spawning and nursery areas (ha), Submerged and intertidal habitats diversity, Species distribution and abundance, Extent of marine protected areas (ha), Mangroves extent</p>	<p>(Muller et al. 2010). Urban forests also perform essential ecosystem functions, such as air purification, microclimate regulation, and water retention, further enhancing their value in the eyes of urban planners (Nowak 2006). _tree size and vitality, with larger, healthier trees providing ecosystem services more effective</p>				
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			(km of coast), Size distribution of reef fish in different habitats (% indiv/size class), Wild shrimp density at high tide (indiv/m2)(Liquete et al., 2016). [ES flow indicators] Relationship between fisheries landings (t/yr) and mangroves edge length (km), Carrying	y (Sjöman et al., 2024)					
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		<p>capacity of mangroves (production) depending on changes in area and market prices (demand), Enhancement of juvenile fish by seagrass habitats (indiv/m²), Annual production of each fish species attributable to seagrass (g/m²), Density of reef fish juveniles</p>					
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		<p>es with comme rcial or recreati onal interest in Cystos eira forests (indiv/ m2), Juvenil e gadoid s associa ted with maerl and other habitat s (indiv/ m3), Chang e in recruit ment of adults (%), Catch- per- unit- effort (kg/day) distrib ution against wetlan d connec</p>						
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			<p>tivity index (%), Catch-per-unit-effort (kg/day)</p> <p>distribution against wetland patch density (ha), Structure of reef fish communities (multi dimensional scaling ordination), Biomass of reef fish in mangrove-rich systems (kg/km²), Biomass of commercial fish in seagrass</p>					
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		<p>s meado ws (kg/ha) (Liquet e et al., 2016). _[Bene fits & Values indicat ors] Annual value of the service s provid ed to the fishery (USD/ km of mangr ove), Econo mic produc tion along the produc tive mangr ove fringe (USD/ ha/yr), Margin al value of a change in mangr</p>					
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		<p>ove area (USD/ ha), Estima ted welfare losses associa ted with an annual mangr ove defores tation (USD), Annual econo mic enhanc ement of comme rcial fish by seagras s (kg/m² , AUD/h a), Comm ercial fishery landin gs linked to seagras s- associa ted species</p>					
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			(EUR/y r, %), Expen diture of recreati onal fishers pursui ng seagras s- associa ted species (EUR/y r, %), Benefit of protect ing fish habitat testing change s in habitat quality (CAD/ ha, CAD/k m), Increas e of fish biomas s from mangr ove- scarce to mangr ove- rich system					
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			<p>s (%), Willin gness to partici pate in mangr ove refores tation project for the nurser y benefit s (%), Willin gness- to-pay for mangr ove refores tation project (Rs/yr), Value of comme rcial fish in seagras s meado ws (EUR/ ha), Benefit s from cultivat ed shrimp over benefit s from</p>					
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			wild shrimp (%) (Liquet e et al., 2016).					
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Regulation & Maintenance (Biotic)	Pest control (including invasive species)	2. 2. 3. 1	– [Snowball] Increase in plant and animal diversity of urban areas from agricultural increase provision of pollination and pest control (Nicholls et al., 2020)	– Generally diversification practices have positive response to pest control, among them crop diversification has most positive response while reduced tillage only has negative response. Organic farming has resulted all negative, positive and neutral response. Inoculation has no show in the results (Tamburini et al., 2020).	– Diversification practices has enhanced pest control (lnRR = 0.23; 95% CI = 0.04 to 0.41) (Tamburini et al., 2020) "Enhancing natural enemy populations to reduce crop pests, resulting in a positive 'top-down' effect on crop productivity" (Shennan, 2007).	– Amount of payment suitable for pest control to landowners and cultivators (Alix-Garcia et al., 2018). Production amount or disservice cost (negative impact or absence of service) (Hougner et al., 2006)	– Payments for pest controlling and environmental services (Alix-Garcia et al., 2018) Direct opinion of local users (Liquete et al., 2016). insect pest control services could be valued by the estimation of yield losses in agriculture or forestry in cases of absence of natural enemies (Hougner et al., 2006)	– (Tamburini et al., 2020) SLR no specific location (Shennan, 2007) LR, no specific location, mainly about rice fields and agricultural areas. (Alix-Garcia et al., 2018) Mexico, national scale and progr	– (Tamburini et al., 2020) SLR for understanding synergy between crop diversification and ES and BD and adding 6 categories (pesticides also) to case indicators comparison response (Shennan, 2007) Literature review and evaluation on differe

		depend on spatial processes especially dispersal and foraging (Shennan, 2007). _Habitat fragmentation by urban development can isolate natural enemies and increase pests (Shennan, 2007). _Pest and disease are impacted by change in tillage, crop rotation and fertility	_ Crop and noncrop diversification increased the provisioning of pest control and pollination (Tamburini et al., 2020) _Spatial scale is important in pest management as landscape features affect species interactions, microclimate, habitat patterns, and migration rates (Shennan, 2007). _"weeds themselves can be hosts for crop				ams. _ (Balzan et al., 2020) Mediterranean European agroecosystems (Wang et al., 2021) Central to eastern parts of northern China (Blalid, 2018) Norway	nt applications _ (Alix-Garcia et al., 2018) Studied communal applications in 1 to 4 length for payment for ES. _ (Balzan et al., 2020) SLR on selected ES dividing to type of land their capacity flow and benefit. _ (Wang et al., 2021) Sampling
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		<p>. (Shennan, 2007). _Mono culture is directly linked to increase pests (Shennan, 2007). _Bioco ntrol agents can reduce pests althou gh they have around 1 percent use (Shennan, 2007). _ Paying landow erns to protect enviro nment and pest control (Alix-Garcia et al.,</p>	<p>pests or provide refugia for natural enemies that can enhance biologic al control"(Shennan , 2007) _"In addition, the lack of plant diversity decrease s the diversity and abundan ce of predator and parasitoid natural enemies of crop pests" (Shenna n, 2007)." _High diversity semi-natural habitats help pest control (Wang et al., 2021)</p>					<p>beetles and farmla nds with two crop types and data analysi s based on that _ (Blaali d, 2018) cost benefit s analysi s for invasiv e species scenari os</p>
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		<p>2018) _Soil arthropod abundance, Soil arthropod functional diversity, Bat passes (per min), Bat dropping collections and DNA extraction and sequencing of pests from bats dropping, morphological analysis of insects fragments from bat droppings, bird</p>	<p>_Lower management levels in semi-natural habitats and Carabid population (Wang et al., 2021) _Some plants with no direct agricultural use is associated with pest control (Wang et al., 2021).</p>					
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			richness species, birds abundance, Weed biomass (g/m ²), What leaf area (mm ² / mg), When mean canopy height (cm), Wheat seed mass (mg) (Balzan et al., 2020)					
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Regulation & Maintenance (Biotic)	Disease control	2. 2. 3. 2	- [Other ES connection] Characteristic of urban environment are influential on disease control such as air and noise pollution (Nawrath et al., 2022)	- Income level of the context has direct relation use green spaces for mental health improvement. (Nawrath et al., 2022)	- Green spaces may reduce prevalence of depressive and anxiety disorder and improve indicators mental health. (Nawrath et al., 2022)	- Direct citizens' engagement without a previous foundation about ES and effects, consisting of interviews and direct questions, and then cross-matching with ES. (Nawrath et al., 2022)	- (Nawrath et al., 2022) Katmandu, Nepal	- (Nawrath et al., 2022) analyzing impact of cultural ES on mental health in low income urban areas by participatory video groups and informed PV
			- [Other ES connection] Cultural ES have a direct connection with the improvement of mental health status (Nawra	- Income level of the context has direct relation use green spaces for mental health improvement. (Nawrath et al., 2022)	- Green spaces may reduce prevalence of depressive and anxiety disorder and improve indicators mental health. (Nawrath et al., 2022)	- Direct citizens' engagement without a previous foundation about ES and effects, consisting of interviews and direct questions, and then cross-matching with ES. (Nawrath et al., 2022)	- (Nawrath et al., 2022) Katmandu, Nepal	- (Nawrath et al., 2022) analyzing impact of cultural ES on mental health in low income urban areas by participatory video groups and informed PV

			<p>th et al., 2022) – Green spaces might negatively impact health by bringing pests and animals transmitting disease (e.g., mosquitoes) (Nawra th et al., 2022) – This ES has strong connection with other ES positively with cultural and negatively with regulat</p>	<p>preferre d most by the partici pants were those with sacred or religious signifi cance.” (Nawrat h et al., 2022) – [Other ES connecti on] Water filtration and provisio n of clean water (Nawrat h et al., 2022) – [Other ES connecti on] “cultural ecosyste m services play only a secondar y role for residents in low-income settings. In fact,</p>	<p>2022) –Enviro nmental factors, includin g exposure to green environ ments, have emerged as protecti ve factors against CAD. Recent investiga tions have shown that natural environ ments, characte rized by green spaces and reduced pollutio n, are associate d with lower stress levels and improve d cardiova scular</p>			
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		<p>ion and provision. (Nawra th et al., 2022)</p> <p>– “Urban green spaces can play a pivotal role in reduci ng the burden of mental (Nawra th et al., 2022)</p> <p>– ill-health for low-income residen ts.” (Nawra th et al., 2022)</p> <p>– Level of Access to green spaces in relatio n to</p>	<p>provisio ning services such as food provisio n and regulatin g services such as air pollutio n reductio n are often describe d as more importa nt to meet people's basic needs.” (Nawrat h et al., 2022)</p> <p>– “cultural norms affect how people use and experien ce greenspa ces, and to which parts and types of greenspa</p>	<p>health (a clear link between access to green environ ments and reduced stress-related CAD risk) (Elendu et al., 2024).</p> <p>– Spendi ng time in green environ ments promote s relaxatio n, lowers stress hormon e levels, and contribu tes to an improve d sense of well-being. These stress-reductio n effects can directly benefit cardiova</p>			
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			<p>Coronary artery disease (Quantitative data from a study[19] on green environments and CAD risk indicated a statistically significant decrease in systolic blood pressure (SBP) after spending time in natural, green surroundings (P < .01). Additionally, heart rate variability</p>	<p>ces they respond to.” (Nawrat h et al., 2022) _Green spaces encourage physical activity, essential for cardiovascular health. The natural surroundings provide an appealing setting for outdoor activities like walking, jogging, and hiking. (Elendu et al., 2024) _Biodiversity in green environments provides ecosystem services</p>	<p>scular health, as chronic stress is a known risk factor for CAD (Elendu et al., 2024). _Green spaces are conducive to social interactions, community gatherings, and recreational events.[27] Positive social interactions have been associated with lower stress levels and better mental health, indirectly contribu</p>				
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		<p>ity (HRV) measurements improved significantly (P < .05) in the green environment group compared to controls. These quantitative findings underscore the benefits of environmental stress reduction) (Elendu et al., 2024). _Green environments often have better air</p>	<p>that benefit human health. These services include the pollination of plants, which supports food sources and nutrition, and the regulation of disease-carrying vectors.[28] A diverse and balanced ecosystem indirectly promotes health by ensuring access to nutritious food and reducing disease burdens. (Elendu</p>	<p>ting to a reduced risk of CAD (Elendu et al., 2024).</p>				
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			<p>quality , as vegetat ion contrib utes to the remova l of polluta nts and the release of oxygen . Clean air is essenti al (Elend u et al., 2024). for cardiov ascular health, as air polluti on has been linked to CAD and other cardiov ascular disease s. (Elend u et al., 2024)</p>	et al., 2024)				
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Regulation & Maintenance (Biotic)	Weathering processes and their effect on soil quality	2.2.4.1	-	<p>_ Soil fertility and nutrient cycling, responded in a consistent positive manner to several diversification practices, mainly to organic amendment and reduced tillage (Tamburini et al., 2020)</p> <p>_ Diversification practices also increased both the quality and quantity components of water regulation provisioning (Tamburini et al., 2020)</p>	-	-	-	-	-
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				ini et al., 2020)					
Regulation & Maintenance (Biotic)	Decomposition and fixing processes and their effect on soil quality	2.2.4.2	-	-	-	-	-	-	-
Regulation & Maintenance (Biotic)	Regulation of the chemical condition of freshwaters by living processes	2.2.5.1	_Soil hydraulic conductivity (mm/h), Water infiltration, Soil microporosity (%), Drinking water supply, Risk of water salinity (Balzan et al., 2020) _Nitrogen leachin	_Practices targeting the aboveground environment, i.e., crop and noncrop diversity, greatly enhanced water regulation.(Tamburini et al., 2020) _Low soil permeability cause fresh water salinizati	_Salinization may cause reduction of agriculture, degradation of infrastructure (Kaushal et al., 2021) _Direct effect on drinking water quality due to salinization risk and contamination risk	-	-	_(Balzan et al., 2020) Agroecosystems within the Mediterranean region	_(Balzan et al., 2020)SLR on 42 paper on 3 ES categories for assessing ES in agroecosystems

			g loss, Nitrogen in runoff, Phosphorus to water, Dissolved Phosphorus, Particulate Phosphorus, Runoff, Bulk density, Porosity, Sediment concentration, Water holding capacity, Soil water storage - content-budget, Root length, Pesticide concentration in runoff,	on (Kaushal et al., 2021) _Soil micropores, texture of soils (clay vs. sand), bedrock and weathering rates, and hydraulic conductivity all affect the speed of capillary rise of groundwater and salt ions and the vulnerability to salinization (Kaushal et al., 2021)	(Kaushal et al., 2021)			
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			Nitrogen and Phosphorus runoff loss, Evapotranspiration, Water infiltration rate, Water use efficiency (Tamburini et al., 2020)						
Regulation & Maintenance (Biotic)	Regulation of the chemical condition of salt waters by living processes	2. 2. 5. 2	Drainage pipes, chemical outputs, air pollution, sewage, fertilizers are impacting the salinization elements in water (Kaushal et al., 2021)	erosion, chemical weathering rates, acidification, alkalization, and ion exchange in soils, impact water salt amounts (Kaushal et al., 2021)	Fresh water salinization causes surface, ground, and drinking water quality, and aquatic and terrestrial ecosystem functions, human health, food production, and degradation	-	-	(Kaushal et al., 2021) All over the globe in humid regions	(Kaushal et al., 2021) Salinization comprehensive overview and analysis of trends all over the world

			<p>_constr ucted draina ge system s in urbani zed areas can be rich in carbon ates and other major ions. The release of these ions due to weathe ring contrib utes to a distinct urban litholo gy known as the “urban karst’ (Kaush al et al., 2021)</p>	<p>g pH and redox determi nes the moveme nt and concentr ation of trace elements in ground water (Kaushal et al., 2021)</p>	<p>ion of infrastru cture (Kaushal et al., 2021). _Water salinizat ion by road salting (Kaushal et al., 2021) _Variety of health issues reported fro increase of salinator chemica l in water due to urban factors such as sewage or drainage pipes (Kaushal et al., 2021)</p>			
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Regulation & Maintenance (Biotic)	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	-	<p>- However, our analysis also demonstrates that organic inputs promote soil fertility, nutrient cycling, carbon sequestration, and water regulation, by increasing soil organic carbon, nutrient availability, and soil water storage and limiting nutrient leaching and runoff (Tamburini et al., 2020)</p>	-	-	-		
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Regulation & Maintenance (Biotic)	Regulation of temperature and humidity, including ventilation and transpiration	2. 2. 6. 2	_ CO2 - CH4 - NO2 - NH3 emissions, CH4 uptake, Plant Nitrogen uptake, Biological N2 fixation, Soil respiration (Tamburini et al., 2020) _Vegetation cools surfaces more effectively than increases in albedo, and the most effective mitigation strategy per unit area redevelop	_Surface properties and weather status, and vegetation density (Rosenzweig et al., 2006)	_Mitigation of heat island effects in urban areas (Rosenzweig et al., 2006)	-	_ (Rosenzweig et al., 2006) New York, USA	_ (Rosenzweig et al., 2006) selection and monitoring of heatwaves in NY and analyzing cooling effects of urban forestry
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			oped is curbsid e plantin g (Rosen zweig at al., 2006)						
Reg ulati on & Mai nten ance (Bio tic)	Other	2. 3. X. X	-	-	-	-	-	-	-
Cult ural (Bio tic)	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	3. 1. 1. 1	_Respo ndents' nature related ness (level of agreem ent to a list of 6 statem ents on a 5- point scale, from 1- strongl y disagre e to 5 strongl y agree) (Colléo ny et al.,	_The availabili ty of trails for walking and cycling strongly affects choices. (Liekens et al., 2013) _People' s interacti on with green spaces depends on local cultural norms (Nawrat h et al., 2022)	_Genera tion of economi c revenue for the area / benefici al for individu al well- being, and also enhance s people's affinity to nature and environ mental attitudes / close contact with	_Direct stateme nt of users by the scale of effectiv eness from 1 to 5 (Colléo ny et al., 2021) _Self- report on experie nce and effects (Marsel le et al., 2021)	-	_(Col léony et al., 2021) Deser t prote cted areas, Israel _(Na wrath et al., 2022) Katm andu, Nepal _(Stig ner et al., 2016) More ton Bay, Austr alia	_(Coll éony et al., 2021) Social survey and statisti cal analysi s of data _(Naw rath et al., 2022) Partici patory and video focus groups with q metho dology and

		2021) _level of importance of area for uses/level of accessibility to facilities in natural areas (Colléony et al., 2021) _local revenue from visiting of natural /green areas (Stigner et al., 2016) _Mental well-being, antidepressant prescriptions; criteria-based diagnosis /physical well-	_Stay period, participation in local communities, age (positive), monthly income (positive), education (positive relation), and purpose of visit (Liu et al., 2019)	nature and change in daily routines (Colléony et al., 2021) _High-intensity visited natural areas have a positive relation to loss of biodiversity (Colléony et al., 2021) _Attraction of more diverse visitors for meaningful interactions (Colléony et al., 2021) _Positive emotions elicited by greenspaces may impact mental			_(Marselle et al., 2021) N/A _(Liu et al., 2019) HNF P, Taiwan	data analysis _(Stigner et al., 2016) Observation and data collection and analysis of true zoning laws _(Marselle et al., 2021) Delphi collection and analysis _(Liu et al., 2019) Contingent evaluation method of non-market values using WTP by questi
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			<p>being: change in levels of mortality and morbidity (Marselle et al., 2021)</p> <p>– Number of people volunteering in local management or observational research (Marselle et al., 2021)</p> <p>_ Value of contribution to the maintenance of green space (Liu et al., 2019)</p> <p>–</p>	<p>health (Nawratih et al., 2022)</p> <p>_ Ecological disruption to local living life (Stigner et al., 2016)</p> <p>_ Improvement of social cohesion with neighborhood/ spending more time outdoors / reduction of exposure to noise and air pollution/promotion of attachment to place and identity (Marselle et al., 2021)</p>				<p>onnaire</p> <p>e</p>
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			Contin gent evaluat ion metho d (using WTP or travel cost) (Liu et al., 2019)						
Cult ural (Bio tic)	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	3. 1. 1. 2	_stated prefere nce/ willing ness to pay (euro/h ouseho ld. Year) (or value citizen s attach to land use change s from agricul tural land to differe nt types of nature	_Availab le substitut es and comple ments and the proximit y to the populati on of beneficia ries (Liekens et al., 2013) _Spatial characte ristics have impact on percepti on, such as surroun	_the nature types, size, accessibi lity and species richness have a positive effect, whereas price and distance have a negative effect. In general, househo lds are willing to pay extra tax for a change	_ Choice experi ment metho d with attribut es of service or the policy alternat ives (can be prices of differe nt values) / includi on of various nature types and	_Data should control spatial variables area size and distance of respondents to place (Liekens et al., 2013) _participatory mapping with GIS and the SOLVES model (Chen et al., 2024)	_ (Liek ens et al., 2013) Fland ers, Belgi um _ (Che n et al., 2024) urban parks in Hang zhou, Chin a _ (Orta- Ortiz & Genel	_ (Lieke ns et al., 2013) Choice experi ment in 2 model s at a region al scale _ (Chen et al., 2024) Social data minin g of the case studies mainly on

			<p>areas) (Liekens et al., 2013) _Choice experiment (also covers non-use value of recreational activities) from citizens on biodiversity and spatial factors (nature type (forest highest WTP), species richness, area size, distance to users, adjacent land use, accessibility,</p>	<p>ding land use, presence of water, and man-made elements / Information about the relationship between individual WTP and the distance from the site to the population is necessary to define the market of beneficiaries of an environmental change, and aggregate individual WTP up to total public WTP /</p>	<p>from agriculture to a nature area. (Liekens et al., 2013) _creation of new nature areas generates the highest public benefits in areas with high population densities, i.e. where the proximity to the population is high. (Liekens et al., 2013) _Facilitating recreational access to nature areas increases the public benefit</p>	<p>different spatial characteristics, such as distance, size and adjacent land-cover, ensures that this value function reflects the main determinants of public perception on nature areas, as was indicated by the focus groups and the self-reported characteristics in the survey. (Liekens et al.,</p>	<p>etti, 2023) Las Palmas de Gran Canaria _ (Sacher et al., 2022) Bavaria, Germany _ (Kendal et al., 2020) SLR</p>	<p>qualitative values _ (Ortiz & Geneletti, 2023) ES demand mapping and linear weighting with match with NbS selection. _Choice experiment and quantification of results _ (Kendal et al., 2020) SLR on bias of on city size</p>
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			<p>respondent character) (Liekens et al., 2013) – Conduct various leisure and recreational activities in urban parks / Experience the pleasure of watching or interacting with animals and plants. (Chen et al., 2024) – Volume of positive reflection on social media / visitors'</p>	<p>Distance-decay is important for the aggregation of WTP estimates over the relevant population that is affected by a land use change / literature on perception of landscapes shows that the adjacent land use can be of positive (variety in landscapes, landscape care) or negative influence (industrial elements) / Women</p>	<p>(Liekens et al., 2013) – adjacent residential or nature areas have a positive effect on WTP for the development of natural land use, compared to bordering agricultural land, whereas WTP is lower for nature areas if they are adjacent to industrial areas. (Liekens et al., 2013) – spiritual fulfillment, cognitive</p>	<p>2013) – The importance of species richness Public preferences for the land use change scenarios were tested by including it as a separate attribute with two levels: (1) few and very common species, or (2) a large number of species, including endangered species. / Four spatial</p>			
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			<p>happin ess level after visit/ Higher users perceiv ed natural appreci ation and recreati on, correla tes with high probab ility of perceiv ing aesthet ic experie nces (Chen et al., 2024) _Increa se in residen ts health status _Dista nce- based proxies for access to comm unity</p>	<p>are less likely to choose an alternati ve and are willing to pay 37euros less for extra nature areas than men. / Older responde nts tend to attach less importa nce to high species richness than younger people./ The results furtherm ore show that the WTP for nature areas is subject to distance decay (Liekens et al., 2013) _1.</p>	<p>develop ment, reflectio n, and aesthetic experien ces, improvi ng mental and physical well- being (Chen et al., 2024)</p>	<p>charact eristics were include d as attribut es in the design: the size, accessi bility, surrou nding land use of the area and distan ce to the respon dents' residen ce. The size of the area under chang ing land use planni ng is include d here./ Questi ons cover ed the percept ion of the attracti</p>		
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			<p>gardens (based on road networks and walking pathways) (Orta-Ortiz & Geneletti, 2023) _Higher level of NbS intervention presence leads to lower level of recreational benefits (Orta-Ortiz & Geneletti, 2023)</p>	<p>range of habitat types and ecological indicators, 2. spatial factors such as proximity, size and adjacent land use, and 3. an indicator for accessibility (Lieken et al., 2013) _Recreation, spiritual services, and aesthetic experiences form a bundle closely related to ponds, natural revegetations, lawns, and groves. (Chen et al., 2024)</p>	<p>veness of different types of landscapes, the familiarity with these types and the importance of certain aspects, such as presence of animal species and possibilities for recreation. The seven different nature types included as attributes were introduced in this part of the survey and depicted by</p>			
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			<p>_Social percepti on might be influenc ed by factors such as a high prevalen ce of mosquit oes in the plant commu nity and a lack of systemat ic introduc tion and interpret ation of historic and cultural landscap es in the parks./ This differenc e might be related to gender habits. Yang et al. found that most male tourists preferre d sitting,</p>		<p>two photos for each type. (Lieken s et al., 2013) _prefer red landsca pe factors in urban parks were decidu ous trees > herbac eous flowers > ponds > gates > pavilio ns (Chen et al., 2024)</p>			
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			<p>while female tourists preferred taking photographs. (Chen et al., 2024)</p> <p>_landscape features and attractiveness (Ortiz & Geneletti, 2023)</p> <p>_recreational experience might be negatively affected by the inclusion of more natural forests. (Sacher et al., 2022)</p> <p>_City size is negatively related to total ecosystem</p>				
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				service value and the recreation potential of vegetation cover (Kendal et al., 2020)					
Cultural (Biotic)	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	3.1.2.1	<p>_Existence of relation local values to local objects (Riechers et al., 2022)</p> <p>_Local identity or value for certain plant or</p>	<p>_Biodiversity of surroundings during time (Steger et al., 2023)</p> <p>_relation al values were linked to aspects of ecological and environmental</p>	<p>_Social cohesion and participation/economic advantage and livelihood / Partnership and collaboration /benefitting governance and manage</p>	<p>_Expert s or local opinion on the functionality of nature or certain species (Steger et al., 2023)</p> <p>_anthropological and</p>	<p>_Sociodemographic information related to monthly income, age, gender, education, municipality of residence, years living in the site, and occupation were included in the survey (resulted positive association) (Cebrián-</p>	<p>_(Riechers et al., 2022) Coastal areas (Steger et al., 2023) Suda no-Guinean Savanna (Cebrián-</p>	<p>_(Riechers et al., 2022) SLR and analysis (Steger et al., 2023) Delphi form local experts and analysis</p>

			<p>animal species (Steger et al., 2023) _environment related profession variable was created using a binary scale (1 = related; 0 = unrelated). Second, the absolute number of visits to the study site was transformed into a 5-level ordinal scale called visits to the site (Cebrián-</p>	<p>change (such as climate change, disasters, coastal erosion, or degradation) and terrestrial aspects of coastal systems (such as farming, forestry, or land cover) (Riecher et al., 2022) _Weakening other ES negatively impacts the creation or progress of local knowledge (Riecher et al., 2022) _socio-demographics, trip</p>	<p>ment (Riecher et al., 2022) _increasing outdoor activities and human-nature relationships (Cebrián - Piqueras et al., 2020) _Positive correlation with other ES especially regulation ES (Cebrián - Piqueras et al., 2020)</p>	<p>ethnographic methods. (Riecher et al., 2022) _Learning exposure: primarily, secondary, or university school; direct contact with the natural environment; reading; television; seminars or courses related to the topic; internet; in contact with others (binary yes or no presence or</p>	<p>Piqueras et al., 2020)</p>	<p>Piqueras et al., 2020) Sierra de Guadarrama protected areas, Spain</p>	<p>_(Cebrián-Piqueras et al., 2020) local user survey and multivariate analysis</p>
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			<p>Piqueras et al., 2020) – Amount or volume of engagement with nature (mushrooms and plants picking, sports, nature observation, picnic and recreation, hunting, fishing, hiking and walking, walking dog, horse riding, bathing, or photography and other</p>	<p>characteristics, previous engagement with nature, and a rural-urban gradient (population, population density, distance to an urban center (i.e., minimum distance to an area with at least 30,000 inhabitants) (Cebrián - Piqueras et al., 2020) – respondents with high LEK and SEK were more focused on</p>	<p>absence) / measuring local knowledge on variety of species in the area of study (Cebrián - Piqueras et al., 2020)</p>			
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			arts) (binary presen ce or absenc e answer) (Cebri án- Piquer as et al., 2020)	regulatin g services and intrinsic values, but also acknowl edged positive effects of humans to nature (Cebrián - Piqueras et al., 2020)					
Cult ural (Bio tic)	Characteristics of living systems that enable education and training	3. 1. 2. 2	-	_visitors' percepti on of science educatio n was mainly related to artificial landscap es, such as identific ation facilities, and they rarely paid attentio n to the knowled ge provided by natural factors,	-	_Surve y and intervie w/ cooper ative mappi ng with citizens on their local knowle dge (spatial -based) mappi ng attribut es, use, and knowle dge of the area. (Davids	-	_(Dav ids et al., 2022) Durb an, South Afric a	_(Davi ds et al., 2022) EIA using indicat ors and comm on knowl edge

				such as plants in urban parks (Chen et al., 2024)		et al., 2022)			
Cultural (Biotic)	Characteristics of living systems that are resonant in terms of culture or heritage	3. 1. 2. 3	-	_The perception of cultural heritage came mainly from landscape factors such as identification facilities and buildings (pavilions, bridges, towers, and modern buildings). These landscapes were usually carriers of poetry and scientific texts. (Chen et al., 2024)	-	-	-	-	-

Cultural (Biotic)	Characteristics of living systems that enable aesthetic experiences	3. 1. 2. 4	_Number of habitats of community importance, Floral richness, Floral biological trait index, Plot edge diversity, Steinh aus index, Plot spatial diversity, Bird species richness, Land-cover/topographic variables, Vineyard management, Shannon land-cover diversity	_Formation of natural features and degree of its effect on safety (Salizzoni, 2021)	_Increase scenic quality/increase in direct relationship with nature/mental inclusion and identity of visitors/increase in safety (with maintenance factor) (Salizzoni, 2021)	_Preference Assessment with locals (Frequency of responses) (Balzan et al., 2020)	_Willingness-to-pay of local residents and tourists (Balzan et al., 2020)	_(Salizzoni, 2021) San Pietro Beach, Sardinia, Italy	_(Salizzoni, 2021)
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			<p>y index, Visual representation of agricultural landscape (Balzan et al., 2020)</p> <p>_Perception of safety (positive relation) (Salizzoni, 2021)</p>						
Cultural (Biotic)	Elements of living systems that have symbolic meaning	3.2.1.1	–	<p>_Level of contrast in use and approach between users and governing system / local values for certain natural feature (Dressler et al., 2021)</p>	<p>_Mental well-being and emotional stability (Nawrath et al., 2022) (Dressler et al., 2021)</p>	–	<p>_Willingness to pay (general on intervals or binary questions of yes or no or maximum amount as an annual tax)</p>	<p>_(Velasco et al., 2018) Mar Menor, Murcia, SE Spain (Nawrath et al., 2022) Katmandu, Nepal (Dressler et al., 2021)</p>	<p>_(Velasco et al., 2018) Local survey-based WTP and CVM methods with analysis (Nawrath et al., 2022) Participatory</p>

								Palawan Island, the Philippines.	and video focus groups with methodology and data analysis (Dressler et al., 2021) Social survey and report and face to face interviews
Cultural (Biotic)	Elements of living systems that have sacred or religious meaning	3. 2. 1. 2	_Number of visits or usage for ritual or religious purposes (Sossa et al., 2024)	_Type of religion of inhabitants and neighbors and its linkage to the nature (Sossa et al., 2024)	_maintenance of cultural identity/ social cohesion/ socialization and transmission of values/place of communion (Sossa et al., 2024) _Conservation of biodiversity	_Direct interview with locals and the importance of ES (Sossa et al., 2024)	-	- (Sossa et al., 2024) Ouedelta, Benin _ (Blicharska et al., 2013) Northwest Ghat India	- (Sossa et al., 2024) Socio-cultural assessment using building block methodology on the river catchment area _ (Blich


					sity and species /valorization of natural areas (Blicharska et al., 2013)			arska et al., 2013) literature review and observation
Cultural (Biotic)	Elements of living systems used for entertainment or representation	3. 2. 1. 3	-	-	-	-	-	_(Riechers et al., 2022) Coastal areas _(Riechers et al., 2022) SLR and analysis

						rs et al., 2022)			
Cultural (Biotic)	Characteristics or features of living systems that have an existence value	3. 2. 2. 1	<p>_Amount of satisfaction people gain from gaining knowledge from certain aspects of biodiversity (Turpie, 2004)</p>	<p>_Additionally, science education, existential values, and cultural heritage form another bundle associated with identification facilities, landscape sketches, and architectural landscapes (other traditional buildings, modern buildings, pavilions, towers, and bridges). Pavilions and bridges</p>	<p>_Cohesion between local communities and local government (positive relation with ES)(e.g., Tlingit in Southeast Alaska is more than just food and plays a unique role in creating important ties between families and individuals as well as shaping their cultural identity, traditional</p>	–	<p>_Typically measured using stated-preference valuation techniques such as the contingent valuation method (Turpie, 2004)</p>	<p>_(Turpie, 2004) South Africa (Konar et al., 2019) N/A</p>	<p>_(Turpie, 2004) Non-systematic literature review (Konar et al., 2019) Values assessment qualitatively and quantitatively of global values of fisheries</p>

				<p>were closely connected to historical and cultural factors, while towers, modern architecture, and roads were closely linked to social interaction. Traditional buildings and signage facilities were closely associated with science education and existential values (Chen et al., 2024)</p>	<p>beliefs, legends and spirituality) (Konar et al., 2019) _Local commercial revenue from/by the objects of value (Konar et al., 2019)</p>				
Cultural (Biotic)	Characteristics or features of living systems that have an option or bequest value	3. 2. 2. 2	-	-	-	-	-	-	-

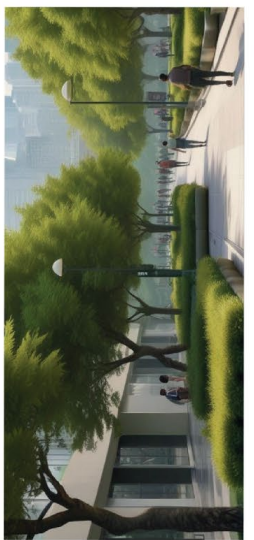
Cultural (Biotic)	Other	3.							
		3.							
		X.	-	-	-	-	-	-	-
		X							

Supplementary Material 3 (Chapter 3)




Creazione di posti di lavoro part-time o attività ricreative per i residenti nelle vicinanze

Risultati in (anni): 0 10 20




Aumento della superficie coperta da verde e riduzione del calore

Risultati in (anni): 0 10 20



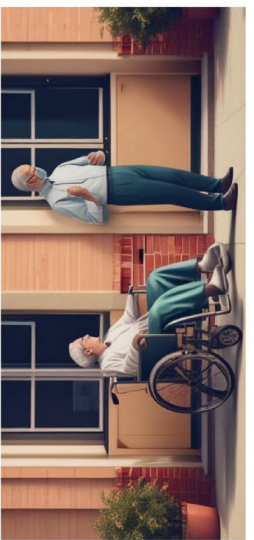
Diminuzione delle malattie neuroendocrine e cardiache

Risultati in (anni): 0 10 20



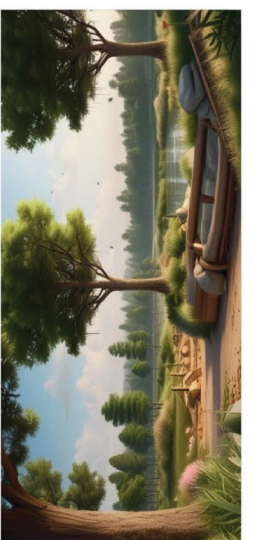
Aumento delle entrate locali grazie alla produzione di cibo dagli orti

Risultati in (anni): 0 10 20



Riduzione delle malattie acute e dei rischi sanitari per i residenti

Risultati in (anni): 0 10 20



Tranquillità del luogo e rumori meno fastidiosi

Risultati in (anni): 0 10 20




Fonte locale per prodotti naturali (commerciali o non)

Risultati in (anni): 0 10 20



Aumento del valore delle proprietà in loco e aumento generale della qualità del terreno

Risultati in (anni): 0 10 20



Diminuzione dei materiali aerodispersi all'esterno e all'interno (ad esempio sabbia, polvere)

Risultati in (anni): 0 10 20

Sezione: Regolazione e manutenzione Codice: 2.1.2.2

Gruppo: Mediazione di fastidi di origine antropica
Classe di servizio ecosistemico: Attenuazione del rumore
Esempio: Riduzione del rumore dei treni e delle ferrovie mediante buffer verde e vegetazione



Sezione: Regolazione e manutenzione Codice: 2.1.2.2

Gruppo: Mediazione di fastidi di origine antropica
Classe di servizio ecosistemico: Attenuazione del rumore
Esempio: Riduzione del rumore dei treni e delle ferrovie mediante buffer verde e vegetazione



Sezione: Regolazione e manutenzione Codice: 2.2.1.4

Gruppo: Regolazione dei flussi di base e degli eventi estremi
Classe di servizio ecosistemico: Protezione dal vento
Esempio: Frangivento e controllo dei danni derivanti da eventi estremi legati al vento



Sezione: Provisioning Codice: 1.2.1.1

Gruppo: Materiale genetico proveniente da piante, alghe o funghi
Classe di servizio ecosistemico: Semi, spore e altri materiali vegetali raccolti per mantenere o stabilire una popolazione
Esempio: Semi o spore che possiamo raccogliere



Sezione: Regolazione e manutenzione Codice: 2.1.1.1

Gruppo: Mediazione di rifiuti o sostanze tossiche di origine antropica da parte di processi viventi
Classe di servizio ecosistemico: Biorisanamento da parte di microrganismi, alghe, piante e animali
Esempio: Biorisanamento di rifiuti industriali mediante smaltimento su terreni agricoli



Sezione: Regolazione e manutenzione Codice: 2.1.1.1

Gruppo: Mediazione di rifiuti o sostanze tossiche di origine antropica da parte di processi viventi
Classe di servizio ecosistemico: Biorisanamento da parte di microrganismi, alghe, piante e animali
Esempio: Biorisanamento di rifiuti industriali mediante smaltimento su terreni agricoli



Sezione: Provisioning Codice: 1.1.1.1

Gruppo: Piante terrestri coltivate per nutrizione, materiali o energia
Classe di servizio ecosistemico: Piante terrestri coltivate (compresi funghi, alghe) coltivate per scopi nutrizionali
Esempio: Coltivazione di ortaggi per il consumo locale o vendita nei mercati locali



Sezione: Provisioning Codice: 1.1.1.1

Gruppo: Piante terrestri coltivate per nutrizione, materiali o energia
Classe di servizio ecosistemico: Piante terrestri coltivate (compresi funghi, alghe) coltivate per scopi nutrizionali
Esempio: Coltivazione di ortaggi per il consumo locale o vendita nei mercati locali



Sezione: Provisioning Codice: 1.1.1.2

Gruppo: Piante terrestri coltivate per nutrizione, materiali o energia
Classe di servizio ecosistemico: Fibre e altri materiali provenienti da piante coltivate, funghi, alghe e batteri per uso diretto o lavorazione (esclusi materiali genetici)
Esempio: Eccedenza raccoglibile della crescita annuale degli alberi Fibre utilizzabili provenienti da piante utilizzate nella produzione





Riduzione dei costi di manutenzione o riparazione degli edifici dai pericoli

Risultati in (anni): 0 10



Miglioramento della biodiversità e migliori habitat per piante e impollinatori

Risultati in (anni): 0 10



Miglioramento della qualità e della durata della coltivazione e delle piantagioni locali

Risultati in (anni): 0 10



Meno difficoltà negli spostamenti nel vicino (per i pedoni)

Risultati in (anni): 0 10



Miglioramenti nella condizione e nella diversità delle piante e della vegetazione

Risultati in (anni): 0 10



Temperature locali più basse nelle stagioni calde e durante le ondate di caldo

Risultati in (anni): 0 10



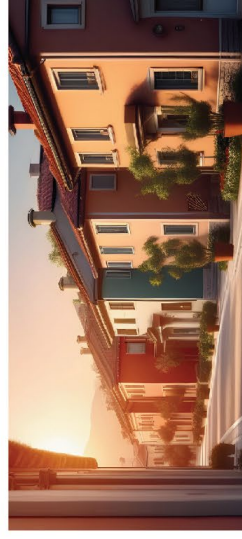
Diminuzione della densità dei parassiti e migliore estetica del paesaggio

Risultati in (anni): 0 10



Riduzione della depressione e dei disturbi d'ansia

Risultati in (anni): 0 10



Minori costi energetici (minori consumi) per le famiglie

Risultati in (anni): 0 10

Sezione: Regolazione e manutenzione Codice: 2.2.3.2

Gruppo: Controllo dei parassiti e delle malattie
Classe di servizio ecosistemico: Controllo delle malattie
Esempio: Riduzione dei danni causati dalle malattie e dei problemi di salute mediante interventi naturali



Sezione: Regolazione e manutenzione Codice: 2.2.6.2

Gruppo: Composizione e condizioni atmosferiche
Classe di servizio ecosistemico: Regolazione della temperatura e dell'umidità, compresa la ventilazione e la traspirazione
Esempio: Raffreddamento superficiale e temperature migliori durante l'estate grazie alla presenza di alberi e piante



Sezione: Regolazione e manutenzione Codice: 2.2.6.2

Gruppo: Composizione e condizioni atmosferiche
Classe di servizio ecosistemico: Regolazione della temperatura e dell'umidità, compresa la ventilazione e la traspirazione
Esempio: Raffreddamento superficiale e temperature migliori durante l'estate grazie alla presenza di alberi e piante



Sezione: Regolazione e manutenzione Codice: 2.2.2.1

Gruppo: Manutenzione del ciclo di vita, protezione dell'habitat e del patrimonio genetico
Classe di servizio ecosistemico: Impollinazione
Esempio: Fornire un habitat per gli impollinatori autoctoni



Sezione: Regolazione e manutenzione Codice: 2.2.3.1

Gruppo: Controllo dei parassiti e delle malattie
Classe di servizio ecosistemico: Controllo dei parassiti
Esempio: Riduzione dei danni causati dai parassiti alle colture coltivate



Sezione: Regolazione e manutenzione Codice: 2.2.3.2

Gruppo: Controllo dei parassiti e delle malattie
Classe di servizio ecosistemico: Controllo delle malattie
Esempio: Riduzione dei danni causati dalle malattie e dei problemi di salute mediante interventi naturali



Sezione: Regolazione e manutenzione Codice: 2.2.1.4

Gruppo: Regolazione dei flussi di base e degli eventi estremi
Classe di servizio ecosistemico: Protezione dal vento
Esempio: Frangivento e controllo dei danni derivanti da eventi estremi legati al vento



Sezione: Regolazione e manutenzione Codice: 2.2.1.4

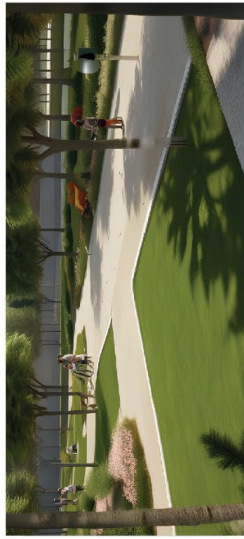
Gruppo: Regolazione dei flussi di base e degli eventi estremi
Classe di servizio ecosistemico: Protezione dal vento
Esempio: Frangivento e controllo dei danni derivanti da eventi estremi legati al vento



Sezione: Regolazione e manutenzione Codice: 2.2.2.1

Gruppo: Manutenzione del ciclo di vita, protezione dell'habitat e del patrimonio genetico
Classe di servizio ecosistemico: Impollinazione
Esempio: Fornire un habitat per gli impollinatori autoctoni





Opportunità per più attività all'aria aperta nella natura

Risultati in (anni): 0 10



Luogo di realizzazione spirituale, sviluppo cognitivo, riflessione

Risultati in (anni): 0 10



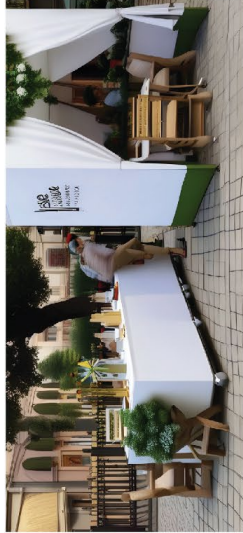
Più senso di appartenenza e identità verso il prossimo

Risultati in (anni): 0 10



Maggiore interazione tra vicini, coesione locale e identità

Risultati in (anni): 0 10



Opportunità di partecipazione ad eventi locali e formazione di comunità

Risultati in (anni): 0 10



Entrate commerciali locali derivanti dagli elementi naturali

Risultati in (anni): 0 10



Maggiore disponibilità a partecipare ad attività all'aperto da parte dei residenti

Risultati in (anni): 0 10



Vivacità del vicino e aumento dei visitatori

Risultati in (anni): 0 10



Senso di connessione con la tradizione e la storia

Risultati in (anni): 0 10

Sezione: Culturale**Codice: 3.1.2.4**

Gruppo: Interazioni intellettuali e rappresentative con l'ambiente naturale
Classe di servizio ecosistemico: Caratteristiche dei sistemi viventi che consentono esperienze estetiche
Esempio: Area di straordinaria bellezza naturale; sito panoramico

**Sezione: Culturale****Codice: 3.2.2.1**

Gruppo: Altre caratteristiche biotiche che hanno un valore di non uso
Classe di servizio ecosistemico: Caratteristiche o caratteristiche dei sistemi viventi che hanno un valore esistenziale
Esempio: Aree designate come selvagge

**Sezione: Culturale****Codice: 3.2.2.1**

Gruppo: Altre caratteristiche biotiche che hanno un valore di non uso
Classe di servizio ecosistemico: Caratteristiche o caratteristiche dei sistemi viventi che hanno un valore esistenziale
Esempio: Aree designate come selvagge

**Sezione: Culturale****Codice: 3.1.1.2**

Gruppo: Interazioni fisiche ed esperienziali con l'ambiente naturale
Classe di servizio ecosistemico: Caratteristiche dei sistemi viventi che consentono attività che promuovono la salute, il recupero o il divertimento attraverso interazioni passive o osservative
Esempio: Osservazione e fruizione degli elementi naturali (animali e piante)

**Sezione: Culturale****Codice: 3.1.2.1**

Gruppo: Interazioni intellettuali e rappresentative con l'ambiente naturale
Classe di servizio ecosistemico: Caratteristiche dei sistemi viventi che consentono la ricerca scientifica o la creazione di conoscenze ecologiche tradizionali
Esempio: Area scientifico naturalistica speciale quale parco agricolo Sud Milano

**Sezione: Culturale****Codice: 3.1.2.1**

Gruppo: Interazioni intellettuali e rappresentative con l'ambiente naturale
Classe di servizio ecosistemico: Caratteristiche dei sistemi viventi che consentono la ricerca scientifica o la creazione di conoscenze ecologiche tradizionali
Esempio: Area scientifico naturalistica speciale quale parco agricolo Sud Milano

**Sezione: Culturale****Codice: 3.1.1.1**

Gruppo: Interazioni fisiche ed esperienziali con l'ambiente naturale
Classe di servizio ecosistemico: Caratteristiche dei sistemi viventi che consentono attività che promuovono la salute, il recupero o il divertimento attraverso interazioni attive o immersive
Esempio: Opportunità per immersioni, nuoto, escursioni e attività ricreative

**Sezione: Culturale****Codice: 3.1.1.1**

Gruppo: Interazioni fisiche ed esperienziali con l'ambiente naturale
Classe di servizio ecosistemico: Caratteristiche dei sistemi viventi che consentono attività che promuovono la salute, il recupero o il divertimento attraverso interazioni attive o immersive
Esempio: Opportunità per immersioni, nuoto, escursioni e attività ricreative

**Sezione: Culturale****Codice: 3.1.1.2**

Gruppo: Interazioni fisiche ed esperienziali con l'ambiente naturale
Classe di servizio ecosistemico: Caratteristiche dei sistemi viventi che consentono attività che promuovono la salute, il recupero o il divertimento attraverso interazioni passive o osservative
Esempio: Osservazione e fruizione degli elementi naturali (animali e piante)



Supplementary Material 4 (Chapter 4)

Methodologies (interviews and workshops)

1. Conceptual Framework

The first theme focused on definitions and perceptions of nature and urban biodiversity among visitors. This theme focuses on responses to the question, “How do you define urban biodiversity? What comes to your mind?” Additionally, interviewees can respond to continuation by mentioning any specific flora or fauna species that correlate to urban biodiversity in their perception.

The second theme focuses on benefits related to nature and biodiversity in daily human lives. The participants openly responded to the question, “What is the value of urban biodiversity for you?”. Consequently, a complementary follow-up question of “What are the benefits of urban biodiversity in your life?” is asked of the participants. Through both questions, if participants are familiar with the concept or definition of ES, they have the option to suggest their perceived benefits of nature through classes of ES. Otherwise, through the data elaboration procedure, the benefits mentioned based on their attributes are correlated with one or more ES for analysis. In case of ambiguities regarding the benefits or if they are perceived in the specific context of the case study or within urban areas, participants are asked to clarify the locations.

The third theme focuses on Botanical Gardens in particular. Participants openly reflect on the questions “What does it mean to you to be in the Botanical Gardens?” and “Do you have any suggestions for improvement of the Botanical Gardens?”. This section orients the focus on the value of botanical gardens and, if applicable, possible rooms for improvement in place.

1.2. Workshops

The first session in in-person mode took place in November 2024 at the Utrecht University facility. In total, five participants (all affiliated with at least one of the academic institutions at the Science Park) and two facilitators discussed openly the raised questions and participated in the gamified procedure about the benefits of the Botanical Gardens. The second open session was formed online through a public invitation in which four participants and a facilitator discussed the same topic as the first session openly in January 2025. In both sessions three boards used to facilitate the process of workshops. Each board has a theme focusing on urban biodiversity, Botanical Gardens, and ecosystem services benefits. Template of the boards used in workshops are observable in Figure 1.

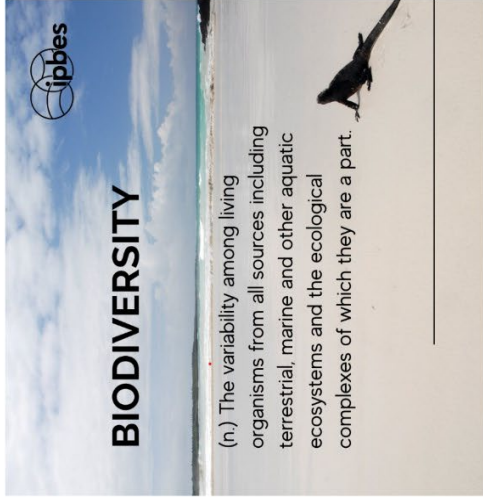
Date -- / -- / --

TOOL A.1.1 – What is urban biodiversity, and what it means for you?



What is the urban biodiversity? What comes to your mind?

[Empty dashed box for notes]



**What is the added value of biodiversity for you?
How does it affect your life?**

What benefits comes to your mind?
What changes does biodiversity make in your daily life?

[Empty dashed box for notes]

What facilities or solutions can help biodiversity in cities?

[Empty dashed box for notes]



Figure 1a: The first board on theme of urban biodiversity

Date -- / -- / --

TOOL A.2.1 - Biodiversity and Utrecht University Botanical Gardens

What does it mean to you to have the Botanical Gardens at UU?



What suggestions do you have for better experience at the Botanical gardens?

For example what facilities or structure can improve access to Botanical Gardens? or write you ideas for better plants and animal care in the Botanical Gardens



Figure 1b: The second board on theme of Botanical Gardens.

What benefits do Botanical Gardens bring in your life?
(What you recognize as benefits?)

"Ecosystem services" are the range of services that natural systems generate for the benefit of humans. According to the definition proposed by the Millennium Ecosystem Assessment (MEA), ecosystem services are the "multiple benefits provided by ecosystems to humankind" (MEA, 2005).






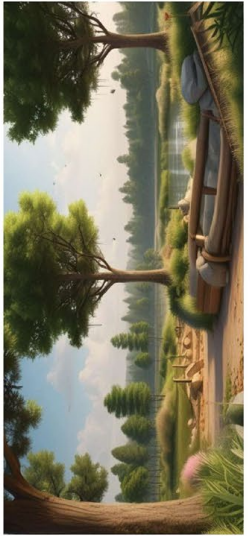
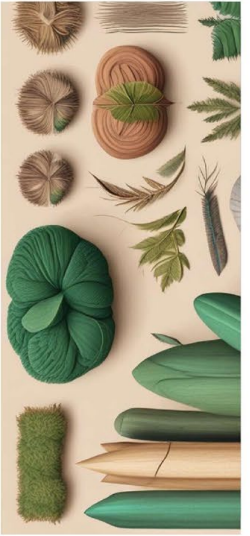
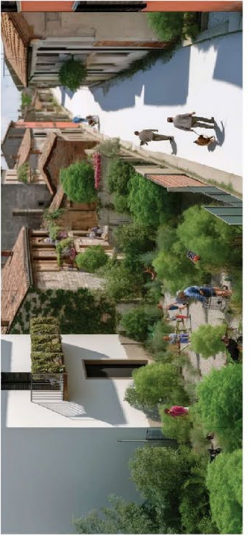

Provisioning services: products that we obtain, e.g., timber.

Regulating services: maintain a condition such as air quality.

Cultural services: non-material benefits such as leisure time.

Figure 1c: The third board on theme of ecosystem services

Supplementary Material 5 (Chapter 4)

 <p>Part-time job creation or leisure activity for residents nearby</p> <p>Results in (years): 0 10 20 30</p>	 <p>Increase in area covered by greenery and heat reduction</p> <p>Results in (years): 0 10 20 30</p>	 <p>Decrease in neuroendocrine and heart disease</p> <p>Results in (years): 0 10 20 30</p>
 <p>Increase in local revenue by production of food from gardens</p> <p>Results in (years): 0 10 20 30</p>	 <p>Reduction of acute diseases and health risks for residents</p> <p>Results in (years): 0 10 20 30</p>	 <p>Tranquility of place and less annoying noises</p> <p>Results in (years): 0 10 20 30</p>
 <p>Local source for nature-based products (commercial or non)</p> <p>Results in (years): 0 10 20 30</p>	 <p>Increased property values on-site and overall increase of land quality</p> <p>Results in (years): 0 10 20 30</p>	 <p>Decrease in airborne materials outdoor and indoor (e.g., sand, dust)</p> <p>Results in (years): 0 10 20 30</p>

Section: Regulation & Maintenance Code: 2.1.2.2

Group: Mediation of nuisances of anthropogenic origin
Class of Ecosystem Service: Noise attenuation
Example: Reduction of trains and railway noise by green buffer and vegetation



Section: Regulation & Maintenance Code: 2.1.2.2

Group: Mediation of nuisances of anthropogenic origin
Class of Ecosystem Service: Noise attenuation
Example: Reduction of trains and railway noise by green buffer and vegetation



Section: Regulation & Maintenance Code: 2.2.1.4

Group: Regulation of baseline flows and extreme events
Class of Ecosystem Service: Wind protection
Example: Wind breaks and controlling of damages of extreme wind-related events



Section: Provisioning Code: 1.2.1.1

Group: Genetic material from plants, algae or fungi
Class of Ecosystem Service: Seeds, spores and other plant materials collected for maintaining or establishing a population
Example: Seeds or spores that we can harvest



Section: Regulation & Maintenance Code: 2.1.1.1

Group: Mediation of wastes or toxic substances of anthropogenic origin by living processes
Class of Ecosystem Service: Bio-remediation by micro-organisms, algae, plants, and animals
Example: Bio-remediation of industrial wastes by disposal on agricultural land



Section: Regulation & Maintenance Code: 2.1.1.1

Group: Mediation of wastes or toxic substances of anthropogenic origin by living processes
Class of Ecosystem Service: Bio-remediation by micro-organisms, algae, plants, and animals
Example: Bio-remediation of industrial wastes by disposal on agricultural land



Section: Provisioning Code: 1.1.1.1

Group: Cultivated terrestrial plants for nutrition, materials or energy
Class of Ecosystem Service: Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes
Example: Growing vegetables for local consumption or selling in local markets



Section: Provisioning Code: 1.1.1.1

Group: Cultivated terrestrial plants for nutrition, materials or energy
Class of Ecosystem Service: Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes
Example: Growing vegetables for local consumption or selling in local markets



Section: Provisioning Code: 1.1.1.2

Group: Cultivated terrestrial plants for nutrition, materials or energy
Class of Ecosystem Service: Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)
Example: Harvestable surplus of annual tree growth Useable fibers from plant used in production





Maintenance or repair cost reduction of buildings from hazards

Results in (years): 0 10



Improvement in biodiversity and better habitats for plants and pollinators

Results in (years): 0 10



Local cultivation and plantations quality and lifespan improvement

Results in (years): 0 10



Fewer difficulties in movements in the neighbour (for pedestrians)

Results in (years): 0 10



Improvements in plants and vegetations condition and diversity

Results in (years): 0 10



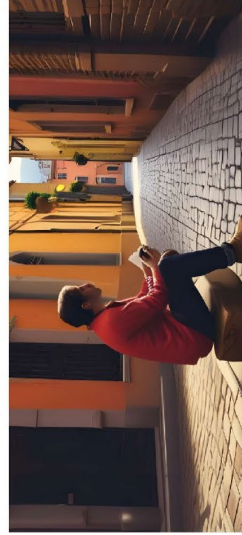
Lower local temperatures in hot seasons and during heatwaves

Results in (years): 0 10



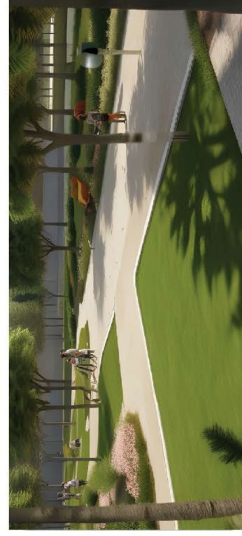
Decrease in pest density and better landscape aesthetic

Results in (years): 0 10



Reduction in depression and anxiety disorders

Results in (years): 0 10



Opportunity for more activities outdoors within nature

Results in (years): 0 10

Section: Regulation & Maintenance Code: 2.2.3.2

Group: Pest and disease control
Class of Ecosystem Service: Disease control
Example: Reduction in disease damage and health issues by natural interventions



Section: Regulation & Maintenance Code: 2.2.6.2

Group: Atmospheric composition and conditions
Class of Ecosystem Service: Regulation of temperature and humidity, including ventilation and transpiration
Example: Surface cooling and better temperatures during summer due to the existence of trees and plants



Section: Cultural Code: 3.1.1.1

Group: Physical and experiential interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
Example: Opportunities for diving, swimming, hiking, and recreation



Section: Regulation & Maintenance Code: 2.2.2.1

Group: Lifecycle maintenance, habitat and gene pool protection
Class of Ecosystem Service: Pollination
Example: Providing a habitat for native pollinators



Section: Regulation & Maintenance Code: 2.2.3.1

Group: Pest and disease control
Class of Ecosystem Service: Pest control
Example: Reduction in pest damage to cultivated crop



Section: Regulation & Maintenance Code: 2.2.3.2

Group: Pest and disease control
Class of Ecosystem Service: Disease control
Example: Reduction in disease damage and health issues by natural interventions



Section: Regulation & Maintenance Code: 2.2.1.4

Group: Regulation of baseline flows and extreme events
Class of Ecosystem Service: Wind protection
Example: Wind breaks and controlling of damage of extreme wind-related events



Section: Regulation & Maintenance Code: 2.2.1.4

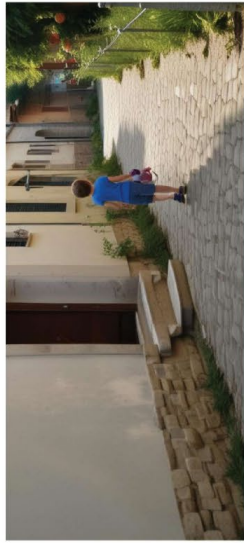
Group: Regulation of baseline flows and extreme events
Class of Ecosystem Service: Wind protection
Example: Wind breaks and controlling of damage of extreme wind-related events



Section: Regulation & Maintenance Code: 2.2.2.1

Group: Lifecycle maintenance, habitat and gene pool protection
Class of Ecosystem Service: Pollination
Example: Providing a habitat for native pollinators





Increased safety by the presence of natural elements

Results in (years): 0 10



Place for spiritual fulfillment, cognitive development, reflection

Results in (years): 0 10



More sense of belonging and identity to the neighbor

Results in (years): 0 10



More interaction between neighbors, local cohesion, and identity

Results in (years): 0 10



Opportunity for participation in local events and communities formation

Results in (years): 0 10



Local commercial revenue from the natural elements

Results in (years): 0 10



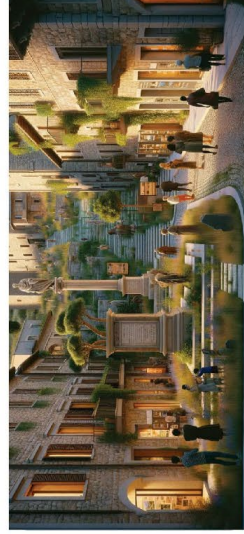
Higher willingness for participation in outdoor activities by residents

Results in (years): 0 10



Liveliness of neighbor and increased visitors

Results in (years): 0 10



Sense of connection with tradition and history

Results in (years): 0 10

Section: Cultural Code: 3.1.2.4

Group: Intellectual and representative interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that enable aesthetic experiences
Example: Area of Outstanding Natural Beauty; panorama site



Section: Cultural Code: 3.2.2.1

Group: Other biotic characteristics that have a non-use value
Class of Ecosystem Service: Characteristics or features of living systems that have an existence value
Example: Areas designated as wilderness



Section: Cultural Code: 3.2.2.1

Group: Other biotic characteristics that have a non-use value
Class of Ecosystem Service: Characteristics or features of living systems that have an existence value
Example: Areas designated as wilderness



Section: Cultural Code: 3.1.1.2

Group: Physical and experiential interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions
Example: Observation and enjoyment from natural elements (animals and plants)



Section: Cultural Code: 3.1.2.1

Group: Intellectual and representative interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge
Example: Special natural scientific area like parco agricolo Sud Milano



Section: Cultural Code: 3.1.2.1

Group: Intellectual and representative interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge
Example: Special natural scientific area like parco agricolo Sud Milano



Section: Cultural Code: 3.1.2.4

Group: Intellectual and representative interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that enable aesthetic experiences
Example: Area of Outstanding Natural Beauty; panorama site



Section: Cultural Code: 3.1.1.1

Group: Physical and experiential interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
Example: Opportunities for diving, swimming, hiking, and recreation



Section: Cultural Code: 3.1.1.2

Group: Physical and experiential interactions with natural environment
Class of Ecosystem Service: Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions
Example: Observation and enjoyment from natural elements (animals and plants)



Date -- / -- / -- **TOOL A.1.1 - What is urban biodiversity, and what it means for you?**



What is the urban biodiversity? What comes to your mind?

Green
walkable

Building around walking - not walking around building.
 brings a balance of industry and nature that
 revolves around the needs of people (walkability).

*Biodiversity should not be excludable/private
 The role of biodiversity - save humans?*

BIODIVERSITY

(n) The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part.

What is the added value of biodiversity for you? How does it affect your life?

It reminds me that there is a whole world outside of my thoughts when I am to focused on something. It allows for an escape or a place of solace from the everyday "chaos."

is nature meant to sense us?

creativity stems from bio. Inspiration.

*What benefits comes to your mind?
 What changes does biodiversity make in your daily life?*

What facilities or solutions can help biodiversity in cities?

- * walking paths, not bicycle paths, to encourage people to feel connected to the land and not maneuver between lakes and other obstacles.
- * More benches. Make people feel welcome in the space, don't rush them to get to their destination. Even just places to sit.
- * Subsidies for greenery.

Neighborhood farms - create a community farm and encourage biodiversity.
 Rooftop community gardens.
 Education on biodiversity.

What does it mean to you to have the Botanical Gardens at UU?



Giving biodiversity a space of its own to emphasize its significance.

Educating on species and significance.

It serves as an escape from academia, for inspiration and letting creativity flow.

For me as a student, I go there to change perspectives and let my mind rest. I can take a walk and reflect calmly.

BIG reminds you to live more sustainably.

Build stronger connections w/ colleagues when going on walks.

Global environment

Historical significance of the wall and species.



What suggestions do you have for better experience at the Botanical gardens?

For example what facilities or structure can improve access to Botanical Gardens? or write you ideas for better plants and animal care in the Botanical Gardens

Community farm.
Museum-like building.
Spaces to be creative.

* Fun facts and seasonal updates on "what to look for" in the CP.

* More workshops/classes on how to maintain an urban garden → increase reach and make it known - communication strategies.

* Lectures on conservation projects, invite the public for after-hours talks.

* P/B presentations and games to work.

* Someone gifts to families of intermedicinal students.

money goes to garden

* Coffee truck that works for longer hours.

* Make publicly accessible, and make this route an activity.

* Entire urban conservation around possible animals running on the road.

* More information and public awareness of BIG.

more languages

of species

description.

* low-barrier activity - outdoor cinema, readings, concerts, free entry, workspace, food facility ethics & connection to BIG.

Opportunities to connect to nature (interview w/ drake).

landscape information, Nature education - gardening.

Paper education of gardening. Organize series of

events w/ BIGs around Nr.



What is the urban biodiversity? What comes to your mind?

Urban biodiversity may consist of different kinds of animals, and various plants in the urban area. As our cities are dense and ~~filled with~~ covered by built environment, I think biodiversity mainly exists in the green and blue spaces of urban areas e.g. the parks, gardens, lakes, rivers.



BIODIVERSITY

(n.) The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part.

What is the added value of biodiversity for you? How does it affect your life?

What benefits comes to your mind? What changes does biodiversity make in your daily life?

Compared to specific "biodiverse" spaces like gardens and parks, the small grassland beside my home and the trees along ~~the~~ ^{highway} ~~road~~ have ~~added~~ added value for me. These things passively benefit me. I feel relaxed and enjoyable to see them and the season changes presented by them. They also ~~inspire~~ ^{be physically} somewhat drive me to ~~be~~ ^{more} active.

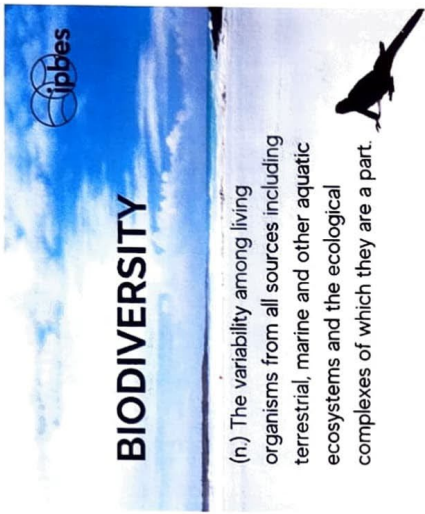
What facilities or solutions can help biodiversity in cities?

Family farms: In cities, people, especially those living in apartments and studios are hardly able to plant flowers or vegetables due to limited spaces. I noticed that in ~~some~~ ^{urban} urban regenerated areas of some cities like Vienna there are family farms around neighbourhood to allow the residents plant ^{their} and farm. These are also good for other species to find habitats.



What is the urban biodiversity? What comes to your mind?

- Maintained not "natural" vs wild nature
- Unique species that love a warmer, steeper environment
- Spatial issue → Nature/Green is always there but does not get enough space. A lot of paved infrastructure around in cities.
- Value issue → valued through ecosystem services such as climate adaptive capabilities, rarely for inherent value in policy (more so in living together / you might tell you they like the tree for being beautiful is already coming more in the direction of the inherent value) → not always valued enough.
- The base of all living things



BIODIVERSITY

(n) The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part.

What is the added value of biodiversity for you? How does it affect your life?

- Makes me feel connected
 - to others
 - to my soul
- Makes me inspired: willingness to live, to adapt, to exist and claim space
- Makes me rely bugs in the house
- Just beautiful to look at.

What benefits comes to your mind? What changes does biodiversity make in your daily life?

- to creativity
- to nature
- to the origins of life
- to balance with sunny skills in nature

What facilities or solutions can help biodiversity in cities?

- Height differences / vertical structures (teeth in soil) → planting interventions
 - Maintenance - introduction of (native) species, removal of invasive species with low impact tools, service
 - Doing things go sometimes → beware from over-plan things to see what occurs
 - Community "drag/drop" = support
- Question: how humans interact better with biodiversity? or for biodiversity itself

level question

What does it mean to you to have the Botanical Gardens at UU?



I have the best view when I am in the office.

It is good for my eye ~~sights~~sights. When I feel tired, looking at the garden is a relaxing way.

I've ~~ob~~ only visited the garden for 4/5 times for the past 3 years because I am not a big fan of plants. But I saw ~~many~~ some plants that are originated from my country, like some species of bamboo, that is quite exciting.

However, with such a ~~big~~ large area in the US, the accessibility is reduced. We may need to walk a longer distance from ~~one~~ one building to another.

What suggestions do you have for better experience at the Botanical gardens?

For example what facilities or structure can improve access to Botanical Gardens or write you ideas for better plants and animal care in the Botanical Gardens

A coffee truck ~~that~~ that works for a longer time.

More accesses for ~~to~~ UU staff may make it more accessible.

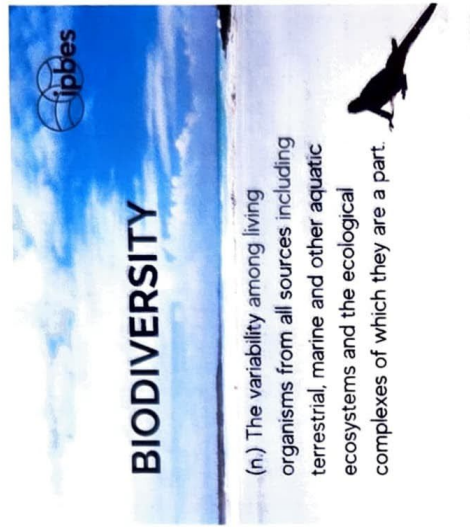
~~At~~ To protect animals, decrease the speed limit of the road beside, I saw some animals hit by high-speed cars. Maybe a sign to notice the drivers that animals are crossing by.

Date -- / -- / --

TOOL A.1.1 - What is urban biodiversity, and what it means for you?

What is the urban biodiversity? What comes to your mind?

Different living ^{creatures} ~~species~~ apart from human beings. Inhabitants such as sheep, cats, birds, dogs.
 Different plants such as flowers and trees. Environment.
 River and sea, forest as well.
 Different social groups. Inhabitants. Inhabitants in city. Environment.



What is the added value of biodiversity for you?

How does it affect your life?

- ① Inhabitants
 - respect life nature
 - disadvantages: mosquitoes, mice
 ② Environment
 - City is not just about built environment - high density?
 - nature is part of the city - health.

What benefits comes to your mind?
 What changes does biodiversity make in your daily life?

What facilities or solutions can help biodiversity in cities?

- ① small scale green space near office buildings
 ② animals protect laws - not killing street animals?
 ③ free tickets for citizens to enter parks.

What does it mean to you to have the Botanical Gardens at UU?



- Historical connection, for the setting but also the ex cultivated species - seedbank or old genetic modification
- Beautiful park to find still less in high-pressure environment
- Greenhouses are really special

What suggestions do you have for better experience at the Botanical gardens?

For example what facilities or structure can improve access to Botanical Gardens? or write you ideas for better plants and animal care in the Botanical Gardens

More visibility physical + online More information in general

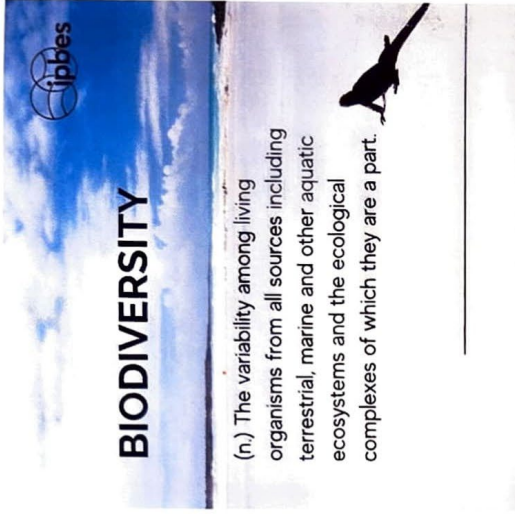
- Not only dutch / latin name of species, also background story of plant what makes the plant special - like in a museum *penningtoner vlogways*
- Organizing low barrier activities that draw in local people (students bring on USP) and people studying at working base, such as readings, low-key concerts outdoors, summer dream nights with longer opening hours / outdoor cinema *of nature movies / documentaries in a green house*
- Free entry
- A food facility with a mission, high quality -> attracting many people for that such as The Cold Kitchen in Amsterdam (local food) / Moestuin *for that*
- A connection to Amsterdam, physical or through stories told or Utrecht next to Amsterdam -> from our garden *Rijnwerf*
- Have trees as treated as persons getting to meet the tree -> gather historical stories of the what has street trees valued and collecting those into interview style meetings
- Have tiny nooks and "discovery paths" to get lost internal paths (without having people destroy nature by walking everywhere)
- Information on types of workscopes, why it is important to conserve them like that
- Have easy trained weekends -> nature education but also for youth: trainings in gardening and encourage people to work in nature. (A lot of gardens with Modern Mindset of conservation *isn't* based on ecological values instead of human-preferred ones) *let nature do the work, not too much intervention that obstructs ecological processes*
- Connection to other botanical gardens in NL -> organise events together in series

Date 15 / 11 / 24

TOOL A.1.1 - What is urban biodiversity, and what it means for you?



What is the urban biodiversity? What comes to your mind?



What is the added value of biodiversity for you?
How does it affect your life?

What benefits comes to your mind?
What changes does biodiversity make in your daily life?

What facilities or solutions can help biodiversity in cities?

with more green maintenance on natural spaces
Keep green spaces lush!

What does it mean to you to have the Botanical Gardens at UU?



Intellectually, it is refreshing and encourages my health, mental and physical

It, intellectually, reminds me of reoccurring times (like botanical studies). I also appreciate the steps for conservation as that is an important social issue to me.

I would like to have more sustainability and the Garden reminds of why in a very visual and comforting manner

What suggestions do you have for better experience at the Botanical gardens?

For example what facilities or structure can improve access to Botanical Gardens? or write you ideas for better plants and animal care in the Botanical Gardens

More workshops!

- Mushroom company workshops
- How to maintain an urban garden (balcony/kitchen)
- Talks about ongoing conservation projects @ the Botanical Garden & elsewhere (Community & wider/world)

↑
 Maybe more & drinks event, proceeds go to Butterfly alpine / Evolution & etc.
 ↑
 More direct connections to Community @ UU, Utrecht, UU

What does it mean to you to have the Botanical Gardens at UU?



- 1 social interactions with colleagues.
- 2 for short breaks - mental and physical health. a walk in the botanical gardens
- 3 butterfly room. temperature. have city

What suggestions do you have for better experience at the Botanical gardens?

For example what facilities or structure can improve access to Botanical Gardens? or write you ideas for better plants and animal care in the Botanical Gardens

- 1 some activities, workshops seminars, social activities.
- 2 exhibitions? to connect researchers with the public? volunteer work.
- 3 souvenirs



Place for spiritual fulfillment, cognitive development, reflection (1)

Results in (years): 0 5 10



Opportunity for more activities outdoors within nature

Results in (years): 0 5 10



Improvement in biodiversity and better habitats for plants and pollinators

Results in (years): 0 5 10




Improvements in plants and vegetations condition and diversity (2)

Results in (years): 0 5 10



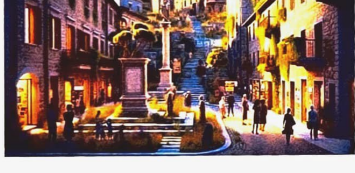
Opportunity for participation in local events and communities formation

Results in (years): 0 5 10




Decrease in airborne materials outdoor and indoor (e.g., sand, dust)

Results in (years): 0 5 10



Sense of connection with tradition and history (3)

Results in (years): 0 5 10




Improvement in biodiversity and better habitats for plants and pollinators

Results in (years): 0 5 10




Improvements in plants and vegetations condition and diversity

Results in (years): 0 5 10




More interaction between neighbors, local cohesion, and identity (4)

Results in (years): 0 5 10



Place for spiritual fulfillment, cognitive development, reflection

Results in (years): 0 5 10



Tranquility of place and less annoying noises

Results in (years): 0 5 10




Opportunity for participation in local events and communities formation (5)

Results in (years): 0 5 10



Fewer difficulties in movements in the neighbour (for pedestrians)

Results in (years): 0 5 10

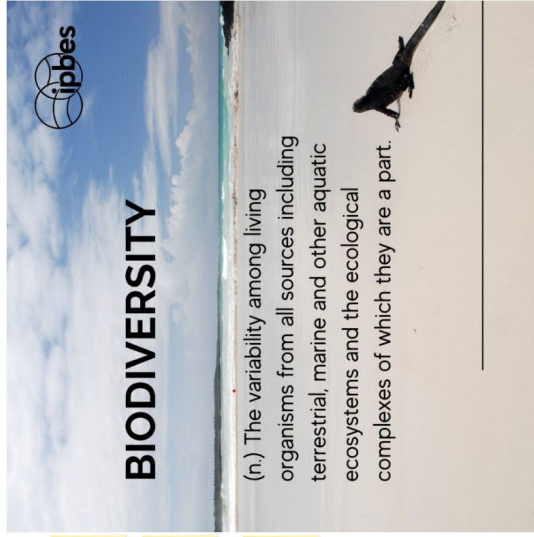
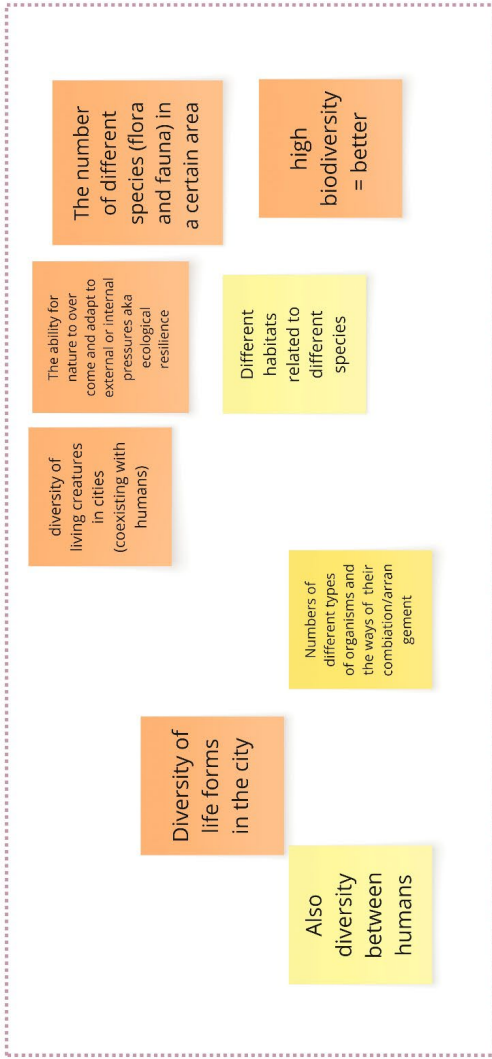


Reduction in depression and anxiety disorders

Results in (years): 0 5 10

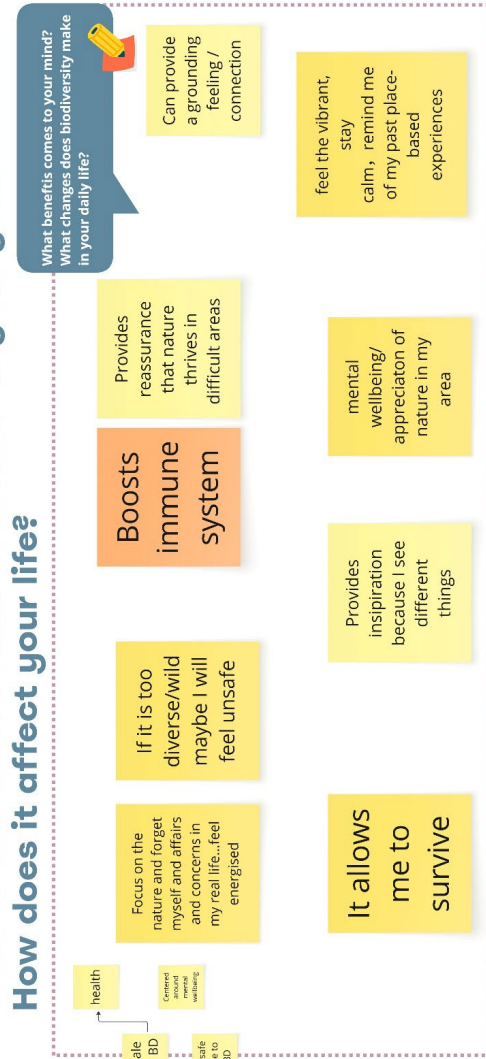


What is the urban biodiversity? What comes to your mind?



- Different perspectives on biodiversity
- Human-nature relations how it shapes BD
- Urban biodiversity and planners

What is the added value of biodiversity for you? How does it affect your life?



What facilities or solutions can biodiversity in cities?



Date -- / -- / --

TOOL A.2.1 – Biodiversity and Utrecht University Botanical Gardens

What does it mean to you to have the Botanical Gardens at UU?



What suggestions do you have for better experience at the Botanical gardens?



Date -- / -- / --

What benefits do Botanical Gardens bring in your life? [What you recognize as benefits?]


"Ecosystem services" are the range of services that natural systems generate for the benefit of humans. According to the definition proposed by the Millennium Ecosystem Assessment (MEA), ecosystem services are the "multiple benefits provided by ecosystems to humankind" (MEA, 2005).

Provisioning services: products that we obtain, e.g., timber.

Regulating services: maintain a condition such as air quality.

Cultural services: non-material benefits such as leisure time.

Group 1 top 5 selections

 <p>Place for spiritual fulfillment, cognitive development, reflection</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Cultural Code: 3.1.1.2</p> <p>Group: Group: Cultural Representative interaction with natural environment Class of Ecosystem Service: Class of Ecosystem Service: Cultural Example: Example: Cultural</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>
 <p>More sense of belonging and identity to the neighborhood</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Cultural Code: 3.1.1.4</p> <p>Group: Group: Cultural Representative interaction with natural environment Class of Ecosystem Service: Class of Ecosystem Service: Cultural Example: Example: Cultural</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>
 <p>Local source for nature-based products (commercial or non)</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Provisioning Code: 3.1.1.2</p> <p>Group: Group: Provisioning Class of Ecosystem Service: Class of Ecosystem Service: Provisioning Example: Example: Provisioning</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>
 <p>High willingness for participation in activities by residents</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Cultural Code: 3.1.1.2</p> <p>Group: Group: Cultural Representative interaction with natural environment Class of Ecosystem Service: Class of Ecosystem Service: Cultural Example: Example: Cultural</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>

Group 2 top 5 selections

 <p>More sense of belonging and identity to the neighborhood</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Cultural Code: 3.1.1.4</p> <p>Group: Group: Cultural Representative interaction with natural environment Class of Ecosystem Service: Class of Ecosystem Service: Cultural Example: Example: Cultural</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>
 <p>More interaction between neighbors, local cohesion and identity</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Cultural Code: 3.1.1.1</p> <p>Group: Group: Cultural Representative interaction with natural environment Class of Ecosystem Service: Class of Ecosystem Service: Cultural Example: Example: Cultural</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>
 <p>Reduction in depression and anxiety disorders</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Regulation & Maintenance Code: 2.2.2.2</p> <p>Group: Group: Regulation & Maintenance Class of Ecosystem Service: Class of Ecosystem Service: Regulation & Maintenance Example: Example: Regulation & Maintenance</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>
 <p>Local source for nature-based products (commercial or non)</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Provisioning Code: 3.1.1.2</p> <p>Group: Group: Provisioning Class of Ecosystem Service: Class of Ecosystem Service: Provisioning Example: Example: Provisioning</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>
 <p>Part-time job creation or leisure activity for residents nearby</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>	<p>Section: Provisioning Code: 3.1.1.1</p> <p>Group: Group: Provisioning Class of Ecosystem Service: Class of Ecosystem Service: Provisioning Example: Example: Provisioning</p> <p>Benefits to humans: 1 2 3 4 5 6 7 8 9 10</p>

Date -- / -- / --

What benefits do Botanical Gardens bring in your life?
 (What you recognize as benefits?)

"Ecosystem services" are the range of services that natural systems generate for the benefit of humans. According to the definition proposed by the Millennium Ecosystem Assessment (MEA), ecosystem services are the "multiple benefits provided by ecosystems to humankind" (MEA, 2005).

- Provisioning services: products that we obtain, e.g., timber.
- Regulating services: maintain a condition such as air quality.
- Cultural services: non-material benefits such as leisure time.

Group 1 top 5 selections



Increase in area covered by greenery and heat reduction
 Benefits to users: ●●●●●



Decrease in airborne materials outdoor and indoor (e.g., sand, dust)
 Benefits to users: ●●●●●



Opportunity for participation in local events and communities formation
 Benefits to users: ●●●●●



Reduction in depression and anxiety disorders
 Benefits to users: ●●●●●



Higher willingness for participation in outdoor activities by residents
 Benefits to users: ●●●●●

Group 2 top 5 selections

Section: Provisioning Code: 1.2.1.1
 Benefit: Provisioning of products (e.g., timber)
 Description: Provisioning of products (e.g., timber) from plants, fungi or fungi
 Example: Provisioning of products (e.g., timber) from plants, fungi or fungi
 Importance: ●●●●●

Section: Regulation & Maintenance Code: 2.2.1.4
 Benefit: Regulation of health, pest and extreme events
 Description: Regulation of health, pest and extreme events
 Example: Regulation of health, pest and extreme events
 Importance: ●●●●●

Section: Cultural Code: 3.1.2.1
 Benefit: Cultural and representative interactions with natural environment
 Description: Cultural and representative interactions with natural environment
 Example: Cultural and representative interactions with natural environment
 Importance: ●●●●●

Section: Regulation & Maintenance Code: 2.2.3.2
 Benefit: Pest and disease control
 Description: Pest and disease control
 Example: Pest and disease control
 Importance: ●●●●●

Section: Cultural Code: 3.1.1.2
 Benefit: Cultural and representative interactions with natural environment
 Description: Cultural and representative interactions with natural environment
 Example: Cultural and representative interactions with natural environment
 Importance: ●●●●●

What benefits do Botanical Gardens bring in your life? [What you recognize as benefits?]






"Ecosystem services" are the range of services that natural systems generate for the benefit of humans. According to the definition proposed by the Millennium Ecosystem Assessment (MEA), ecosystem services are the "multiple benefits provided by ecosystems to humankind" (MEA, 2005).

Provisioning services: products that we obtain, e.g., timber.

Regulating services: maintain a condition such as air quality.

Cultural services: non-material benefits such as leisure time.

Group 3 top 5 selections

 <p>Improvement in biodiversity and better habitats for plants and pollinators score: 100%</p>	<p>Section: Regulation & Maintenance Code: E.2.2.1 (Ecological maintenance, habitat and gene pool protection) Class of Ecosystem Service: Provision Example: Providing a habitat for native pollinators Importance: 0 1 2 3 4 5 6 7 8 9 10</p>
 <p>Increase in local revenue by production of food from gardens score: 100%</p>	<p>Section: Provisioning Code: E.1.1.1 Example: Cultivated terrestrial plants for nutrition, materials or energy Class of Ecosystem Service: Food and Agriculture Services Example: Production of food from gardens including high-yield plants for institutional programs Importance: 0 1 2 3 4 5 6 7 8 9 10</p>
 <p>Higher willingness for participation in outdoor activities by residents score: 100%</p>	<p>Section: Cultural Code: E.1.1.2 Example: Recreational and experiential interactions with natural environments Class of Ecosystem Service: Cultural Services Example: Opportunities of using systems that enable activities or experiences in natural environments or agricultural landscape Importance: 0 1 2 3 4 5 6 7 8 9 10</p>
 <p>Opportunity for participation in local events and communities through score: 100%</p>	<p>Section: Cultural Code: E.1.1.1 Example: Recreational and experiential interactions with natural environments Class of Ecosystem Service: Cultural Services Example: Opportunities of using systems that enable activities or experiences in natural environments or agricultural landscape Importance: 0 1 2 3 4 5 6 7 8 9 10</p>
 <p>Local source for nature-based products (compost or hay) score: 100%</p>	<p>Section: Provisioning Code: E.1.1.1 Example: Cultivated terrestrial plants for nutrition, materials or energy Class of Ecosystem Service: Food and Agriculture Services Example: Production of food from gardens including high-yield plants and biomass for direct use or processing including plants Importance: 0 1 2 3 4 5 6 7 8 9 10</p>

Group 4 top 5 selections

Supplementary Material 7 (Chapter 4)

Interviewee	Q1 Definition of UBD	Q2 Value of UB	Q3 Benefits of ES	Q4 Value of BG	Q5 BG Improvement
1	1. Animals, birds, and different lizard species (biodiversity is about animals and how they live)	1. Intrinsic value of nature and animals	1. Enjoying nature by being in the gardens and searching for plants and animals 2. Cultural value 3. Sighting animals 4. Relaxation and stress reduction 5. Cleanness of living spaces	1. Sighting rare animals in different varieties	1. Need more relaxing spaces and observation points 2. No other issues
2	1. Squirrels, trees, and birds, and in general, animals in different forms	1. Hearing different birds and seeing squirrels 2. Seeing habits of animals, how do they behave	1. Enjoying the greenery, trees and in general nature 2. Less pollution and better air 3. "It is quiet and nicer to walk by"	1. A place to relax (it's quieter than the city with more trees) 2. A clean space with good sight	1. Better to be closed to the public (entrance by fee) to keep the place less crowded, and it is a good idea that for UU-affiliated people, it is free 2. No other significant issue
3	1. Changes in nature over time 2. Different animals and how they are becoming less and less in the city 3. Rabbits, hares ("I like to see them	1. Changes in the neighborhood's face and appearance, and it is more lively 2. "Biodiversity	1. "Providing somewhere quiet and green to satisfy my needs" 2. Less pollution and noise, cleaner air	1. Clean, quiet, and less crowded space during work breaks to wander 2. Visit shows and be	1. Better to be closed to the public (having a fee) so people can value nature 2. Requires access from Venning building also

	and they mean biodiversity to me")	makes places more beautiful and people want to spend more time around those places"	3. Cleanness of space and gardens	in activities in the garden	
4	1. Plant species and flowers 2. Forests, herbs, and density of trees	1. Intrinsic value, specially plants (flora)	–	1. "Less chaotic space comparing to city helping me to relax"	1. "it is good that it is has paid entrance but in summer in can be open to public" 2. "It is very organized here"
5	1. "Besides plants and animals, creatures in soil are quite diverse"	1. "It has something like domino effect on human lives, if biodiversity declines we suffer"	1. Learning from nature and new ideas	1. "I come here during weekends for morning walks" 2. Learning more about rare species and plants that are not in the Netherlands	No issues
6	1. Biodiversity is in places where 2. Seeing butterflies in the city	1. Intrinsic value 2. Symbolic meaning for neighborhood	1. Temperature control 2. Noise cancellation 3. Learning 4. Observation	1. A cooler place during summer and the heat 2. Relaxing and being away from the stress of the streets 3. Learning from a nearly extinct plant	No issues

7	1. "Everything in nature is biodiversity for me"	1. Providing living space for humans	1. Nature observation 2. Temperature control 3. Promoting health	1. Bird watching	1."There is highway and soccer field noise needs to be managed" 2. In many areas there is wind making it less pleasant to visit
8	1. Different animals	1. "Biodiversity provides me something to take care of"	1. Mental health and well-being	1. "It helps me to avoid depressions"	No issues
9	1. Insects, ants, and small animals	1. Providing a food chain for living things 2. "It helps we have fewer heat islands"	1. Temperature control	1. A place to increase knowledge and become aware 2. Relaxing from life	No issues
10	1. Plants, grass, and flowers 2. Butterflies and insects	1. "Biodiversity increases the quality of space and helps me. I usually sit down and try to find butterflies"	1."To sit down and slow down for hours"	1. As a different workplace	No issues
11	1. Natural areas, especially woodlands 2. Any greenery and wild area outside of the city 3. Different colors and sizes of plants	1. Making cities more resilient to climate change 2. Better quality of natural products	1. Economical values from natural products 2. Agriculture in the city	1. Education 2. Recreation and relaxation 3. Conservation of nature and species	1. Issues in wheelchair accessibility

	4. Animals differ from each other				
12	1. Species richness 2."Biodiversity is much less in complex spaces like Science Park"	1. Interconnected cascade effects on human lives in all aspects of human life	1. Health and well-being 2. Enjoyment and observation 3. Fewer diseases and pests	1. Taking a break 2. Relaxing 3. Nature in the vicinity of work place	1. Need for improvement in wheelchair accessibility 2. There is only 1 main entrance which is not enough

Supplementary Material 8 (Chapter 5)

SMG Step I

Table	ID	Indicator	Weight	Absolute
1	S1	Number of park visitors in different age groups	6.3%	1.0%
2	S2	Number of sociocultural activities/gatherings held in SMG	12.2%	7.1%
3	S3	Perception of SMG functionality	15.9%	14.6%
4	S4	Local sense of belonging regarding SMG	20.9%	11.4%
5	E1	Perception of greenery (perceived flora/fauna richness)	6.8%	3.0%
6	E2	Level of green coverage and seasonal stability	5.7%	0.8%
7	E3	Pollinators' abundance	14.4%	9.7%
8	E4	Temperature and heat level within SMG	17.9%	8.6%

Result	Eigenvalue	Lambda:	8.924	MRE:	54.8%
	Consistency Ratio	0.37	GCI: 0.33	CR:	9.4%

Social-ecological indicators pairing

	S1	S2	S3	S4	E1	E2	E3	E4	Normalized principal Eigenvector
S1	1	1/2	1/2	1/3	1	1	1/2	1/2	6.26%
S2	2	1	2	1/3	2	2	1	1/3	12.19%
S3	2	1/2	1	1/3	1	2	2	3	15.91%
S4	3	3	3	1	3	3	1/2	1	20.90%
E1	1	1/2	1	1/3	1	1	1/2	1/3	6.82%
E2	1	1/2	1/2	1/3	1	1	1/3	1/3	5.66%
E3	2	1	1/2	2	2	3	1	1/2	14.39%
E4	2	3	1/3	1	3	3	2	1	17.86%

	S1	S2	S3	S4	E1	E2	E3	E4
S1	1	1/2	1/2	1/3	1	1	1/2	1/2
S2	2	1	2	1/3	2	2	1	1/3
S3	2	1/2	1	1/3	1	2	2	3
S4	3	3	3	1	3	3	1/2	1
E1	1	1/2	1	1/3	1	1	1/2	1/3
E2	1	1/2	1/2	1/3	1	1	1/3	1/3
E3	2	1	1/2	2	2	3	1	1/2
E4	2	3	1/3	1	3	3	2	1

SMG Step 2

Dimension	Criteria Included	Final Weight
NN (Nature/Nature)	E1+E2+E3+E4	57.00%
NC (Nature/Culture)	S2+S4	23.70%
NS (Nature/Society)	S1+S3	27.60%

SMG Step 3

Future ID	Type	NN Score	NC Score	NS Score	
PF1	Plausible	3	8	10	
PF2	Plausible	9	5	2	
PF3	Plausible	8	9	4	Optimal Future
PF4	Plausible	5	6	6	Dominated
PF5	Plausible	8	4	7	Dominated by SF
DF	Desired	5	8	7	Desired future
SF	Strategic	8	6	8	Strategic future

PF1 (3,8,10)	$(3 \times 0.448) + (8 \times 0.331) + (10 \times 0.222)$	5th	6.21
PF2 (9,5,2)	$(9 \times 0.448) + (5 \times 0.331) + (2 \times 0.222)$	6th	6.13
PF3 (8,9,4)	$(8 \times 0.448) + (9 \times 0.331) + (4 \times 0.222)$	1st	7.45
PF4 (5,6,6)	$(5 \times 0.448) + (6 \times 0.331) + (6 \times 0.222)$	7th	5.56
PF5 (8,4,7)	$(8 \times 0.448) + (4 \times 0.331) + (7 \times 0.222)$	3rd	6.46
DF (5,8,7)	$(5 \times 0.448) + (8 \times 0.331) + (7 \times 0.222)$	4th	6.44
SF (8,6,8)	$(8 \times 0.448) + (6 \times 0.331) + (8 \times 0.222)$	2nd	7.35

(Challenger)-
(Contender)

PF1 (3,8,10)	PF2 (9,5,2)	PF3 (8,9,4)	PF4 (5,6,6)	PF5 (8,4,7)	DF (5,8,7)	SF (8,6,8)
N/A	(+6, -3, -8)	(+5, +1, -6)	(+2, -2, -4)	(+5, -4, -3)	(+2, 0, -3)	(+5, -2, -2)
(-6, +3, +8)	N/A	(-1, +4, +2)	(-4, +1, +4)	(-1, -1, +5)	(-4, +3, +5)	(-1, +1, +6)
(-5, -1, +6)	(+1, -4, -2)	N/A	(-3, -3, +2)	(0, -5, +3)	(-3, -1, +3)	(0, -3, +4)

(-2, +2, +4)	(+4, -1, -4)	(+3, +3, -2)	N/A	(+3, -2, +1)	(0, +2, +2)	(+3, 0, +2)
(-5, +4, +3)	(+1, +1, -5)	(0, +5, -3)	(-3, +2, -1)	N/A	(-3, +4, 0)	(0, +2, +1)
(-2, 0, +3)	(+4, -3, -5)	(+3, +1, -3)	(0, -2, -1)	(+3, -4, 0)	N/A	(+3, -2, +1)
(+5, +2, +2)	(-1, -1, -6)	(0, +3, -4)	(-3, 0, -2)	(0, -2, -1)	(-3, +2, -1)	N/A

UUBG Step I

Table	ID	Indicator	Weight	Absolute
1	S1	Number of park visitors in different age groups	8.3%	3.2%
2	S2	Number of sociocultural activities/gatherings held in UUBG	8.2%	5.5%
3	S3	Perception of UUBG functionality	11.1%	5.1%
4	S4	Local sense of belonging regarding UUBG	15.5%	3.7%
5	E1	Perception of greenery (perceived flora/fauna richness)	11.4%	6.5%
6	E2	Level of green coverage and seasonal stability	6.7%	1.1%
7	E3	Pollinators' abundance	25.9%	5.8%
8	E4	Temperature and heat level within UUBG	13.0%	4.7%

Result	Eigenvalue	8.565			MRE: 41.9%
	Consistency Ratio	0.37	GCI: 0.21	CR: 5.8%	

Social-ecological indicators pairing

	S1	S2	S3	S4	E1	E2	E3	E4
S1	1	2	1	1/2	1/2	1	1/3	1/2
S2	1/2	1	1/2	1/2	2	1	1/3	1/2
S3	1	2	1	1/2	2	2	1/3	1/2
S4	2	2	2	1	2	2	1/2	1
E1	2	1/2	1/2	1/2	1	2	1/2	2
E2	1	1	1/2	1/2	1/2	1	1/3	1/2
E3	3	3	3	2	2	3	1	3
E4	2	2	2	1	1/2	2	1/3	1

Normalized principal Eigenvector

8.29%
8.20%
11.07%
15.50%
11.40%
6.69%
25.85%
13.00%

	S1	S2	S3	S4	E1	E2	E3	E4
S1	1	2	1	1/2	1/2	1	1/3	1/2
S2	1/2	1	1/2	1/2	2	1	1/3	1/2
S3	1	2	1	1/2	2	2	1/3	1/2
S4	2	2	2	1	2	2	1/2	1
E1	2	1/2	1/2	1/2	1	2	1/2	2
E2	1	1	1/2	1/2	1/2	1	1/3	1/2

E3	3	3	3	2	2	3	1	3
E4	2	2	2	1	1/2	2	1/3	1

UUBG Step 2

Dimension	Criteria Included	Final Weight
NN (Nature/Nature)	E1+E2+E3+E4	44.80%
NC (Nature/Culture)	S2+S4	33.10%
NS (Nature/Society)	S1+S3	22.20%

UUBG Step 3

Future ID	Type	NN Score	NC Score	NS Score	
UPF1	Plausible	6	5	8	
UPF2	Plausible	7	6	6	
UPF3	Plausible	4	6	5	Dominated UPF2
UPF4	Plausible	10	6	4	Optimal future
UPF5	Plausible	8	4	7	
DF	Desired	8	7	5	Desired future
SF	Strategic	9	5	6	Strategic future

Future ID	UPF ID	Score Calculation	Rank	Weighted Score
UPF1 (6,5,8)	UPF1	$(6 \times 0.448) + (5 \times 0.331) + (8 \times 0.222)$	6th	6.12
UPF2 (7,6,6)	UPF2	$(7 \times 0.448) + (6 \times 0.331) + (6 \times 0.222)$	5th	6.45
UPF3 (4,6,5)	UPF3	$(4 \times 0.448) + (6 \times 0.331) + (5 \times 0.222)$	7th	4.89
UPF4 (10,6,4)	UPF4	$(10 \times 0.448) + (6 \times 0.331) + (4 \times 0.222)$	1st	7.35
UPF5 (8,4,7)	UPF5	$(8 \times 0.448) + (4 \times 0.331) + (7 \times 0.222)$	4th	6.46
DF (8,7,5)	DF	$(8 \times 0.448) + (7 \times 0.331) + (5 \times 0.222)$	3rd	7.01
SF (9,5,6)	SF	$(9 \times 0.448) + (5 \times 0.331) + (6 \times 0.222)$	2nd	7.02

(Challenger)-(Contender)

UPF1 (6,5,8)	UPF2 (7,6,6)	UPF3 (4,6,5)	UPF4 (10,6,4)	UPF5 (8,4,7)	DF (8,7,5)	SF (9,5,6)
N/A	(+1,+1,-2)	(-2,+1,-3)	(+4,+1,-4)	(+2,-1,-1)	(+2,+2,-3)	(+3,0,-2)
(-1,-1,+2)	N/A	(-3,0,-1)	(+3,0,-2)	(+1,-2,+1)	(+1,+1,-1)	(+2,-1,0)
(+2,-1,+3)	(+3,0,+1)	N/A	(+6,0,-1)	(+4,-2,+2)	(+4,+1,0)	(+5,-1,+1)
(-4,-1,+4)	(-3,0,+2)	(-6,0,+1)	N/A	(-2,-2,+3)	(-2,+1,+1)	(-1,-1,+2)
(-2,+1,+1)	(-1,+2,-1)	(-4,+2,-2)	(+2,+2,-3)	N/A	(0,+3,-2)	(+1,+1,-1)
(-2,-2,+3)	(-1,-1,+1)	(-4,-1,0)	(+2,-1,-1)	(0,-3,+2)	N/A	(+1,-2,+1)
(-3,0,+2)	(-2,-1,+0)	(-5,-1,+1)	(+1,+1,-2)	(-1,-1,+1)	(-1,-2,+1)	N/A

Supplementary Material 9 (Chapter 6)

Details on the Dynamic Adaptive Policy Pathways (DAPP) framework and Results on uncertainties, vulnerabilities, opportunities, and disagreements in the context of the Sorelle Mirabal Garden (SMG).

I. Conceptual Framework

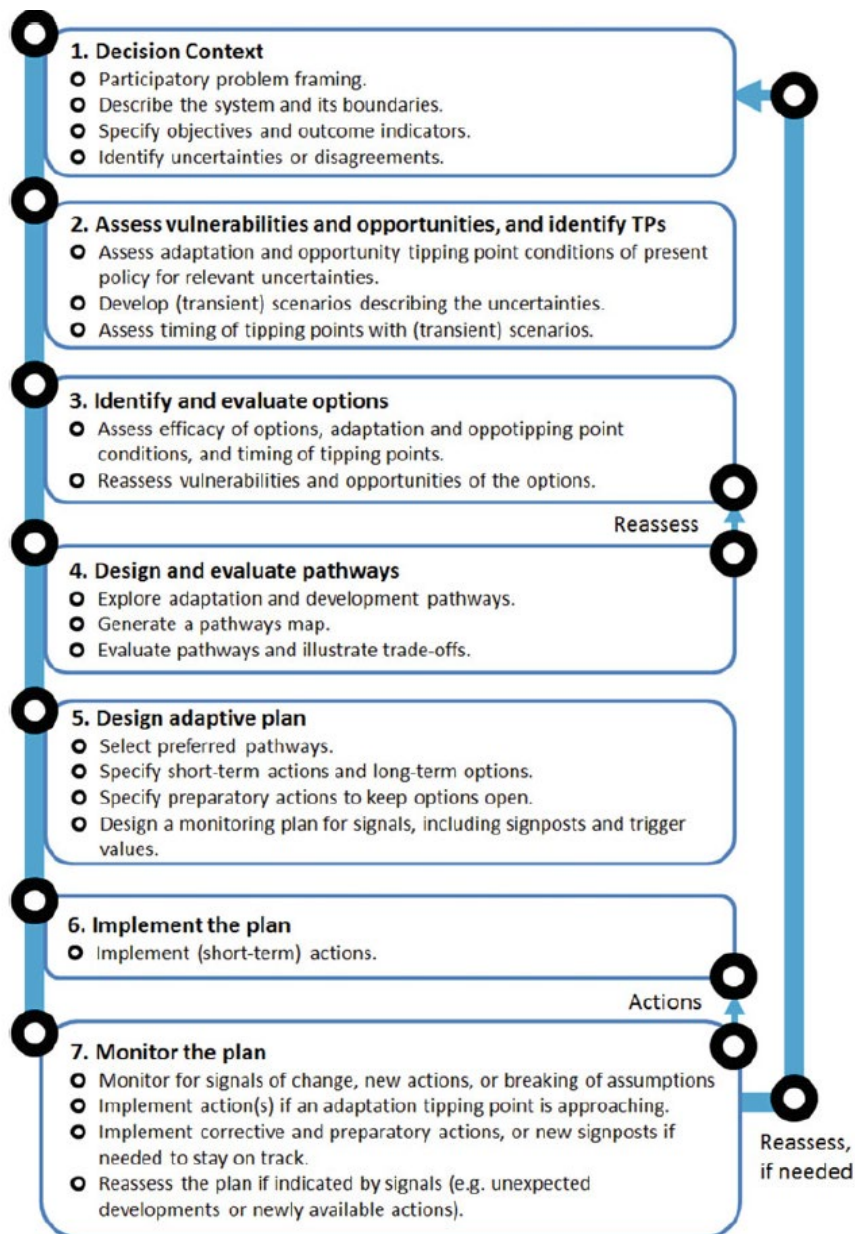


Figure 1: Process of DAPP approach. Reproduced from Haasnoot et al. (2019).

Figure 1 presents a step-by-step process of implementing the DAPP framework in the context of SMG. In this study, all steps are followed except 6 and 7, as the case study is a public Garden aimed at reopening, and due to limitations in experiments and analysis, steps regarding implementation and monitoring are not followed.

2. Results

This section presents uncertainties, vulnerabilities, opportunities, and disagreements in the context of SMG discovered and elaborated through co-creation sessions in relation to section 4.1. Evaluation of the case study.

To achieve the objectives, several uncertainties and disagreements exist. Ecological uncertainties, such as biodiversity status and temporal stability (especially faunal diversity), changes in the presence of invasive species (especially flora), and pest control at SMG, are reflected by participants and experts. Additionally, one of the main concerns is meeting the baseline expectations set by the neighborhood's plan (set by the local municipality), which, due to the temporary closure of Garden and the lack of coordination among stakeholders, is uncertain. On the social side, uncertainties are focused on social use and levels of engagement with the Garden. In this case, experts were mainly concerned with how perceptions of the place after reopening shape social use and whether certain activities (such as learning) are dominated by social use, which could be harmful to the ecological dimension. In this case, social use and engagement with the park are mainly affected by newly imposed policies and interventions, and it is uncertain if the Garden becomes a monofunctional place or is misused (for instance, vandalized over time). Additionally, as there is an imposed restriction on dogs' entry to the park and the dog area is separated from the Garden, a perceived disagreement between daily users and the Garden's administration is evident, which impacts the multifunctionality objective. In a broader perspective for the future, SMG also addresses the impacts of climate change and high summer heat on plants, informal use of the Garden for restricted social activities, and possible conflicts among management actors.

In light of the SMG objective, the area faces vulnerabilities and opportunities, as identified through the co-creation process. Vulnerability concerns are mainly about the risk in pest density increase, especially flies, mosquitoes, and flora pests, a decrease in safety during nighttime due to the density of vegetation (at the side facing the street), misuse of Garden furniture and spaces, vandalism (both installed sensors and furniture), and greenery destruction, and unwanted encounters with wild species with sanitary concerns. Furthermore, the use of the Garden for walking pets (especially dogs) and interference with local wildlife, despite the restrictive policies, remains a concern for experts and administration. Additionally, there is an overarching vulnerability regarding the planned biodiverse area of the Garden's decay. As there are fenced, inaccessible, biodiverse areas planned (Morello et al., 2024). It might be vulnerable to extreme heat, invasive species, user interference or misuse, and the permeability of the protected space and public perception of greenery. Regarding opportunities, SMG has the capacity to serve as a local refuge for local species and pollinators and, simultaneously, as a social and cultural gathering center for locals, with controlled temperatures during hot seasons.

Supplementary Material 10 (Chapter 6)

List of elaborated details for context evaluation within the DAPP framework and Pathways evaluations with a complete list of pathways

Step 1	Parts	Details	Descriptions	Data from/by
	Describing the system	System characteristics	Mirabal garden, east of Milano, the Ortica-Lambrate area, and the surrounding neighborhoods. The park is in the north, and the south is limited to the elderly houses; the west is limited to railways (with scheduled train passage); and the east is limited via San Faustino. Next to via San Faustino, there are development areas for housing and recent interventions with tactical interventions. The park was previously closed and is being reopened to the public. South of the park, there is a dog area and a planned children's playground that citizens informally use.	Expert, Municipality, citizens
	Objective and outcome indicators	Objectives	Main: Multispecies and multifunctional garden for all actors with preservation and promotion of biodiversity Sub: Respect and enjoyment for citizens. Creating a sense of belonging to the garden. United approaches and find ways to achieve comprehensive involvement.	Citizens, experts, Municipality, Cascina, RFI

		<p>Outcome indicators</p> <p>The ecological indicators are primarily quantitative biodiversity sustainability indicators (1. amount pollinators per day, 2. air quality in the neighbor, 3. amount of tree canopy coverage at SMG, 4. temperature at SMG) which are measured by the installed indicators at SMG or through remote sensing information on daily (for local sensors) and monthly (for remote sensing) basis and changes over time (yearly basis) indicate improvement or decline in biodiversity status. Additionally, four qualitative indicators of 5. amount animal observations SMG area, 6. local perception on greenery coverage, 7. perceived plant richness at SMG, and 8. plants' seasonal stability are established. These indicators are measured through anonymous online reports from citizens or by expert observations on a bimonthly basis. Qualitative indicators provide an opportunity to directly incorporate locals' opinions into decision-making over time and enrich calculations by integrating local perceptions into measurements. The social indicators are focused on public opinion, which are 9. perception of park multifunctionality (increase in visitors, diversity in age and activities), 10. perception and awareness of SMG functions (number of events and gatherings and their type) 11.</p>	<p>Experts, Citizens, Municipality</p>
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			<p>Sense of belonging (local awareness of activities at SMG, changes in social gathering patterns, or social use). Information on social indicators is collected through a publicly accessible online questionnaire and interviews conducted at SMG with users on a bimonthly basis.</p>	
	Participatory problem framing	Constraints in the current situation	<p>1. Biodiversity instability 2. Public engagement and participation levels 3. Noise and limits by railway 4. Political resistance</p>	Experts, Municipality, Cascina
		Potential constraints in the future	<p>1. Climate change and natural decline 2. Informal use and interruptions 3. Engagement, use, and awareness 4. Funding and conflict of interest</p>	Experts
	Uncertainties	Uncertainties	<p>1. Biodiversity status 2. Usage levels and patterns (I. Level of actors and stakeholders' engagement through time II. Municipal plan for the development of the park and surroundings, and conflict with RFI) 3. Spaces functionality, especially at the south of the park for reserved areas, use of fences 4. Perceptions and values 5. Multifunctionality of the park</p>	Experts, citizens
		Disagreements	<p>1. Usage of space for dedicated areas by visitors 2. Stakeholders conflicts</p>	Municipality, expert, citizen

	Initial scenarios	Scenarios and type	1. NN: Dedicated preservation of nature and biodiversity, limited use of public spaces with public awareness about natural values and mutual respect for nature 2. NC: Moderate local activities and gatherings in the park with preservation of biodiverse area, controlled use of space, and increased awareness about local values 3. NS: Increase formal and informal usage of the park by actors and stakeholders, limited preservation of biodiversity, increased perception about the utility value of nature, and an increased number of visits	Experts, citizens
		Success	Trifold success status	Expert
Step 2	Identifying under which situation scenarios start to act unacceptably (ATP)		We use the bottom-up approach to identify ATPs, which means first we consider the threshold and then the timing	
	Assess TPs with uncertainties	Adaptation tipping points	<p>NN: ATP1: Biodiversity decay (Quantitative: green coverage decrease. Qualitative: Perception and observation decrease).</p> <p>ATP2: Increased use of space and breaching the biodiversity area</p> <p>NC: ATP1: Biodiversity decay (same as NN with lower threshold over time)</p> <p>ATP2: Shifting Identity of Park in perceptions (outward NS, NN) (ES can be sued)</p> <p>ATP3: Monodimensionality or lack of usage.</p> <p>NS: ATP1: Biodiversity collapse</p>	Expert (based on the input of citizens and the municipality)

			(below the lowest threshold or perceptions). ATP2: Management and maintenance failure ATP3: Lower perception of ES functionality	
		Opportunity tipping points	NN: OTP1: Connecting corridor with botanical gardens in the west NC: OTP1: Enforcing local policy as the ark functions as the center of the neighborhood NS: OTP1: Local developments and higher function of regulating ES OTP2: Higher budget allocation	Expert
	Developing transient scenarios	Scenarios and uncertainty	S1: NN: 2 ATPs: 2: Focus on preserving the biodiversity with limited social use and respect to cultural and intrinsic values S2: NC: 3 ATPs: 3: balanced development with normal use of the park and social activities in respect to defined biodiversity areas S3: NS: 3 ATPs: 3: use of the park for social and individual activities, focusing on social values and minimal biodiversity preservation.	Expert
	Timing of TPs	Timing of TPs for scenarios	See the tables	Expert

Timeline 2025-2030-2040-2050 5 years interval

Biodiverse park	No BD change	Negative BD	Positive BD
NN	2045	2035	>2050
NC	2040	2035	>2050
NS	2040	2030	>2050

AND condition

Timeline 2025-2030-2040-2050 5 years interval

Multifunctional park	No use change	Negative use	Positive use
NN	2045	2040	2045
NC	>2050	2040	>2050
NS	>2050	2045	>2050

Biodiverse park	No BD change	Negative BD	Positive BD	No use change	Negative use	Positive use
NN	2045	2035	>2050	2045	2040	2045
NC	2040	2035	>2050	>2050	2040	>2050
NS	2040	2030	>2050	>2050	2045	>2050

Horizons:

H1: 2025-2030 (5 years)

H2: 2030 - 2040 (15 years)

H3: 2040 - 2050 (25 years)

	Overlapping ATPs so instead of 12 total, we have 11
	No connection needed
	Fail, no connection afterwards
	Connected (combinations)
	Connected sequence

Research paper

Co-creation for Urban Biodiversity:

The experience of a public participation process in a living lab in Milan, Italy

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Abstract

This contribution investigates the fine line between engaging citizens on topics related to urban biodiversity and experimenting with co-creation processes in a real living lab setting in Milan, Italy. The participatory process established within the “Laboratorio per la Biodiversità Urbana” (LABU) provided an opportunity to test a novel co-creation methodology, supported by the local municipality’s commitment to redesign an area characterized by high urban biodiversity, the Sorelle Mirabal Garden, in the eastern part of the city, currently closed to the public. The process draws on the understanding of the often-invisible relationships between humans and nature embedded in the collective memory of the Garden, aiming to reactivate it as a public space. Testing co-creation methods for enhancing urban biodiversity in a living lab setting has led to significant participant engagement and awareness, fostering recognition of the importance of more-than-human species. It has also enabled the collaborative definition of design solutions that promote inclusivity across different social groups. The measures proposed benefited from the experts’ input and the local knowledge provided by citizens. Moreover, the urban living lab approach revealed to be an appropriate environment for managing frictions that originate when jointly addressing the needs of different human and non-human communities within emerging concurrent solutions in the use of space.

Keywords

Urban biodiversity, co-creation, urban regeneration, urban greening, more-than-human, urban planning

Introduction: Co-creation for supporting biodiversity in cities

Over the past two decades, awareness has steadily increased across various levels of society about the important role of nature in tackling the environmental and social challenges faced by cities. Urban biodiversity (UB) —defined as the genetic, species and ecosystem diversity found in urban environments— has become a key focus for urban research and city planning agendas (Secretariat of the Convention on Biological Diversity, 2012; European Commission, 2021; Chan et al., 2021). Despite its multiple benefits provided to inhabitants at individual and community levels (Nilon et al., 2017b), the integration of biodiversity in cities faces numerous challenges, particularly in public spaces, where the co-existence of human life and nature

demands a shift in societal attitudes. One of the challenges is the social acceptance of nature and wilderness within cities. Individual and social perceptions of biodiversity integration in cities is shaped not only by aesthetic preferences but also by a number of eco-system disservices that animal and plant lives in proximity to human life can generate (e.g., diseases, allergies, physical accidents, maintenance costs, diminished sense of control of spaces, psychological resistances related to the fear of the unknown). In addition, urban biodiversity is not considered a priority on the value scale when deciding how to allocate the budget for urban interventions (Bulkeley et al., 2022; Oke et al., 2021). This significantly limits political commitment and public action. All this often results in forms of resistance by citizens to initiatives aimed at preserving and increasing urban biodiversity. Indeed, implementing biodiversity interventions in cities requires significant resources and will to understand citizens' preferences regarding how they interpret and value urban biodiversity (Schneider et al., 2024). In this vein, several authors (McDonnell, 2007; Cilliers, 2010; Varumo et al., 2022) have highlighted the need to align the cultural and social values of biodiversity with the ecological and economic ones as a way to foster social acceptance and prevent the tensions that often arise from biodiversity initiatives. Varumo et al. (2022) pointed out that, in order to achieve socio-political acceptance, biodiversity initiatives must acknowledge the existing societal norms and values and reconcile the contradictions between the various objectives and interpretations that individuals or groups may assign to biodiversity.

Since few years, the themes of co-creation and public participation oriented towards strengthening natural capital preservation became hot topics in the domain of citizen engagement and local governance (Røiseland et al., 2024), often occurring through an urban living lab setting. As co-creation has been recently used for promoting urban greening and more recently Nature-Based Solutions (NBS), several projects funded by the Horizon 2020 and Horizon Europe research programs showcase on the successes and challenges through which a public participation process go through to create awareness about nature benefits and co-benefits in the urban environment (European Commission, 2023). In this context, the National Biodiversity Future Center (NBFC)⁷ initiated a research stream called "Laboratorio per la Biodiversità Urbana" (LABU), which aims to establish a co-creation guidance and ad hoc methodology specifically designed to preserve and enhance urban biodiversity, ultimately striving to research, raise awareness, and achieve a positive impact on nature.

On the one hand, the people's engagement in longer-term urban regeneration processes that include nature and biodiversity aspects generally generate a positive impact on the sense of belonging and increase of attachment to place-based contexts, for instance through urban living labs settings (Nesti, 2018; Xie & Bulkeley, 2020). On the other hand, engagement processes are needed to maintain and support nature itself to thrive in these local contexts and consequently address challenges of climate change and adaptive planning (Galan et al., 2023). Similar co-creation experiences with nature and for nature have highlighted the importance of including local communities and mobilizing place-based knowledge in the process through which ecological restoration is pursued and a wider range of species could be protected (Pineda-Pinto et al., 2024). Such approach should be supported by an adaptive, resilient and novel design process that could be developed and implemented through experimentation and deeply altered by the structure of the shared information flows between locals and municipal authorities (Abson et al., 2017).

In this article, we explore the experimentation with urban biodiversity in a real living lab setting in Milan, Italy, through the testing of a novel co-creation methodology with the commitment of the local municipality to re-design an area characterized by high urban biodiversity, the Sorelle Mirabal garden located in the neighborhood of Ortica, in the eastern part of the city. Building on several experiences of co-creation practices showcase that this approach requires a paradigm shift when it comes to work with urban nature and nature-based solutions (NBS), as living systems require time and space to thrive. We build on the understanding of the invisible relationships humans and nature have in the collective memory of the Sorelle Mirabal Garden, to reactivate a public garden and currently closed to the public, together with local authorities and community.

This research paper is divided into six sections. After the introduction, the methodological section underpins the approach through which the scientific framework was implemented, and different workshops were held to converge on one design scenario as generated by the living lab participants. Followingly, the case study section showcases the different tools that were explored during the implementation of the process towards reaching a shared consensus for the designed plan. The final

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NBFC (2022-25) is a research initiative funded by the National Recovery and Resilience Plan as part of the NextGenerationEU program dedicated to the topic of biodiversity conservation, monitoring, and enhancement in the Mediterranean context.

sections present the discussion and conclusions drawn from this experience, as well as prospects for replicating the envisioned co-creation process in other urban biodiversity living labs.

Methodology: Scientific framework for co-creation for nature and with nature

In this research, a newly established scientific framework for the co-creation process focusing on the themes of urban biodiversity and to be applied in a living lab setting was established. The pathway is divided into three main phases: (1) co-creation planning, (2) co-designing with stakeholders, and (3) co-implementation with citizens and local associations. During the co-creation planning phase (see figure 1) two meetings were held with the municipality officials and responsible associations that helped shape the direction of the co-designing process and its expected outcomes. A simulation of a theory of change on a vision, mission and objectives of the process was carried out with the local co-creation team and several stakeholders, followed by a public event that opened the co-creation process to the public. It is worth noting that the co-monitoring phase is developed in parallel with co-design and co-implementation phases. This parallelization has the potential to better inform the decision-making process when it comes to the specific design solutions that could be developed in place within the living labs. The last phase of the co-creation process focuses on mainstreaming the solutions with local communities, as well as replicating the experience and establishing new living labs around the city or beyond.

In this framework, there is a focus on developing new methods and tools for engaging citizens in the co-design process on the longer term, such as: role playing technique in which citizens empathize with the animal and plant species that inhabit the park for developing awareness on the biodiversity present in the park, and a collaborative workshop for identifying the NBS and design elements to be implemented in the garden. These different methods were established in a guidance document that encompasses also tools such as cards, boards and design charrettes on how to be used and samples for printing.

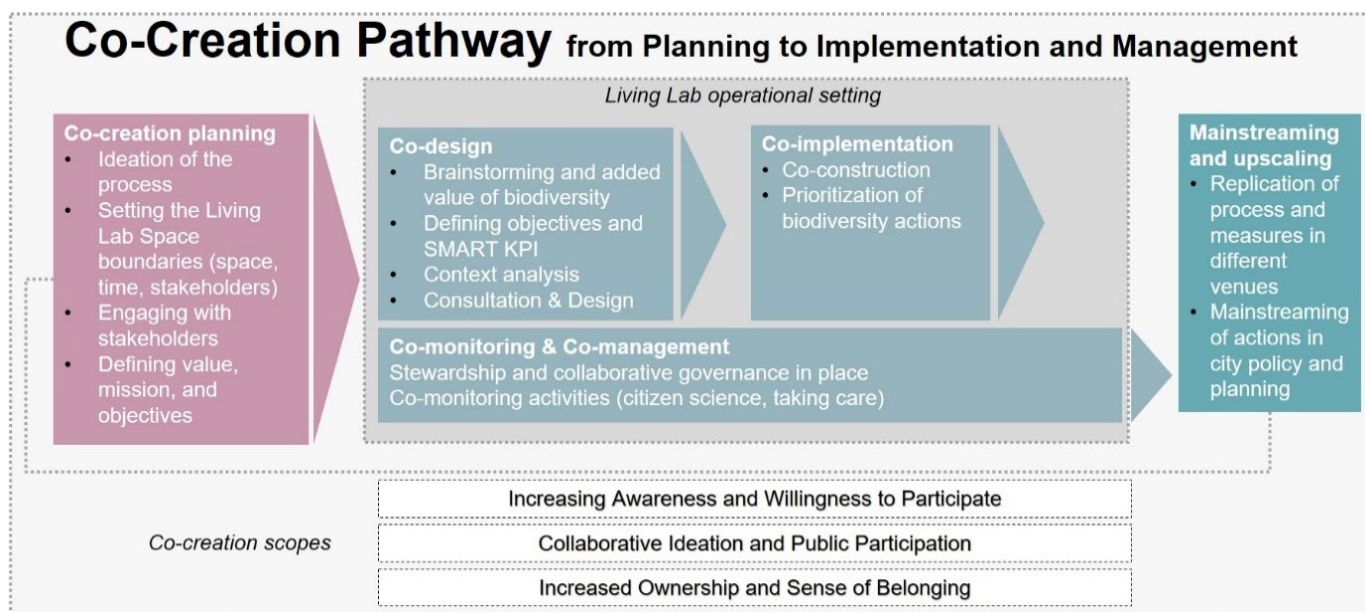


Figure 1. The Co-Creation Pathway organized in four main phases and in a living lab setting, with particular attention to the expected results and scope of the process. Source: the authors.

Regarding Ecosystem Services (ES) cards, a systematic literature review and experts’ opinions (using deductive coding) guided the selection of 28 benefits, distributed into three ES categories: provisional, regulating, and cultural. In this step, the emphasis was on the selection of targets’ benefits that appear less frequently in public perception. This approach helps to present a comprehensive variety of benefits to participants. A guiding table accompanies all selected benefits, containing the ES class, code, examples of benefits, and the general category.

The Application: a living lab for urban biodiversity in Milan

In the first phase of co-creation planning, the municipality of Milan has signed a collaboration agreement with the Politecnico di Milano for co-designing with citizens the Sorelle Mirabal Garden in May 2023, a recently acquired space that was

temporarily open for a short period of time more than a year ago and now seeks for a new identity. In this agreement, two different research groups from urban planning and ecology disciplines engage on designing a co-creation plan for involving citizens and local associations in the redesigning of the garden in a way that preserves its past identity, while leveraging urban biodiversity. The project was launched in the beginning of May 2024 and during May and June, three workshops were organized, see figure 2. The different workshops were then followed by a public presentation during the Milano Green Week, an annual event in town dedicated to promoting environmental sustainability, in September 2024 that has put together experts and citizens on the convergence on one desirable designed scenario and permitted a collection of feedback on the criticalities of the park design.



Figure 2. The co-creation pathway articulated in four workshops with citizens, experts and stakeholders. Source: the authors.

LABU Co-design Lab#1 focused on establishing a primary definition of urban biodiversity and its benefits, with particular emphasis on the social values provided by nature. To capture social values connected to nature and urban biodiversity, we used ecosystem services to identify benefits. Ecosystem Services (ES) are benefits people obtain through ecosystems and natural processes that contribute directly or indirectly to sustaining their health and well-being (Daily, 1997; Lique et al., 2016). Through our review of literature based on each class of ES established by The Common International Classification of Ecosystem Services (CICES)(Haines-Young & Potschin-Young, 2018), we identified a series of values, benefits, and impacts of ES in urban areas that are related to urban biodiversity. Each associated a class of ES (provisional, regulation, and cultural). In the first session, after defining a basic definition of ES to participants, identified values were presented to participants in a set of 28 cards. The cards, divided by color into 3 ES categories, present a simplified benefit or impact of nature on human lives alongside approximate result appearance timeline in years and artificially generated image based on the definition of that impact or benefit. On the card's back, classification information of associated ES (code, section, group, class, and example) was available for further information. Participants in two groups simultaneously discussed the cards, selected their top five benefits, and presented them on the board. Two facilitators assisted throughout these activities, providing information and clarifying terms as needed. By the end of this activity, participants, experts, and facilitators elaborated on the results and selections, and each group expressed their reasoning behind selecting the benefits for the case study context. Among the selected benefits, heat reduction to increase greenery coverage, enhanced local interaction among neighbors, anxiety and depression reduction, and control of disease and sanitary risk is the top selection of participants. The results allow planners to identify ES to focus on during implementation phases and show participants prioritized ES benefits expecting to be present in their neighborhood in the future.

The main objective of LABU Co-design Lab#2 was to acknowledge and value the biodiversity of the garden, guiding participants to identify the needs and trajectories of the species and understand the potential conflicts with humans. To achieve this, participants were asked to engage in a multispecies role-playing game. A set of cards featuring various animal and plant species (both native and invasive), selected with the support of two local experts, was shared during the lab. Most species were chosen based on their actual presence in the habitats of the garden, while others were identified as potential future inhabitants. Each card featured an animal or plant species, showing a picture (downloaded from the Portal of Italian Flora and Fauna) along with the common and scientific names. Participants were divided into groups of two members and asked to randomly choose two cards, one representing an animal and the other a plant. Two A3 boards illustrating the species' user journeys were also distributed to each group, one representing the daily user journey (24 hours) and the other the yearly user journey (4 seasons). Each A3 board showcases a table with the main row showing, respectively, the 4 seasons and the 24 hours, and the columns outlining five aspects: i) the daily and yearly trajectory, ii) the specific needs of each species, iii) the potential interactions with other species, iv) the possible benefits, and v) the disservices for humans. Participants were asked to discuss collaboratively within their groups and fill out the boards with the relevant information. After 15 minutes of group discussion, all groups presented and shared the outcomes of their role-playing game with the other participants. The discussion also involved two experts who provided feedback and additional insights on the species' user journeys. This allowed for a collaborative learning process, enabling participants to deepen their understanding of the species, and their specific needs in relation to their habitat. During the session, a mediator was responsible for filling out a digital board, taking notes of both the desired and unwanted species that could be considered in the co-design of the multispecies garden.

In the next step, the LABU Co-design Lab#3, the objective was to collaboratively identify the design elements to be implemented in the garden. Thus, a set of cards was prepared featuring a selection of nature-based solutions from available catalogues, along with other types of urban furniture needed for the public use of the garden. The cards were placed on the table, and participants were asked to collaboratively discuss and decide which elements could be introduced into the garden space, in line with the vision, mission, and objectives established during Lab#1.

Following the three abovementioned workshops, Lab#4 focused on discussing preliminary results with public participants, stakeholders, and biodiversity experts. Through this session organized within Milan Green Week in 2024, the initial interventions and location of nature-based solutions were discussed and analyzed in open dialogue with participants. Within this setting citizens communicated their concerns and feedback for current and future stages of the research alongside the dissemination of pre-intervention results from co-monitoring and co-production for raising awareness regarding urban biodiversity and human-nature relations.

Findings and Discussion

Several findings could be extrapolated from the co-creation experimentation for urban biodiversity in this case study. Throughout the co-creation planning and co-designing process, several bottlenecks and hindrances have been encountered which slightly affected the project timeline and opening the park to the public. These bottlenecks could be thought as follows:

- 1) *Co-creating for biodiversity*: The co-creation methodology and tools implemented effectively supported the primary goal of enhancing biodiversity and establishing a multispecies garden. By stepping into the perspectives of other species, participants developed a deeper attachment to biodiversity values and expressed a strong commitment to defending these values by the end of the process. However, the line between raising awareness and subtly nudging or even influencing participants toward biodiversity-friendly solutions may be a fine one.
- 2) *Political resistance*: the municipal authority had the full capacity to supervise the planning and implementation of desired solutions in the park, which often did not go in line with the strategies and measures selected by citizens. These frictions have risked to slow down the co-design process, since it clearly affected the official approvals needed to proceed to next phases of implementation and the final adoption of solutions.
- 3) *Citizen engagement* in co-creation processes requires longer time commitment and a special attention to a variety of aspects related to the outcomes of the project without being selfishly biased by the needed versus the expected results. In such complex processes as the case of Sorelle Mirabal Garden, we have experienced the consistency of attendance from the affectionate group of citizens that had a very long and historical connection with the park and its

neighborhood area. Nonetheless, the possibility of including other groups of citizens has been very limited due to the time availability and the lack of territorial connections with larger groups of local associations.

- 4) *Replicability of the process* is often considered hard to conceive if the funding process is not reliable within the municipality itself, and if the urban biodiversity aspects are not prioritized in the political agenda of the city.

Conclusions

Engaging people in the commitment to preserving urban biodiversity poses a significant challenge. Involving them in shared values and decision-making processes can effectively foster support and heighten awareness of the importance of biodiversity planning. In this study, we suggest that a co-creation pathway specifically designed to promote urban biodiversity could offer a promising solution.

Despite the limited timeframe, the envisioned co-creation procedures proved effective in illustrating social-ecological relationships and the benefits of nature to humans. Using Ecosystem Services (ES) as a tool to gauge public perceptions of urban biodiversity allowed for efficient analysis of complex systems, such as cities, and for flexible replication in different contexts with new variables. ES also helps in identifying the appropriate implementation of Nature-Based Solutions (NBS) using ecological tools highlighted by participants.

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Authorship Credits

Eugenio Morello: Coordination, Conceptualization, Methodology, Writing—original draft, Writing—review and editing. Israa Mahmoud: Conceptualization, Methodology, Writing—original draft, Writing—review and editing. Luca Lazzarini: Methodology, Writing—original draft, Writing—review and editing. Asef Ayatollahi: Methodology, Writing—original draft, Writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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هر نفس نو می شود دنیا و ما
بی خبر از نو شدن اندر بقا
مولانا

*“Every moment the world is renewed,
and we are unaware of its being renewed whilst it remains (the same in appearance)”*

Rumi

ABSTRACT

To improve and preserve urban biodiversity, re-naturing measures that enhance human-nature interactions are essential. However, urban re-naturing faces three primary challenges: rapid biodiversity loss, complex human-nature relationships, and deep uncertainty regarding the future. To address these, this thesis proposes an adaptive planning framework structured as a cycle of monitoring, assessment, scenario-making, implementation, and learning. This research introduces a three-step social impact assessment (SIA) methodology for evaluating the co-benefits of re-naturing by analyzing ecosystem services (ES) at the local scale. The methodology is built on direct interaction with citizens and stakeholders through collaborative sessions to gather perceptions, narratives, and social values related to nature. The resulting SIA package is a replicable, cost-effective tool that uses ES to optimize urban re-naturing policies. This research demonstrates that SIA must be a continuous, inclusive, engaging, and evidence-based process that can uncover the social values of re-naturing, interpret social-ecological dynamics using ES and biodiversity values, support scenario-based planning for future studies, and guide decision-makers in conditions of uncertainty. By recasting the process of SIA at the conceptual, methodological, and practical levels, and bridging theory and practice within a practical, replicable SIA framework, this study ultimately lays the groundwork for orienting planners and policymakers toward the inclusion of social values in the policy-making process for urban green areas through continuous monitoring and evaluation.

