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A place-based framework for assessing the effectiveness of inclusive climate actions for nature-based solutions in cities

Virginia Pellerey *, Sara Torabi Moghadam

Interuniversity Department of Regional & Urban Studies and Planning-DIST, Politecnico di Torino, Viale Mattioli 39, 10125, Turin, Italy

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ABSTRACT

Nature-based Solutions (NbS) are recognized as important strategies to adapt and mitigate the effects of climate change. To better account for NbS justice implications, theory and practice have embraced Inclusive Climate Actions (ICAs) that simultaneously tackle climate change and urban inequalities. While the (in)justice repercussions of climate actions have extensively been discussed theoretically and empirically, an in-depth assessment of the environmental, economic, and social implications of ICAs is lacking. This research develops a novel framework for evaluating and monitoring the effectiveness of ICAs for NbS. The relevance of the framework lies in its double applicability: the framework has a generic core of 13 KPIs that can be applied for assessment in all European cities, while it can also be integrated by supporting place-based indicators that are specific to each city and NbS project. Prisma methodology, Pareto analysis, qualitative compatibility check, and Fuzzy Delphi methodology are the methodologies used for the selection of the core KPIs. Supporting place-based indicators can be selected though workshops involving local stakeholders. The framework helps cities to implement ICAs that result in more than just delivery of NbS by distributing NbS impacts as equitably as possible. The relevance of the proposed framework lies in several aspects: firstly, its emphasis on ICAs for NbS, offering a thorough and systematic insight into the environmental, social, and economic trade-offs and synergies associated with NbS; secondly, the pioneering methodological approach that merges cutting-edge methodologies with the consideration of stakeholders' perspectives, and thirdly, its ability to integrate context-specific analyses and its applicability in both the planning and monitoring phases of ICAs. This study is conducted under the auspices of the DUT European project GREEN-INC: Growing effective and equitable Nature-based Solutions through Inclusive Climate Actions.

1. Introduction

The impacts of climate change on urban areas in recent years have turned the spotlight on the need for cities to adapt to the predicted worsening of climatic conditions as well as to mitigate the impact of human activities on the environment. Making cities more resilient to climate change, while simultaneously favouring transformative actions that can shape more sustainable urban development has become a key objective in different policy agendas and at different scales (100 Resilient Cities, 2023; European Commission, 2023; Lee et al., 2023; United Nations, 2015). At the same time, the impacts of climate change are also highlighting the vast issues of injustice and inequality that are embedded in the urban environment as not only the effects of changing climatic conditions affect citizens unevenly, but also the implications of adaptation, mitigation and resilience actions might bring diverging benefits for different groups of citizens (Anguelovski and Connolly, 2021; Berrang-Ford et al., 2021; Cousins, 2024). Therefore, it is now more relevant than ever to start considering the intersectionality of climate actions and to find new pathways for cities to transition towards climate resilience in more inclusive, just, and future-oriented manners (Amorim-Maia et al., 2022).

In recent years, Nature-based Solutions (NbS) have been proposed in the European context as efficient and cost-effective measures for climate-resilient urban landscapes and built environments (Bayulken et al., 2021; Castellari et al., 2021; Lafortezza et al., 2018; United Nations, 2013). NbS – such as green roofs, raingardens, or constructed urban wetlands - contribute to climate mitigation and adaptation efforts and simultaneously provide wider ecological, social, cultural, and economic functions and benefits (Goodwin et al., 2023). However, while research on NbS′ environmental impacts is extensive, comprehensive assessments on NbS' intersectional implications are lacking (Brink et al.,

* Corresponding author.
E-mail address: virginia.pellerey@polito.it (V. Pellerey).

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Abbreviations and glossary:

Inclusive Climate Actions (ICAs) – Actions that consider how people and communities may be impacted by climate change and climate actions, given their wellbeing, prosperity and location in a city. Implementing innovative and transformational actions that tackle both climate change and social injustice (C40, 2019)
Nature-based Solutions (NbS) – Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions (Dumitru and Wendling, 2021)
Assessment framework – Conceptual basis which sets out the parameters for assessment and guidelines for practitioners (Crisp et al., 2007)
Key Performance Indicators (KPIs) – Critical (key) quantifiable indicators of progress toward an intended result (Abbasi et al., 2023)
Place-based supporting indicators – quantifiable indicators of progress toward an intended results, selected in references to a specific context
Pareto analysis – Decision-making technique that separates a statistically limited number of input factors into the largest effect on a desired or undesired result (Abbasi et al., 2023)
Fuzzy Delphi Method (FDM) – Analytical methodology the extends the traditional Delphi method to incorporate fuzzy logic to handle uncertainties and imprecise information during the decision-making process (Murray et al., 1985)

2016; Kabisch et al., 2016). Specifically, an empirical framework accounting for the intersectoral benefits at the urban scale, and associated uneven implications, is lacking (Dumitru et al., 2020). To tackle the complexity of addressing climate change while simultaneously enhancing social inclusion, well-being, and justice, scholars and practitioners are turning towards Inclusive Climate Actions (ICAs) that enable a structural and systemic implementation of NbS for equal benefits to communities and ecosystems (C40, 2019; Cousins, 2021). Compared to the now-conventional NbS approach, ICAs consider wider outcomes and impacts and focus on the intersectionality of urban issues as well as the justice implications and trade-offs (Wijsman and Berbes-Blazquez, 2022). However, as of yet, no systematic framework for ICAs as NbS evaluation has been carried out. Moreover, the existing frameworks proposed for analyses on NbS are currently not suitable for replicable yet context-sensitive comprehensive assessment of the effectiveness of NbS.

With the intent of addressing this gap, this research develops a novel framework for evaluating the effectiveness of ICAs for NbS. This framework aims to (i) integrate inclusive methodologies in the selection of Key Performance Indicators (KPIs) and supporting indicators for NbS considering the stakeholders' opinions, (ii) consider wider environmental, economic, and social implications and trade-offs of NbS, (iii) develop a replicable methodology that can be the first milestone towards the systematic evaluation of ICAs in different cities, and (iv) propose an inclusive methodology to make sure that the context-sensitive nature of NbS is addressed. By achieving these aims, the framework provides an outlook on the effectiveness of ICAs, which is lacking in the existing literature. Moreover, the novelty of the proposed framework lies in several aspects: firstly, its emphasis on ICAs for NbS, offering a thorough and systematic insight into the trade-offs and synergies associated with NbS; secondly, the pioneering methodological approach that merges cutting-edge methodologies with the consideration of stakeholders' perspectives, and thirdly, its ability to integrate into context-specific analyses and its applicability in both the planning and monitoring phases of ICAs. The framework's distinctive feature is its replicability across specific case studies, aimed at envisioning future transformative scenarios, as well as monitoring and evaluating implemented NbS.

This study is one of the results conducted under the auspices of the European project DUT GREEN-INC: growing effective and equitable nature-based solutions through inclusive climate actions.

The article begins by illustrating the necessity for an assessment framework for NbS and ICAs. Second, the methodology is comprehensively described. Third, results for each step of the methodology are presented. Finally, the conclusion discusses the validity and replicability of the results and proposes future uses for the proposed framework.

2. The motivation for an assessment framework for nature-based solutions

A necessary measure to ensure successful transitions and long-lasting climate resilience in cities is a valid, reliable, and comprehensive assessment of the implemented solutions (Escorcia Hernández et al., 2023). For this purpose, defining the indicator-based evaluation and monitoring framework is crucial as it allows urban practitioners (i.e., urban actors, designers, researchers, policy-makers, and public administrators) to measure and assess the progress and outcomes of ongoing or completed projects aiming to enhance urban sustainability (Svensson de Jong, 2021). Specifically, KPIs have been praised for (1) their usability as reference benchmarks for the comparison of different scenarios, and (2) their applicability in adherence with internationally recognized standards (Mickovski and Thomson, 2017).

NbS are embedded in the complexity of the urban system and thus are not immune to the trade-offs and injustice issues emerging from contemporary urban phenomena. For this reason, treating NbS as ICAs is vital if we want to develop a comprehensive assessment framework that can tackle climate change and socio-economic issues simultaneously (C40, 2019; Cousins, 2021).

Raymond et al. (2017) provide a systematic overview of the costs and benefits of NbS, fitting within ten identified societal challenges. Their framework represents a valuable tool for identifying the multiple values of NBS implementation in many different sectors of planning, yet they do not provide a definitive list of indicators or KPIs to be used for assessment and monitoring. Similarly, Calliari et al. (2019) propose an innovative assessment framework that explicitly accounts for the impact of climate change on the effectiveness of the proposed NBS by including system analysis and backcasting in the process. Yet, they also do not provide a set of KPIs to be used for the critical monitoring phase. Another study that presents a complete framework and a large number of assessment indicators is by Sowińska-Świerkosz and García (2021), who propose the framework to analyse effectiveness, synergies and trade-off of NbS before the implementation of a project. Their framework does not account for the monitoring phase which is critical for validity and possibility to reproduce and upscale NbS projects. Camacho-Caballero et al. (2024) also present a framework to analyse effectiveness of NbS; however, their comprehensive framework places emphasis on NbS' role in the reduction of vulnerability rather than on the direct effectiveness of NbS. On the other hand, Alshehri et al. (2023) propose a monitoring framework for NbS that integrates environmental and economic sustainability in the impact assessment of NbS, but they do not consider the social benefits and/or disadvantages of such projects. Similarly, Kumar et al. (2021) provide a comprehensive list of indicators used in different international projects for the assessment of NbS, categorizing them by type of hazard or type of impact. However, their analysis lacks focus on the economic and social implications of NbS and remains difficult to implement empirically due to the excessive number of proposed indicators. To account for this issue, most studies define assessment framework with indicators related to one specific impact of NbS, such as water management (Beceiro et al., 2020; Pagano et al., 2019), urban resilience (Beceiro et al., 2022), or pollution (Liquete et al., 2016).

In addition to the frameworks proposed in the literature, many European projects dealing with NbS (e.g., ProGIreg, 2023; Conexus, 2023; UNaLab, 2023; Nature4Cities, 2023) have proposed their framework for monitoring the results of the measures implemented during the project. Interestingly, the European Commission handbook collects all indicators proposed in European projects for NbS (Dumitru Wendling, 2021).

While some frameworks for the assessment and analysis of the impacts of NbS are available, five gaps emerge from the existing work. First, most studies on NbS are limited to focusing on a single aspect of sustainability. A holistic approach that integrates economic, social, and environmental dimensions is essential for comprehensive and effective implementation. Second, the proposed frameworks lack a specific focus on social implications and trade-offs emerging from the implementation of NbS (Dumitru et al., 2020). Third, quantitative assessments of the direct and indirect benefits, damages, and trade-offs of NbS are scarce (Carvalho et al., 2022). Fourth, the existing frameworks are all very dense in a number of proposed indicators and thus are difficult to implement empirically and to replicate in different contexts. Fifth, the frameworks in the academic literature are very general and tend to disregard the fact that NbS effectiveness is highly site-specific, while the assessment frameworks defined for specific projects are too context-specific and cannot be generalized or compared between different cities (Alves et al., 2024).

In a nutshell, currently, no holistic assessment and evaluation framework for ICAs has been proposed, thus there is an important lack of empirical evidence on the effectiveness and applicability of ICAs to the NbS at the urban level. An important way to start proposing an assessment framework for ICAs is to make the framework itself inclusive and place-based, by integrating the preferences, values, and opinions of stakeholders and experts in the development process. This is supported by different existing methodologies that allow the inclusion of stakeholders' preferences and values in the creation of assessment frameworks (Behmel et al., 2016; Kloprogge and Sluijs, 2006). Therefore, the existing sources support the need for including stakeholders' values in the development of an inclusive and context-dependent assessment framework for ICAs for NbS.

3. Methodology

3.1. Applicability of the framework

In light of the existing gaps in the literature and the need for a holistic assessment framework for ICAs as NbS in cities, this article aims to propose an inclusive methodology to select and a set of KPIs and supporting place-based indicators for assessing the environmental, economic, and social effectiveness of NbS that could be replicable for different contexts and for different types of NbS intervention. In particular, *the target of the proposed framework is to assess the environmental, economic, and social efficiency of NbS as ICAs*. The proposed level of analysis of the framework is the district scale. The choice to focus on the district scale is supported by observations of previous studies which claim that small-scale measures are sufficient for having a concrete impact on the urban fabric and the local community, while they also remain open to opportunities for replicability at larger – urban - scale (Bibri, 2022; Fitzgerald and Lenhart, 2016; Frantzeskaki, 2019).

Moreover, two very important aspects emerge for the applicability of the framework. First, the framework allows to observe the integration of social, economic and environmental impacts of NbS, in order to achieve a comprehensive assessment of ICAs and an analysis of the synergies and trade-offs between different impacts. Synergies and trade-offs (one the opposite of the other) can be observed by monitoring a set of indicators encompassing a large set of impacts (social, economic, and environmental). A comprehensive selection of indicators opens the possibility to notice when some solutions might be very effective in improving certain conditions, but could actually have negative effects on others, or, on the opposite, when some solutions are very effective at improving a lot of different conditions simultaneously. Second, the framework is applicable to different typologies of NbS interventions implemented at the urban scale. This point is especially relevant due to the large number of diverse typologies of interventions which fall under the NbS definition (for references and examples of the different typologies, see the projects ProGIreg, 2023, or UNaLab, 2023). Given the many different types of challenges and solutions fall under the NbS umbrella, the need for a framework that is applicable to all typologies of NbS, is an important characteristic included in the proposed framework.

3.2. Research design

The development of the monitoring and assessment framework is subdivided in two parts (Fig. 1). The first part deals with the identification of the generic, or core KPIs: a specific subset of environmental, economic, and social indicators to be assessed for all NbS cases in different urban contexts. The second part engages with the context-dependent nature of NbS, and entails the definition of supporting place-based indicators selected through the involvement of local stakeholders. The choice to include these two parts in the research design is driven by the need to propose an assessment framework that can be (1) widely applied and replicable, and (2) context-sensitive and adaptable (Adams et al., 2024).

3.2.1. Generic framework – selection of core KPIs

According to Abbasi et al., (2023), the methodology for selecting KPIs consists of three phases, (1) identification, (2) refinement, and (3) prioritization, comprised of five stages, which are illustrated in Fig. 2. The process starts with the selection stage in which a preliminary list of indicators that have been applied in academic literature, projects, standards, and assessment frameworks for NbS studies are gathered. Consequently, a wide range of relevant indicators are acquired at this stage, which must be reviewed and classified to shape the categories necessary for the evaluation. As a result, the selected indicators have been classified into three categories following an internationally accepted evaluation framework to comply with the principles of sustainability, which define sustainability in terms of the three pillars of the economy, society, and environment. Based on their final impact, the identified indicators are re-classified as economic, social, or environmental indicators.

The plethora of indicators, however, is troublesome since it complicates data collecting and processing. Furthermore, the reliability and maturity of sustainability evaluation are dependent on the development of a coherent collection of indicators capable of laying the groundwork for sensible comparisons and decisions. Therefore, it becomes critical to reduce the number of indicators, to decrease the complexity of future data collection and data processing (Abbasi et al., 2023). As a result, the second phase, the refinement phase, consists of two stages that are intended to eliminate unnecessary indicators and instead pick those that reflect the most relevant elements of NbS. The first stage of refinement is the Pareto analysis method which is used to identify the most frequently used indicators in the relevant literature. The second stage consists of a compatibility check that removes indicators that are not applicable or relevant to the district level, as well as those that are redundant. This is integrated with interviews to validate, revise, or improve the selected indicators using the experts' opinions. To do so, three individual interviews are carried out to collect reliable comments from economists, sociologists, and environmental experts. Moreover, the interviews lead to further limiting the number of indicators that may be too complex to

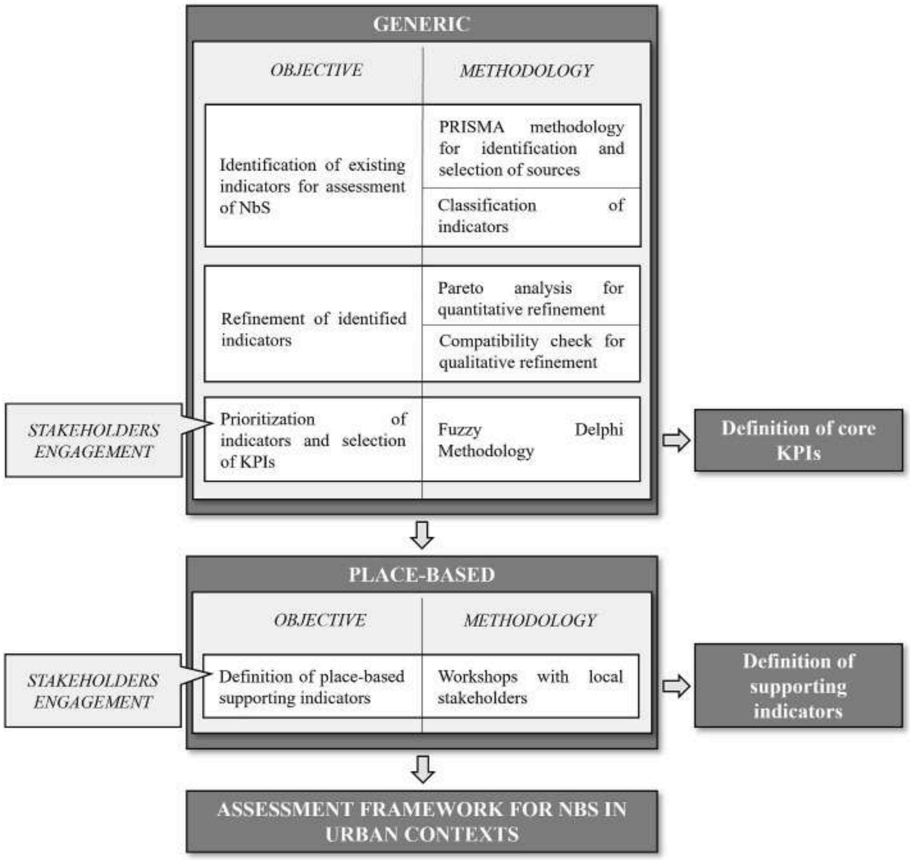

Fig. 1. Research design for the definition of the assessment framework.

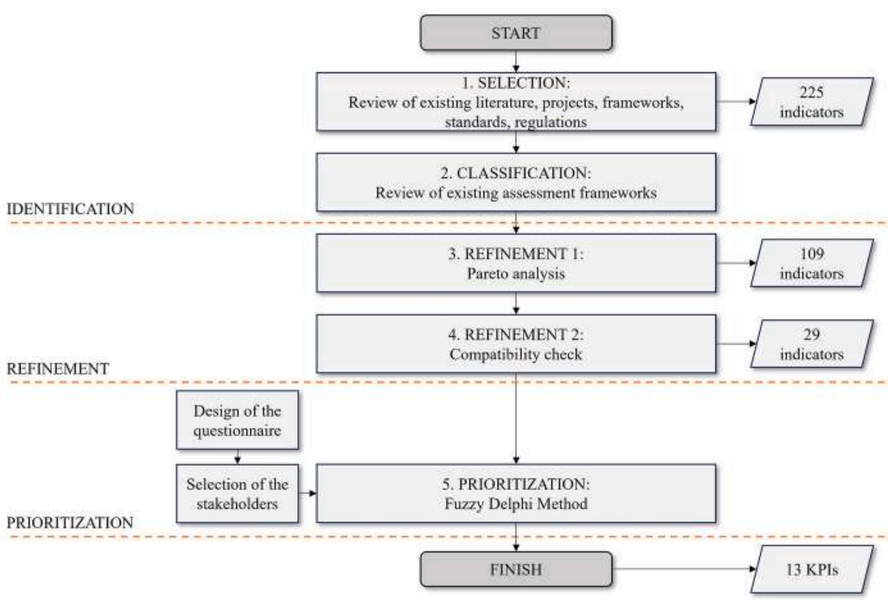

Fig. 2. Research methodology design for the identification of core KPIs.

measure or that are too generic, making them less valid and reliable.

The final selected indicators have different levels of importance and impact on the effectiveness of NbS. Thus, the last phase of the framework deals with the prioritization of the indicators according to the Fuzzy Delphi Method (FDM) (Padilla-Rivera et al., 2021). To do so, an online questionnaire is distributed to a large network of stakeholders to evaluate the importance of the identified indicators.

3.2.2. *Place-based framework – definition of supporting indicators*

Once the generic framework is developed, it is still necessary to ensure that the framework also has a strong element of inclusivity and contextualization. For this goal, the second part of the methodology entails the involvement of local stakeholders for the inclusive selection of place-based indicators acting as supporting indicators to the core KPIs. The methodology for this objective entails the organization of participatory workshops held in different cities where the assessment and monitoring framework is to be implemented. Compared to individual decision-making techniques, inclusive methods provides the advantages of greater localized knowledge, contextual experience, and integration of different perspectives, while also reducing the influence of individuals' cognitive biases and evaluation mistakes (Ossadnik et al., 2016). Moreover, this step enhances the inclusiveness of the framework, ensuring representation of both international (for the selection of core KPIs) as well as local stakeholders. At the local scale, this type of inclusion can increase long-term commitment and cooperation for the monitoring process (Grafakos et al., 2017).

4. Results

This section provides the results of each framework's methodological steps and their application to the case of NbS as ICAs. The collected data, analysis, and resulting outcomes are shown below.

4.1. Identification stage 1: selection

This stage aims to identify a comprehensive and systematic list of all indicators proposed for the assessment of NbS. This systematic review involved the identification of sources explicitly mentioning (1) Nature-based Solutions as a measure to address climate change and achieve sustainability, resilience, and/or transition, and (2) indicators and KPIs for assessment evaluation of NbS' effects. Prisma Methodology was selected as systematic method to identify, filter, and select sources for the selection of indicators (Fig. 3). The methodology follows the example provided by Dawodu et al. (2022), simplified to exclude the final steps of coding and visualization as those steps are not required for the scope of this study. For the keywords search string, the following combination was applied for the search on the Scopus and Web of Science databases:

("assessment" OR "monitoring" OR "evaluation") AND ("Nature-based Solutions" OR″Nature based Solutions") AND ("indicator" OR "indicators") AND ("urban" OR "city" OR "cities") AND ("climate change" OR "resilience" OR "sustainability" OR "transition")

After identifying the records through Scopus and Web of Science databases and removing the duplicate records, papers falling outside the scope of the study were removed by screening the abstracts and the methodology sections. This screening process ensured that only papers meeting these criteria were included in the selection.

- Articles directly concerned with the assessment of the effects or impacts of the implementation of NbS
- Articles proposing a set of KPIs or indicators for the monitoring and assessment process
- Articles proposing an innovative set of indicators not previously used for other studies

Along with the scientific publications, additional records were also identified through desk research with the intent of expanding the validity of the results beyond academic literature. As a matter of fact, multiple national and international projects have already embarked on the monitoring and assessment processes after the implementation of new NbS, and published results in the form of reports. Similarly, A large number of existing consolidated frameworks, policies, and standards were included since they recognize the role of NbS in the sustainable transition, and propose indicators for monitoring and evaluating the impacts of NbS or similar climate actions. After the screening step, the literature selected through the Prisma Methodology included: 21 academic articles, 17 European projects, 10 assessment frameworks, 8 international and European reports, 2 European policies, and an international standard. All sources are listed in APPENDIX I.

For each item selected, all proposed indicators were extracted and listed in an exhaustive spreadsheet. From this first stage, a total of 225 indicators were identified.

4.2. Identification stage 2: classification

As the identified indicators are a long list comprising of multiple topics, a classification step is necessary before proceeding to the rest of the methodology. For this framework, three macro-categories were defined as the three main objectives of NbS implementation identified in the IUCN Global Standard for Nature-based Solutions (2020): environmental impact, economic impact, and social impact. These categories also resonate with the commonly employed Triple Bottom Line (TBL) sustainability dimensions, thus confirming the applicability of the framework for sustainability and resilience in cities (Abbasi et al., 2023). As these three categories are still relatively broad, sub-categories were also introduced according to the framework defined by the European Commission: *Evaluating the impact of Nature-based Solutions: a handbook for practitioners* (Dumitru and Wending (2021). The final categories and sub-categories for the classification of indicators are reported in Fig. 4. Indicators were classified into the TBL categories and the relative sub-categories at the discretion of the authors.

4.3. Refinement stage 1: Pareto Analysis

After identifying and classifying the indicators, the refinement phase is performed. In the first refinement stage, the quantitative Pareto Analysis is employed to identify the critical indicators that are frequently previously used and to reduce the number of indicators. This technique is used to restrict the number of factors from a larger number of factors by identifying the ones that statistically have a more significant overall effect (Craft and Leake, 2002). The methodology is derived from the Pareto principle, which states that "80% of consequences in

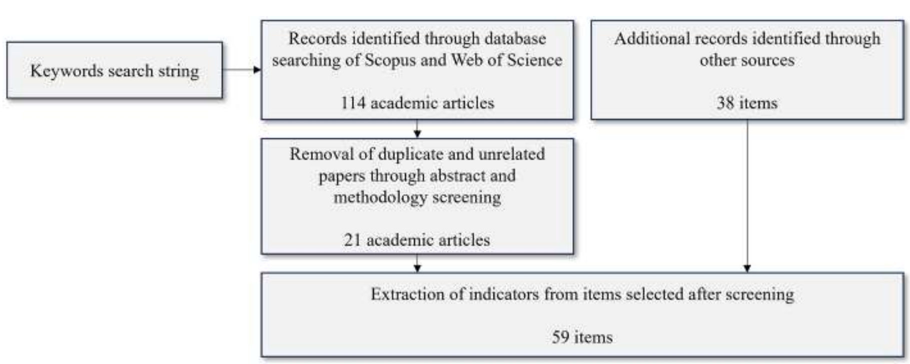

Fig. 3. Prisma methodology for literature selection.

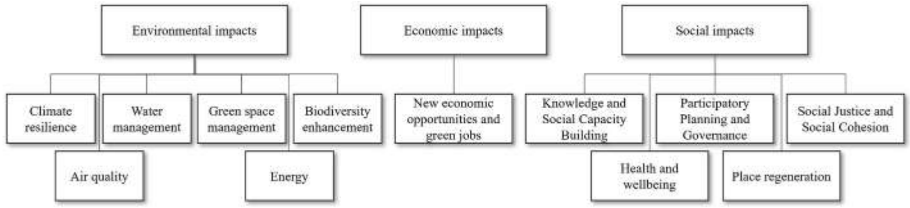

Fig. 4. Classification categories for the indicators according to Dumitru and Wendling (2021).

many problems come from 20% of causes" (Abbasi et al., 2023, p. 7; Fernandez-Sanchez and Rodríguez-Lopez, 2010). It follows that from an extensive list of indicators, 80% of the final impacts of NbS in cities can be explained by 20% of the identified indicators. Therefore, at this stage, the Pareto Analysis filters the most critical indicators by counting how many times each indicator is used in the sources and then selecting the indicators with less than or equal to 80% cumulative frequency (approximating the indicators with the closest frequency to 80%).

To achieve more accurate refinement, and to ensure that a significant number of indicators was maintained for each of the three macro-categories, the Pareto Analysis was repeated three times: one for the indicators classified as environmental impacts, one for the indicators classified as economic impacts, and one for the indicators classified as social impacts. The process is shown graphically in Figs. 5–7, respectively. Applying the Pareto analysis to the list of identified indicators, this list is narrowed down to 109 critical indicators that are frequently

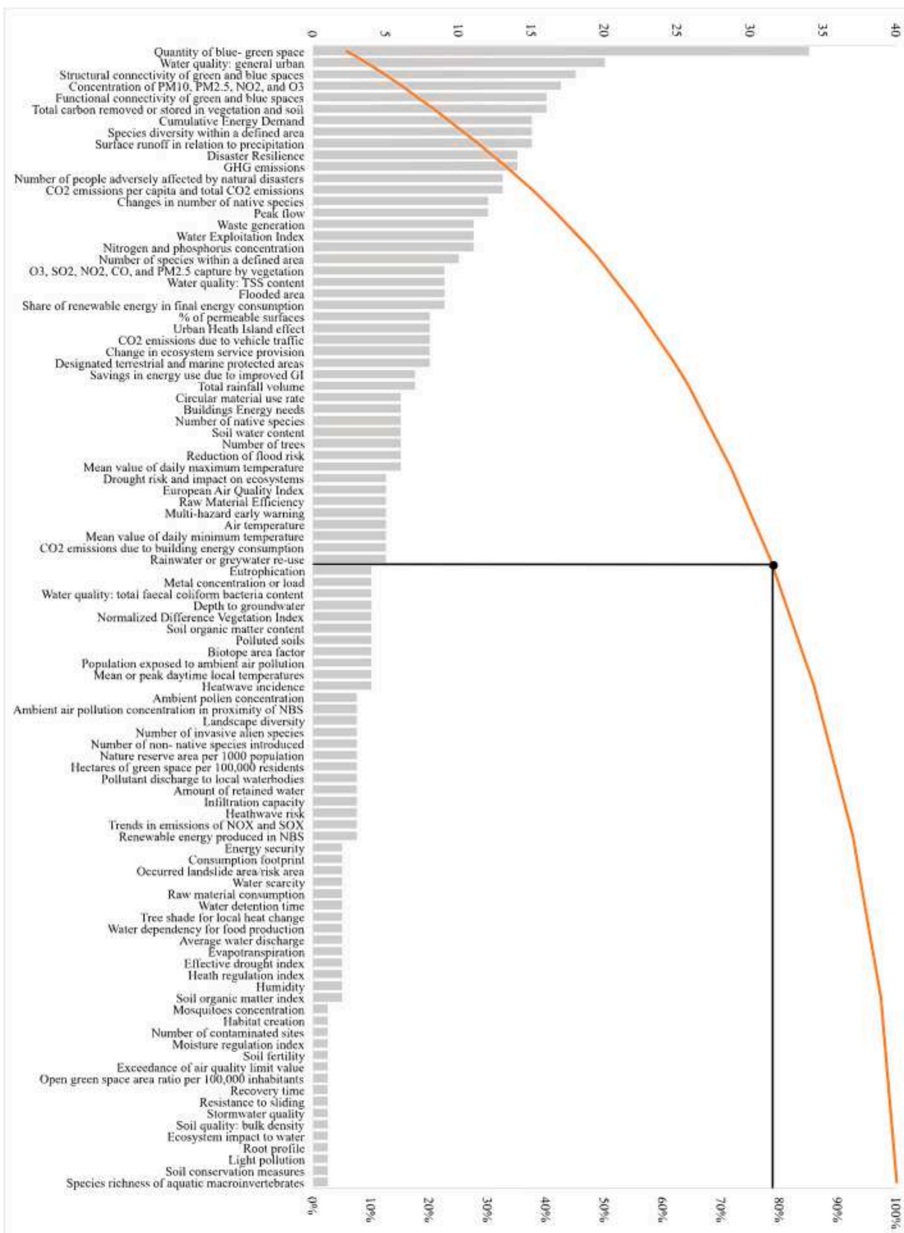

Fig. 5. Pareto chart for indicators of environmental impacts.

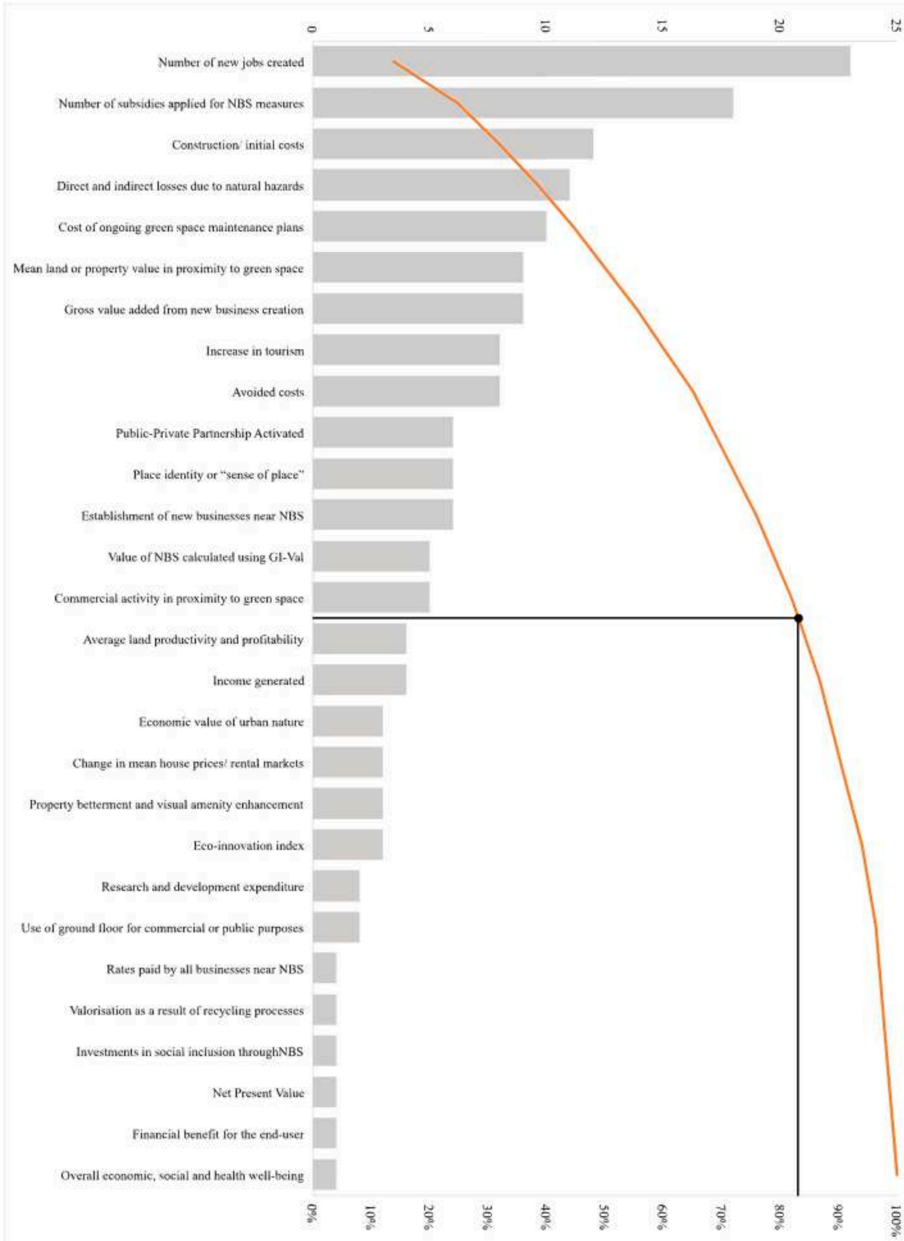

Fig. 6. Pareto chart for indicators of economic impacts.

used within mentioned sources. Regarding the environmental impacts category, 99 indicators were initially identified, and 46 were selected after Pareto Analysis, making up 78.3% of the cumulative frequency of environmental indicators. For the economic impacts category, 29 indicators were initially identified, and 15 were selected after Pareto Analysis, making 81.9% of the cumulative frequency. Also, the social impacts category indicators are reduced from 87 indicators to 38 critical ones after the Pareto Analysis, where the selected ones make 78.5% of cumulative frequency.

4.4. Refinement stage 2: compatibility check

Results from the Pareto Analysis allow to filter out indicators that are less significant for the evaluation of the effectiveness of NbS. Yet, this quantitative approach is not sufficient for the final selection of KPIs as (1) the number of indicators is still too high for valid and reliable use of the Delphi methodology, (2) not all indicators identified from the literature and selected from Pareto Analysis are relevant for the district scale, (3) some indicators are redundant. Therefore, a qualitative compatibility check is the following necessary step to define the framework. The compatibility check is done in two separate rounds.

The first round was conducted based on the authors' knowledge and expertise with the intent of validating the identified indicators, selecting the most relevant ones, and reducing the number of indicators. The following criteria were used to choose which indicators to keep or eliminate.

- Indicators that overlap or correlate in topic and functionality are merged to ensure that repetition or autocorrelation is avoided. For this, similar indicators are grouped by topic with the intent of identifying which indicator of the group is more comprehensive and correlates with the other ones. If it is possible to find one indicator that includes or highly correlates with other ones, said indicator is kept while the others are removed. If two or more indicators of a group are not sufficiently correlated or redundant, they are both kept as valid. Examples of removed indicators are:

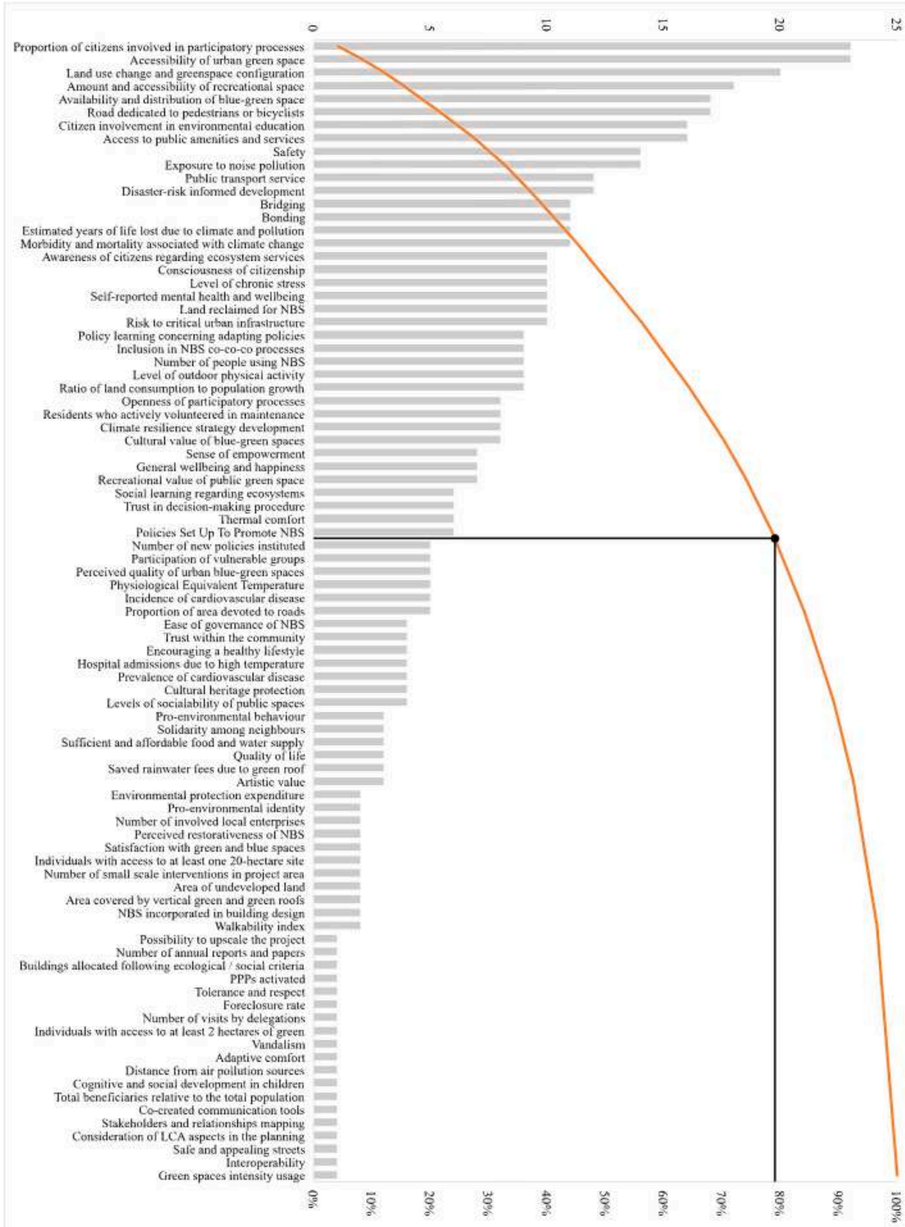

Fig. 7. Pareto chart for indicators of social impacts.

- Monthly mean value of daily minimum/maximum temperature – this indicator is incorporated in the more general Air temperature, which is highly correlated with daily minimum and maximum temperature.
- Inclusion of different social groups in NBS co-co-co processes – this indicator is removed as it is very similar to Proportion of citizens involved in participatory processes. Moreover, it is possible to assess the proportion of social groups involved as part of the proportion of citizens involved in the evaluation.

- Indicators that are not relevant for NbS implemented at the district scale or that cannot be assessed at the district scale are removed to ensure the feasibility of data collection and data analysis. This is further validated through the interviews with experts who discuss the feasibility of assessment and validate the selected indicators. Examples of removed indicators are:
  - Water quality – water quality is usually assessed at the urban level as it is affected not only by the urban infrastructure but also by the peri-urban and rural areas surrounding the city's water basin. Therefore, this indicator is removed as collecting data specifically related to the district level would not be feasible.
- Indicators that are specific policies related to NbS are removed. This choice is guided by the target of the framework to identify and assess the KPIs that have a direct focus on the effectiveness of NbS. Therefore, indicators assessing the enablers of NbS (policies or financial incentives) fall out of the scope of the framework. Examples of removed indicators are:
  - Policies set up to promote NBS – the amount and/or quality of policies promoting the uptake of NbS is a factor enabling NbS and ICAs. Still, it is not an indicator assessing the efficiency of NbS.
  - Multi-hazard early warning –a multi-hazard early warning system is an important means to achieve climate resilience and a serious sign of cities' commitment towards adaptation; however, this indicator does not assess the efficiency of one or more specific implemented NbS.
- Indicators that are too broad or not specifically related to the impacts of NbS are removed to enhance the validity of the framework

concerning its target defined in Section 3.1. For instance, indicators measuring impacts that cannot di directly linked to the implementation of one or more NbS are removed if the impacts or NbS cannot be clearly discerned from impacts of other measures of existing urban phenomena. Examples of removed indicators are:

- Place attachment: Place identity or "sense of place" – this indicator is very broad and abstract as it is based on residents' feelings and emotions, which might be influenced by a variety of factors eluding from the impacts of NbS.

Through this refinement, 27 environmental impact indicators, 7 economic impact indicators, and 18 social impact indicators are removed. All removed indicators and the reasons for the refinement are reported in APPENDIX II.

In the second round, four different experts were interviewed for additional refinement, specifically with the intent of removing additional indicators as well as validating the selected ones. One expert was interviewed for environmental impact indicators, one for economic impact indicators, and two experts were interviewed concerning social impact indicators. Examples of indicators removed or modified in this round are.

- Drought risk and impact on ecosystems – this indicator is usually used outside of urban settings and in large scale areas where the environmental impacts of drought are more visible and have a strong effect on human activities like agriculture. Therefore, this indicator is removed as it is not feasible to assess the specific effects of a NbS on reducing drought risk at the district scale.
  - Cost of ongoing green space maintenance plans – this indicator was validated by including also the assessment of the cost of blues space maintenance plans in order to be more comprehensive of all NbS projects. Thus, the indicator becomes "Cost of ongoing green and blue infrastructure maintenance plans".

Removed indicators from this phase are also reported in APPENDIX II. The outcome of the second stage of refinement is a comprehensive yet restricted list of 29 indicators covering the environmental, economic, and social impacts of NbS for assessment at the district level.

4.5. *Prioritization: Fuzzy Delphi analysis*

To further refine the number of selected indicators and to make the selection process more inclusive, the next phase of the framework involves the use of the FDM to account for the preferences of stakeholders. This methodology involves the distribution of a questionnaire to selected stakeholders, and the analysis of their responses through FDM. This participatory approach enhances the existing literature by adding to the process an element of inclusion, an aspect often left out in assessment and evaluation methodologies (Svensson de Jong, 2021). Furthermore, including stakeholders' values and opinions in all phases of design, implementation, and monitoring of NbS is a vital aspect of ICAs, and thus it needs to be integrated into the assessment framework.

The following paragraphs describe the different phases required for the identification of KPIs through the use of the participatory FDM.

4.5.1. *Design of the questionnaire*

All previous steps of the framework (described in Sections 4.1, 4.2, 4.3, and 4.4) are integrated into the design of the questionnaire to be sent to the stakeholders to finalize the selection of KPIs through participatory FDM. The questionnaire is designed to collect the stakeholders' opinions on the importance of each of the 29 indicators defined in the Refinement phase. To do so, the stakeholders were asked to rate how relevant each indicator is for assessing the effectiveness of NbS on a Likert Scale ranging from 1 to 5 (1 = not relevant, 2 = of little relevance, 3 = average relevance, 4 = relevant, 5 = very relevant). Respondents were given a brief definition and the unit of measurement for each of the 29 indicators and could provide feedback and opinions in an open question at the end of each section.

4.5.2. *Selection of the stakeholders*

Another necessary input for the prioritization phase is the selection of the stakeholders to be included in the development of the framework. For this framework, the definition of stakeholders is the one provided by Banville et al. (1998, p. 18), who regard stakeholders as "those that are both affected by and affecting the problem and are, at the same time, participating in the process of formulating and solving it". The selection of stakeholders can have a significant effect on the final results; thus, it needs to be conducted systematically (Geist, 2010). There are many methods proposed in existing literature for the selection of stakeholders for participatory studies (Rauschmayer and Risse, 2005). For this framework, stakeholders were not selected randomly, but purposely to meet a set of criteria required for valid participatory processes (Zio, 1996).

- Stakeholders were required to be independent from each other with the intent of representing a diverse spectrum of options and avoid group biases;
- There needed to be an even representation of the three main actor groups involved in the process of designing, implementing, and monitoring NbS in cities:
  - Academic and research actors: these stakeholders are involved in the process as experts who can provide knowledge on context, technologies, policies, citizens involvement and other important aspects that affect the efficiency of ICAs. These actors are mostly affiliated to local universities or research centres.
  - Administrative actors: these stakeholders are civil servants who work for the political, administrative, or technical bodies of the municipality, the districts or the region. They can provide technical, financial, legal, and political resources for ICAs in the city.
  - Local associations and businesses: these stakeholders are the ones more in touch with the population of the city, and act as a bridge between the citizens and the municipality. The provide financial resources (in the case of businesses and foundations) and can support citizens involvement.
- Stakeholders needed to show interest, adequate time, and ability to participate in the process of the exercise.

The questionnaire was sent to a total of 129 stakeholders belonging to these three categories. The group of participants was intentionally diverse in backgrounds and viewpoints, in order to account for the uncertainty which might be caused by a diverse group of respondents (Zio, 1996). Out of the 129 participants contacted, 34 of them responded to the questionnaire, a number higher than expected. Of these 34, 13 respondents (38%) are academic and research actors, 11 (32%) are administrative actors, and 10 (30%) are from local associations and businesses. The response rate was 26%, which is acceptable given that the average response rate for these types of questionnaires is between 10% and 15% (Abbasi et al., 2023). Moreover, the number of respondents is appropriate for questionnaires involving participants from heterogeneous groups, which should usually range between 20 and 60 (Ahmad and Wong, 2019).

4.5.3. *Result of questionnaire*

FDM is used to analyse the responses to the questionnaire, to understand (i) if there is sufficient consensus between the answers of the different stakeholders, and (ii) the ranking of the indicators according to the stakeholders' answers. The FDM is a methodology that integrated the classic Delphi Method (see Okoli and Pawlowski (2004) for a complete review of the definition and use of this methodology) with innovative statistical techniques to reduce the uncertainty and the ambiguity of the classic methodology (Murray et al., 1985). As explained by Padilla-Rivera et al. (2021, p. 103), "The use of fuzzy theory avoids the distortion of individual expert opinions, captures the semantic structure of predicted items, and considers the unclear nature of the data collected". Thus, the combination provided by FDM requires a smaller number of samples and offers a more complete expression of stakeholders' opinions. For this study, the methodology employed follows the process described by Hu et al. (2011) and Abdullah and Yusof (2018). Fig. 8 summarises the whole process required for completing the Fuzzy Delphi analysis. For a more comprehensive evaluation of the responses, the process is repeated four times, one for the analysis of all 34 responses, and one for each of the categories of stakeholders. Final results of the analysis are described and discussed in Section 4.6.

First, the FDM requires defining the fuzzy scale values relative to the linguistic Likert scale to be used for the fuzzification of the responses. The purpose of this fuzzy scale and the Triangular Fuzzy Numbers is to assess the overlap between the stakeholders' answers, and thus evaluate whether a consensus is reached in the first round of the questionnaire (Abdullah and Yusof, 2018). In other words, Triangular Fuzzy Numbers represent the overlaps between stakeholders' answers where there are ambiguous opinions. For a complete explanation and definition of Triangular Fuzzy Numbers see Molinari (2016). For this study, the fuzzy scale used for fuzzification of the responses is reported in Table 1. Compared to the classical fuzzy scale generally used for the FDM (as described by Habibi et al., 2015), the proposed fuzzy scale gives less emphasis on the upper and lower bound answers, and greater emphasis on the overlap in the central values of the Likert Scale.

The stakeholders' answers and fuzzified through the use of the proposed fuzzy scale. With this, the Threshold Value for each of the indicators can be calculated by using the vertex method (Abdullah and Yusof, 2018). The condition for reaching a consensus with the questionnaire responses is that at least 75% of the indicators must have reached a Threshold Value lower or equal to 0.2 (Chu and Hwang, 2008). In this study, consensus was reached as 22 out of the 29 indicators had an acceptable Threshold Value, and the average Threshold was 0.19, thus indicating an acceptable level of consensus between stakeholders' answers. If the consensus had not been reached, the questionnaire would have needed to be repeated to guarantee agreement with the results.

Second, the FDM is the De-fuzzification of the responses, which is done with the formula:

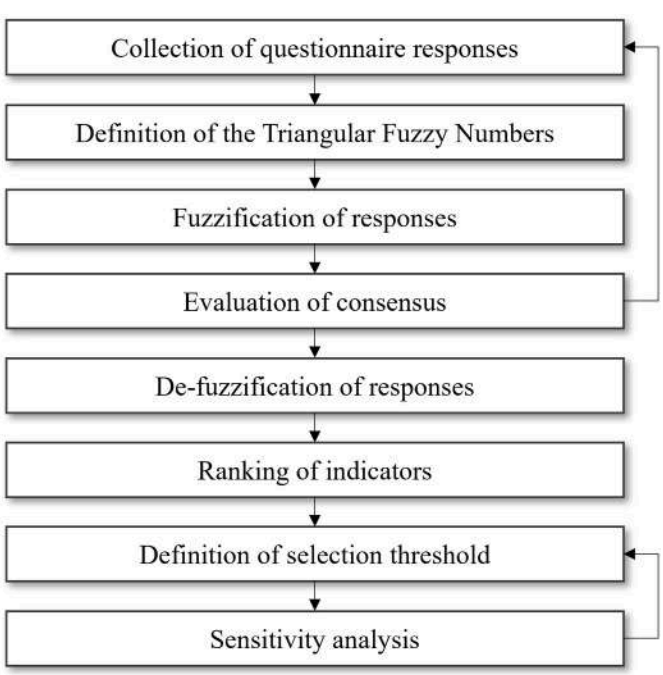

Fig. 8. Fuzzy Delphi method.

Table 1
Fuzzy scale values used for the study.

Likert Scale	Linguistic value	Fuzzy scale
1	Not relevant	(0.0, 0.2, 0.3)
2	Of little relevance	(0.2, 0.4, 0.5)
3	Average relevance	(0.4, 0.5, 0.6)
4	Relevant	(0.5, 0.6, 0.8)
5	Very relevant	(0.7, 0.8, 1.0)

$$A = (1/3)^*(m1 + m2 + m3)$$

Where A is the average fuzzy score value of each indicator, and m1, m2, and m3 are the Triangular Fuzzy Numbers for each indicator (Abdullah and Yusof, 2018). The resulting values determine the ranking of indicators included in the analysis. Table 2 reports the results of the FDM of this case study.

Finally, for selecting the final KPIs from the obtained ranking of indicators it is necessary to determine a threshold for inclusion and exclusion of the KPIs. Such threshold was set to be the average value of the fuzzy scores for the 29 indicators, which, for the FDM including responses from all the stakeholders, is 0.643. With this value as a threshold, 13 out of the 29 indicators are selected as KPIs for assessing the efficiency of NbS. The final list of KPIs is reported in Section 4.6.

To conclude the FDM, a sensitivity analysis is performed in order to validate the selected threshold value, as suggested by Padilla-Rivera et al. (2021) and Ocampo et al. (2018). To conduct the test, two different threshold values were tested: (I) 0.643 + 0.05 = 0.693 and (II) 0.643–0.5 = 0.593. With both new values, drastic changes can be seen in the total number of accepted indicators, as almost all indicators would fall in KPIs selection. On the other hand, if the threshold value is only changed by + - 0.1, then the change in selected KPIs is minimal. Therefore, it can be asserted that the chosen threshold value is acceptable and significant for the results of the study.

4.5.3.1. Comparison of stakeholders' responses. For a more comprehensive analysis of the values and preferences of the stakeholders reached for the implementation of the presented framework, an additional analysis was conducted by comparing the results of the questionnaire and FDM for all respondents and the results for the three groups of stakeholders separately. The results of this analysis are presented in Table 2, where the fuzzy scores and ranking of each indicator for the different groups are compared. Before observing these results, it is interesting to notice that two out of the three groups of stakeholders (academic and research actors and local associations and businesses) failed to reach the consensus threshold. However, this is most likely caused by the restricted number of respondents, which leads to an increase in the significance of outlier responses, and thus greater difficulties in achieving consensus. On the other hand, it is also interesting to notice that consensus was reached by administrative actors' responses, thus showing that the values and objectives of policy-makers are currently aligned. Besides these observations, it is also interesting to notice the differences in ranking for the three categories. While the overall rankings are quite similar for all three groups (meaning that indicators ranking in the first half and the second half of the ranking coincided for all groups), there are noticeable differences in the first-ranking KPIs. For academic and research actors, the KPIs with highest fuzzy score is "Cost of ongoing green space maintenance plans", an indicator for economic impacts. For administrative actors, the highest ranking if for "Estimated morbidity and mortality associated with climate change and air pollution", which coincides with the general ranking. Finally, the KPIs with highest score for local associations and businesses are "Land use change" and "Accessibility of urban green space and recreational space". Overall, such divergent results confirm the need, already expressed in existing literature on Delphi methodology and participatory research, for an heterogeneous group of respondents

Table 2
Results of the FDM.

INDICATOR	FUZZY SCORE	RANKING	RANKING – academic and research actors	RANKING – administrative actors	RANKING – local associations and businesses
Estimated morbidity and mortality associated with climate change	0.707	1	8	1	4
Rainwater and greywater capture and reuse	0.7	2	4	6	3
Citizen involvement in environmental education activities	0.7	2	2	5	4
Accessibility of urban green and blue space and recreational space	0.7	2	8	2	1
Cost of ongoing green and blue infrastructure maintenance plans	0.696	5	1	13	9
Mean annual direct and indirect losses due to natural and climate hazards	0.687	6	10	3	7
Air temperature	0.674	7	12	3	12
Proportion of citizens involved in participatory processes	0.672	8	7	18	6
Structural and functional connectivity of blue and green spaces	0.663	9	16	11	7
Annual CO2 equivalent emissions per capita and total CO2 emissions	0.651	10	12	7	22
Number of people adversely affected by natural disasters each year	0.648	11	3	7	29
Exposure to noise pollution	0.647	12	21	10	9
Land use change	0.644	13	23	14	1
Thermal comfort	0.642	14	11	27	14
Number of people using NbS at different times and for different activities	0.640	15	4	26	23
Concentration of PM10, PM2.5, NO2 and = 3 in ambient air	0.635	16	17	11	20
Construction/Initial costs	0.635	16	6	24	26
Savings in energy use due to improved Green Infrastructure	0.633	18	18	16	15
Flooding risk	0.633	19	14	7	27
Number and type of residents who have actively volunteered in maintenance activities	0.624	20	18	16	18
Level of outdoor physical activity	0.624	21	25	14	12
Quality of land	0.616	22	21	21	17
Mean land and/or property value in proximity to green space	0.614	23	15	18	28
Direct economic activity: Number of new jobs created	0.612	24	20	22	23
Trust in decision-making procedure and sense of empowerment	0.610	25	24	29	11
Local food production	0.590	26	25	28	23
Quality of interactions within and between social groups (bridging and bonding)	0.587	27	27	23	18
Waste generation	0.586	28	29	18	16
Increase in tourism	0.577	29	28	24	20

in order to account for many different points of view, opinions, and localized knowledge.

4.6. Set of KPIs

The provided methodology yielded a set of 13 KPIs that may be used for evaluating and monitoring NbS's environmental, economic, and social effectiveness. Moreover, the selected KPIs allow to frame NbS as ICAs that can support cities in achieving justice and inclusion in climate resilience, adaptation, and mitigation measures. Table 3 and APPENDIX III present the 13 identified KPIs, highlighting their relevance for the assessment of NbS and ICAs. In addition, the table mentions, as suggested by Dumitru and Wendling (2021), whether indicators are outcome-oriented, meaning that they evaluate the results of the implemented solution, or process-oriented, if they evaluate a specific aspect of the design or implementing phases. Another important information provided in the table is how each of the selected KPIs connects to one or more of the Justice Principles described by Anguelovski and Corbera (2023). This is very important for the scope of the framework as it specifically indicates the relevance of NbS′ impacts for ICAs and justice in the urban context.

Out of the 13 selected KPIs, 5 assess environmental impacts, 2 economic impacts, and 6 social impacts. This is not expected as environmental KPIs are most often highlighted in the literature as the most relevant ones for the assessment of NbS. Yet, the results of this framework shed light on the need for a more comprehensive assessment of the social consequences of climate actions, and thus for the inclusion of social impacts in evaluation frameworks. Apart from this unexpected observation, all the selected KPIs emerged as very relevant since the very first steps of the framework. For instance, each of the 13 indicators is mentioned in at least five different documents, 11 out of 13 are mentioned in more than 10 sources, and 5 out of 13 in more than 15 sources. From the FDM, the 5 KPIs that emerge as most relevant for the stakeholders are (in order): Estimated morbidity and mortality associated with climate change and air pollution, Rainwater and greywater capture and reuse, Citizen involvement in environmental education activities, Accessibility of urban green space and recreational space, Cost of ongoing green space maintenance plans. It is interesting to notice that between these 5 KPIs, which all score very similarly in the ratings, there is at least one KPI per macro-category. Apart from this, all other KPIs have very similar score, and take a similar percentage in the final rating. The graphical representation of the selected KPIs is shown in Fig. 10. A final observation on these results concerns their applicability to the assessment of ICAs as NbS. The 13 selected KPIs cover all the Justice Principles proposed by Anguelovski and Corbera (2023), they it can be argued that they provide a comprehensive picture not only on the

Table 3
Selected KPIs for assessing the efficiency of NbS.

MACRO-CATEGORY	SUB-CATEGORY	INDICATOR	DESCRIPTION	UNIT	JUSTICE PRINCIPLES
Environmental impacts	Climate resilience	Number of people adversely affected by natural disasters each year	Count and spatial distribution of people affected by natural disasters (flooding, drought, heath waves etc.).	n° of people	Rigorous assessment of mitigation and adaptation benefits, People's relationship with land and nature repaired and supported
		Air temperature (reduction of heath island effect)	Measurement of mean and peak daytime temperature, includes the effect of albedo and tree shades as factors affecting air temperature.	°C	Rigorous assessment of mitigation and adaptation benefits
		Annual CO2 equivalent emissions	Total amount of CO2 emitted and stored within the study area.	t/y	Rigorous assessment of mitigation and adaptation benefits
	Biodiversity enhancement	Structural and functional connectivity of urban green and blue spaces	Structural connectivity is measured by the proximity of blue-green spaces and the infrastructure matrix across a city. Functional connectivity is measured in relation to the ability of the landscape to support the movement of organisms through it.	hectares 0–1 index	Rigorous assessment of mitigation and adaptation benefits
	Water management	Rainwater and greywater capture and reuse	Volume of rainwater or greywater captured and re-used for irrigation or other purposes	m3/y	Rigorous assessment of mitigation and adaptation benefits, Regenerative and sustainable economic pathways
Economic impacts	New Economic Opportunities and Green Jobs	Cost of ongoing green and blue infrastructure maintenance plans	Costs incurred to keep the project in good condition or good working order (must include total annual labour costs, land leasing costs, machinery, energy costs, licensing, etc.).	€	Regenerative and sustainable economic pathways
		Mean annual direct and indirect losses due to natural and climate hazards	Expected annual damage (monetary) from hydrometeorological risks.	€	Regenerative and sustainable economic pathways
Social impacts	Knowledge and Social Capacity Building	Citizen involvement in environmental education activities	Number of educational programs sponsored by elementary and secondary schools, colleges and universities, youth camps, municipal recreation departments, local or international not-for-profit organizations, and private entrepreneurs.	n° educational programs	People's relationship with land and nature repaired and supported, Inclusive empowering and participatory schemes
	Participatory Planning and Governance	Proportion of citizens involved in participatory processes	The proportion of citizens involved in participatory governance and design/ planning phases.	%	Inclusive empowering and participatory schemes, Long-term green inequalities tackled
	Social Justice and Social Cohesion	Accessibility of urban green and blue space and recreational space	Percentage of residents living within acceptable access of the available green and recreational areas.	m min	Alternatives to appropriation and/or enclosure of land for greening and conservation, No land speculation and associated green gentrification, No greenwashing and privatization of nature for profit
	Health and wellbeing	Estimated morbidity and mortality associated with climate change	Prediction of illness and death rates caused by environmental or social factors.	n° cases/y	People's relationship with land and nature repaired and supported
		Exposure to noise pollution	The per cent reduction of noise level measured at the receiver, or the number of inhabitants exposed to noise >55 dB(A).	%	People's relationship with land and nature repaired and supported
	Place regeneration	Land use change	Assessment of changes in the urban forms, with specific attention to the reclamation of land for NbS.	ha per capita %	Alternatives to appropriation and/or enclosure of land for greening and conservation, No land speculation and associated green gentrification, No greenwashing and privatization of nature for profit

Fig. 9. Assessment and evaluation framework as proposed by the authors with the integration of supporting indicators proposed by Dumitru and Wendling (2021).

Fig. 10. Photos from the workshops in Brussels, Skelleftea and Torino.

impacts of NbS in cities, but also on the justice implications of ICAs as NbS.

4.7. Definition of supporting indicators

After the definition of a generic set of KPIs, implementable and comparable in different cities, it is also necessary to engage with the context-specific nature of NbS (Alves et al., 2024; Battisti et al., 2024). For the framework's methodology, this means integrating a restricted number of place-based supporting indicators, selected with specific reference to the context in which the monitoring and assessment will be performed. The following section presents the methodology proposed for the definition of place-based supporting indicators. Moreover, the following section presents the results of the methodology implemented in three different cities selected as case studies: Torino (Italy), Brussels (Belgium), and Skellefteå (Sweden).

In 2021, the European Commission (Dumitru and Wendling, 2021) collected and listed a large number of indicators to be used as references for future projects and studies assessing the effectiveness of NbS. Thanks to its exhaustive coverage of different challenges and solutions, applicable in diverse cities or districts, this list is taken as the starting point for integrating the core KPIs with supporting indicators specific to one (or more) of the 12 challenges that NbS can address. Supporting indicators, place-based for each case in which the framework is implemented, are selected though workshops with local stakeholders who combine their expertise to select a subsect of supporting indicators to integrate the core KPIs.

4.7.1. Setting the local workshops

The definition of supporting indicators requires the inclusive participation of local stakeholders who can support the selection process with knowledge and experience in the local context. It follows that one workshop should be carried out in each city where the framework is to be implemented. The required steps for the organization of the workshops entail.

1. Defining the boundaries of the study area, or the specific part(s) of the city or NbS projects which will be the focus of the monitoring and assessment process.
2. Carrying out, through desk research and/or on-site visits, an initial analysis of the specific challenges of the study area.
3. Selecting from a restricted number of indicators (around 3–5 for each challenge, for a total of 15 indicators per city) from the ones proposed in the European Commission's comprehensive list (Dumitru and Wendling, 2021). Indicators should be selected based on knowledge of experts, and should follow these criteria: (i) the indicators can explicitly evaluate the impact of the NbS implemented in the study area, and (ii) the indicator is feasible to measure. A card showing indicator name, description, and unit of measure should be prepared for each of the indicators selected.
4. Selecting and inviting stakeholders. For this step the selection of stakeholders follows the same methodology as the one described in Section 4.5.2. For each workshop, it would be advisable to have the participation of at least (i) 5 stakeholders from local academic and research institutions, (ii) 5 stakeholders from the local administration, (iii) 5 stakeholders from local associations and businesses.

Once all these steps are completed, the workshop can be carried out. A simplified version of the Simos Roy Figueira (SRF) methodology (Simons, 1990; Figueira et al., 2016), also known as 'playing cards', is recommended for engaging with the stakeholders and, most importantly, incentivize dialogue and discussion to reach group consensus. This semi-structured participative procedure supports group discussions by allowing the stakeholders involved to discuss and confirm how they want to rank the different indicators in a specific context by using a deck of cards, each representing an indicator. APPENDIX IV shows and example of the board game that the stakeholders use for ranking the supporting indicators selected based on the local challenges. In addition, stakeholders can propose other indicators to integrate into the ranking. As a final outcome, a minimum of ten indicators should be ranked from most to least important according to the consensus of the participants.

4.7.2. Results in European cities

To test the validity of the proposed methodology for selecting supporting indicators, workshops were carried out in three European cities: Torino, Brussels, and Skellefteå. Each workshop lasted 2 h and was divided in three parts (Fig. 9. The first 45 min were used to describe the GREEN-INC project, the local NbS projects to be assessed, the methodology used for the development of the framework, the identified KPIs, and the rules of the workshops for the definition of supporting indicators. The following hour was dedicated to the 'playing cards' game (as presented in Section 4.7.1) and the discussions between participants. The remaining 15 min were dedicated to validation of the completed framework though group discussion. Table 4 reports the results of the three workshops. Out of the 10 indicators ranked in each study area, only the ones ranked in the first rows were selected for the assessment process to reduce the number of indicators and make the assessment more feasible (since the selected supporting indicators are integrating the 13 KPIs to be monitored in each study area). While a more in-depth analysis of the workshops' results goes beyond the scope of this paper (which is concerned with the methodology for the definition of the framework, rather than its application), it is interesting to notice how the results in the three study areas validate the need for the integration of place-based supporting indicators. Stakeholders in each of the three cities selected supporting indicators stressing the challenges perceived as most relevant in each area: social capacity building in Torino, environmental (water and green space) management in Brussels, and economic/cultural value in Skellefteå.

Table 4
Results of the workshops for the selections of supporting place-based indicators.

	N° of stakeholders	Focus challenges of the study area	Indicators selected
Torino	20 (8 from local academic and research institutions, 8 from local administration, 4 from local associations and businesses)	-Place regeneration -Water management -Knowledge and social capacity building	•Perceived quality of urban spaces •Proportion of community who volunteer •Bridging and bonding •Surface runoff •Energy consumption •Soil quality •Food production in urban allotments and NbS •Mean land and property value in proximity to NbS
Brussels	14 (4 from local academic and research institutions, 4 from local administration, 6 from local associations and businesses)	-Place regeneration -Water management -Green space management	•Perceived quality of urban spaces •Surface runoff •Soil quality •Number of species •Air quality •Mean land and property value in proximity to NbS
Skellefteå	13 (4 from local academic and research institutions, 6 from local administration, 3 from local associations and businesses)	-New economic opportunities and green jobs -Place regeneration -Health and wellbeing	•Perceived quality of urban spaces •Number of species •Energy consumption •Secondary raw materials •Recreational value

5. Validity and replicability

Fig. 10 shows a graphical representation of the framework, with the identified core KPIs at the centre, and the categories for additional indicators (as presented by Dumitru Wendling, 2021) on the outside.

The relevance of the proposed assessment framework extends further beyond the scope of this study. Therefore, a discussion on the possibilities for replicability and implementation of the framework is vital. In terms of replicability, the presented framework applies to the assessment of NbS in all European cities as it defines a set of core KPIs to be commonly used for evaluating the effectiveness of NbS. Moreover, the framework can also be further contextualised for different empirical cases (as shown in the three examples provided in the manuscript) by involving stakeholders in defining the supporting indicators specific to the local challenges and implemented NbS. This is necessary to make sure that the final results while originating from a common baseline literature on the assessment of the efficiency of NbS in urban contexts, are also localized and take into account the values of the local stakeholders, which might differ from city to city (Battisti et al., 2024). Another important aspect to be discussed is the replicability of the framework in settings beyond the urban scale. While the scope of this study was limited to urban areas, NbS are often implemented also in other settings, but their impacts can largely differ at different scales of analysis. Therefore, a different framework should be developed for assessing the effectiveness of NbS in rural or non-urban areas. For this, it would be necessary to repeat all the steps from Section 4.5 onwards as these steps are directly influenced by the participation of stakeholders who are engaged in urban contexts. Moreover, some indicators were removed during the compatibility check as they are not relevant at the urban/district scale, while they might be relevant at larger scales or in non-urban areas.

The validity of the presented framework is also an important topic, as its applicability and replicability strictly depend on how comprehensive the framework is in addressing the identified target: *to assess the environmental, economic, and social efficiency of NbS as ICAs at the district scale*. From the review of the literature, the interviews with experts, and the comments of the respondents, the need for the selection of a restricted number of core KPIs for the assessment emerged as a vital requirement. Yet, it is also necessary to stress that the identified KPIs can always be integrated by additional indicators in case of further need. In other words, while the proposed assessment framework identifies general KPIs that need to be measured and compared for assessing the efficiency of NbS in different cities, other indicators can be integrated into the assessment if there is a need to address specific issues that are relevant to distinct cases, projects, or challenges to be addressed. With this, the framework achieves two important goals: (1) defining a general core that can be further integrated to account for specific types of NbS, unique projects, or distinct goals, and (2) proposing and implementing an inclusive methodology that allows to contextualize the framework through the involvement of local stakeholders and the selection of place-based supporting indicators.

The complete and replicable assessment framework proposed opens a new path for extensive future research in the field of climate actions, inclusive planning, and just climate transition. For instance, by applying the framework in other case studies it will be possible to perform a more detailed comparison of the results in different cities, and thus analysing the differences in stakeholders' values. Such operation has been done in the contexts of the DUT European project *GREEN-INC, growing effective* *and equitable nature-based solutions through inclusive climate actions*, which uses the proposed framework as baseline results for the evaluation of efficiency of ICAs in European cities. Through the course of this project, the framework will be replicated in five different European cities (Turin, Brussels, Skellefteå, Amsterdam and Bucharest). After the selection, the identified KPIs and indicators will be used for assessing the effectiveness of ICAs in the five cities, and later employed for the development and monitoring of five Urban Living Labs. Finally, the framework also gives the opportunity for replication and implementation in all other European cities with relative similar size and climate intentions.

6. Conclusion

This study set the goal to propose an assessment framework for the evaluation and monitoring of ICAs as NbS in the urban context. To develop the proposed framework, a combination of quantitative and qualitative methodologies are employed. The final result of the framework is a set of core KPIs which are dependent on the context and values of stakeholders and can be integrated with supporting indicators considering the NbS particularities.

While a limited number of frameworks for the assessment of NbS is already available, no comprehensive framework for ICAs is yet available. Moreover, the proposed framework is specifically relevant for the integration of multiple important approaches.

- The holistic focus on ICAs as Nbs. While most studies on NbS are limited to focusing on a single aspect of sustainability, this holistic approach integrates economic, social, and environmental dimensions and is essential for comprehensive and effective implementation and for observing possible implications and trade-offs in the impacts of ICAs as NbS;
- The combination of cross-cutting quantitative and qualitative methodologies (for example, Pareto analysis, and Fuzzy Delphi Method as quantitative methods, and Prisma methodology, Compatibility check, and Playing Card as qualitative) and use of existing literature to support the research and enhance scientific validity of the results;
- The selection of a limited number of KPIs which allows for feasibility and replicability of the evaluation, but also gives space for integration and applicability to specific case studies;
- The integration, at different steps of the process, of participatory approaches which makes the assessment process more inclusive and dependent on the values and preferences of the local stakeholders;
- The possibility to use the framework for both general comparison between case studies (with the generic core KPIs) as well as the possibility for place-based contextualization (with the supporting indicators);
- The presentation of the implementation in three different European cities (Torino, Brussels, and Skellefteå) showing the possibilities of contextualization and replication of the framework, while simultaneously validating the identified set of core KPIs.

Considering the benefits of this proposed assessment framework, the proposed methodology can not only be replicated in other cities, but also enhanced by additional integrations that might strengthen the relevance of the framework in the transition to resilient, sustainable, and circular cities. An example of future use for the proposed framework could be the integration of weighting techniques, or the development of an interactive digital tool that recreates the framework and its results automatically based on the inputs of the users. More importantly, the main future benefit of the proposed framework is the use of the identified KPIs for assessment of baseline and future scenarios for the planning, implementation, and monitoring of ICAs (examples of KPIs assessment are provided by Pignatelli et al., 2023; Moghadam and Lombardi, 2019). In particular, KPIs and supporting indicators can be an important baseline for the inclusive development (through participatory methodologies) and technical assessment (through methodologies such as backcasting or what-if analysis) of future scenarios, a necessary step for envisioning and designing a just and inclusive climate transition. As a matter of fact, the complete impact assessment for evaluating the effectiveness of NbS in the cities of Torino, Brussels and Skellefteå is already under progress and will be presented in future publications to show the applicability of the proposed framework.

CRediT authorship contribution statement

Virginia Pellerey: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sara Torabi Moghadam:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

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

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APPENDIX I. Sources for the selection of indicators

ACADEMIC LITERATURE			
AUTHORS	TITLE	YEAR	JOURNAL
Liquete et al.	Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits	2016	Ecosystem Services
Watkin et al.	A Framework for Assessing Benefits of Implemented Nature-Based Solutions	2019	Sustainability
Sørup et al.	An SDG-based framework for assessing urban stormwater management systems	2019	Blue-Green Systems
Andreucci et al.	Designing Urban Green Blue Infrastructure for Mental Health and Elderly Wellbeing	2019	Sustainability

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ACADEMIC LITERATURE

AUTHORS	TITLE	YEAR	JOURNAL
Quatrini et al.	Is new always better than old? Accessibility and usability of the urban green areas of the municipality of Rome	2019	Urban Forestry & Urban Greening
Nika et al.	Nature-based solutions as enablers of circularity in water systems: A review on assessment methodologies, tools and indicators	2020	Water research
Okada et al.	A comparative method for evaluating ecosystem services from the viewpoint of public works	2021	Ocean & Coastal Management
Chrysoulakis et al.	Monitoring and Evaluating Nature-Based Solutions Implementation in Urban Areas by Means of Earth Observation	2021	Remote Sensing
Gonzalez-Ollauri et al.	The 'Rocket Framework': A Novel Framework to Define Key Performance Indicators for Nature-based Solutions Against Shallow Landslides and Erosion	2021	Frontiers in Earth Science
Balzan et al.	Assessing urban ecosystem services to prioritise nature-based solutions in a high-density urban area	2021	Nature-Based Solutions
Sowinska-Swierkosz et al.	An Assessment of the Ecological Landscape Quality (ELQ) of Nature-Based Solutions (NBS) Based on Existing Elements of Green and Blue Infrastructure (GBI)	2021	Sustainability
Qiu et al.	Assessing cost-effectiveness of nature-based solutions scenarios: Integrating hydrological impacts and life cycle costs	2021	Journal of Cleaner Production
Hysa	Introducing Transversal Connectivity Index (TCI) as a method to evaluate the effectiveness of the blue-green infrastructure at metropolitan scale	2021	Ecological Indicators
Rodl and Arlati	A general procedure to identify indicators for evaluation and monitoring of nature-based solution projects	2022	Ambio
Mabon et al.	Whose knowledge counts in nature-based solutions? Understanding epistemic justice for nature-based solutions through a multi-city comparison across Europe and Asia	2022	Environmental Science & Policy
Nasrabadi	How do nature-based solutions contribute to urban landscape sustainability?	2022	Environment, Development and Sustainability
Baldarelli and Cardillo	Managerial Paths, Social Inclusion, and NBS in Tactile Cultural Products: Theory and Practice	2022	Journal of Hospitality & Tourism Research
Caroppi et al.	A comprehensive framework tool for performance assessment of NBS for hydro-meteorological risk management	2023	Journal of Environmental Planning and Management
Asghari et al.	Resilience Assessment in Urban Water Infrastructure: A Critical Review of Approaches, Strategies and Applications	2023	Sustainability
Garcia-Blanco et al.	Adopting Resilience Thinking through Nature-Based Solutions within Urban Planning: A Case Study in the City of Valencia	2023	Buildings
Jegatheesan et al.	Co-development of an integrated assessment framework to evaluate the effectiveness and impact of selected nature-based water treatment technologies in Sri Lanka, The Philippines, and Vietnam	2023	Environmental Quality Management

EUROPEAN NBS PROJECTS

PROJECT	DOCUMENT	PUBLICATION YEAR
CITYKEYS	Smart City performance measurement system	2017
EKLIPSE	An impact evaluation framework to support planning and evaluation of nature-based solutions projects	2017
Nature4Cities	System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS	2018
UNaLab	Performance and Impact Monitoring of Nature-Based Solutions	2019
PHUSICOS	Comprehensive Framework for NBS Assessment	2019
URBAN GreenUP	City diagnosis and monitoring procedures	2019
Naturvation	URBAN NATURE NAVIGATOR - Exploring Indicators forNature-Based Solutions	2020
MAvES	Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment	2020
CONNECTING Nature	Nature-based solution evaluation indicators: Environmental Indicators Review	2020
EdiCitNet	Prioritised indicators and baseline	2020
Clever Cities	Monitoring strategy in the FR interventions	2020
proGIreg	Report on benefits produced by implemented NBS	2021
REGREEN	Conceptual framework for mapping and modelling ecosystem services	2022
GROW GREEN	Dissemination of Monitoring Results	2022
JUST NATURE	Conceptual & action framework on Low carbon | High air quality NbS potentials	2023

ASSESSMENT TOOLS AND FRAMEWORKS

TOOL	DOCUMENT	PUBLICATION YEAR
BREEAM	BREEAM Communities	2012
ARUP	City Resilience Index	2015
CASBEE	CASBEE city worldwide	2015
GEF-7	Sustainable Cities Impact Programme	2015
EBRD	Green City Action Plan methodology	2016
DGNB System	Districts criteria set	2020
IUCN	Global Standard for Nature-based Solutions	2020

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ASSESSMENT TOOLS AND FRAMEWORKS		
TOOL	DOCUMENT	PUBLICATION YEAR
SDG Indicators	Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development	2023
LEED	LEED for cities and communities	2023

EUROPEAN AND INTERNATIONAL REPORTS		
AUTHORS	DOCUMENT	PUBLICATION YEAR
OECD	Cities and Green Growth: A ConceptualFramework	2011
UNECE	Collection Methodology for Key Performance Indicators for Smart Sustainable Cities	2017
Global Platform for Sustainable Cities (GPSC)	Urban Sustainability Framework (USF)	2018
IPBES	The global assessment report on BIODIVERSITY AND ECOSYSTEM SERVICES	2019
GLOBAL COVENANT OF MAYORS	Common Reporting Framework	2019
European Commission	EVALUATING THE IMPACT OF NATURE-BASED SOLUTIONS	2021
INCA	Accounting for ecosystems and their services in the European Union	2021
European Commission	European handbook for SDG Voluntary Local Review	2022

POLICIES		
POLICY	DOCUMENT	PUBLICATION YEAR
Environment Action Programme to 2030	Monitoring framework for the 8th Environment Action Programme: Measuring progress towards the attainment of the Programme's 2030 and 2050 priority objectives	2022
European Council	Fit for 55	2023

STANDARDS		
STANDARD	TITLE	PUBLICATION YEAR
ISO 37120:2018	Sustainable cities and communities — Indicators for city services and quality of life	2018

APPENDIX II. Indicators removed during the refinement check

MACRO-CATEGORY	SUB-CATEGORY	INDICATOR	EXCLUSION PHASE	RATIONALE
Environmental impacts	Climate resilience	CO2 emissions due to building energy consumption	Initial refinement	Redundant with *Total CO2 emissions*
		GHG emissions	Initial refinement	Redundant with *Total CO2 emissions*
		Disaster Resilience (structural and functional)	Initial refinement	Indicator is too broad and not specifically related to the effects of NbS
		Monthly mean value of daily minimum temperature (TNn)	Initial refinement	Redundant with *Air temperature*
		Monthly mean value of daily maximum temperature (TXx)	Initial refinement	Redundant with *Air temperature*
		Multi-hazard early warning	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		CO2 emissions due to vehicle traffic	Initial refinement	Redundant with *Total CO2 emissions*
		Urban Heath Island effect (surface temperature and albedo)	Initial refinement	Redundant with *Air temperature*
		Raw Material Efficiency	Initial refinement	Indicator is not specifically related to the effects of NbS
		Circular material use rate	Initial refinement	Indicator is not specifically related to the effects of NbS
	Water management	Total rainfall volume	Initial refinement	Indicator is not specifically related to the effects of NbS
		Water quality: total faecal coliform bacteria content of NBS effluents	Initial refinement	Redundant with *Water quality*
		Metal concentration or load	Initial refinement	Redundant with *Water quality*
		Flooded area (area and population exposed)	Initial refinement	Redundant with *Number of people affected by natural disasters each year*
		Water quality: TSS content	Initial refinement	Redundant with *Water quality*
		Nitrogen and phosphorus concentration or load	Initial refinement	Redundant with *Water quality*

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MACRO-CATEGORY	SUB-CATEGORY	INDICATOR	EXCLUSION PHASE	RATIONALE
		Peak flow	Initial refinement	Redundant with *Flooding risk*
		% of permeable surfaces	Initial refinement	Redundant with *Flooding risk*
		Surface runoff in relation to precipitation quantity	Initial refinement	Redundant with *Flooding risk*
		Water quality	Experts refinement	Too difficult to discern specific effects of NbS as the indicator needs to be observed at an urban scale
		Water Exploitation Index	Experts refinement	Too difficult to discern specific effects of NbS as the indicator needs to be observed at an urban scale
		Flooded area	Experts refinement	Redundant with *Flooding risk*
		Drought risk and impact on ecosystems	Experts refinement	Indicator is not related to nbs in urban settings
	Green space management	Total carbon removed or stored in vegetation and soil per unit area per unit time	Initial refinement	Redundant with *Total CO2 emissions*
		Biotope area factor	Initial refinement	Redundant with *Flooding risk*
		Number of trees	Initial refinement	Redundant with *Air temperature*
		Soil water content	Initial refinement	Redundant with *Soil quality*
		Soil organic matter content	Initial refinement	Redundant with *Soil quality*
		Quantity of blue- green space (as a ratio to built form)	Experts refinement	Redundant with *Land use change* and *Accessibility of urban green space*
		NDVI - Normalized Difference Vegetation Index	Experts refinement	Redundant with *Total CO2 emissions*
	Biodiversity enhancement	Change in ecosystem service provision	Initial refinement	Indicator is too broad and not specifically related to the effects of NbS
		Designated terrestrial and marine protected areas	Initial refinement	Indicator is not realted to nbs in urban settings
		Changes in number of native species	Initial refinement	Redundant with *Species diversity within a defined area*
		Number of species within a defined area	Initial refinement	Redundant with *Species diversity within a defined area*
		Number of native species	Initial refinement	Redundant with *Species diversity within a defined area*
		Functional connectivity of urban green and blue spaces	Initial refinement	Merged with *Structural connectivity of urban green and blue spaces*
		Species diversity within a defined area	Experts refinement	Too broad, difficult to evaluate empirically
	Air quality	European Air Quality Index	Initial refinement	Redundant with *Concentration of PM10, PM2.5, NO2, and O3 in ambient air*
		Annual O3, SO2, NO2, CO, and PM2.5 capture/ removal by vegetation	Initial refinement	Redundant with *Concentration of PM10, PM2.5, NO2, and O3 in ambient air*
		Proportion of population exposed to ambient air pollution	Initial refinement	Redundant with *Concentration of PM10, PM2.5, NO2, and O3 in ambient air*
	Energy	Share of renewable energy in gross final energy consumption	Initial refinement	Indicator is not specifically related to the effects of NbS
		Buildings Energy needs	Initial refinement	Redundant with *Cumulative energy demand*
		Cumulative Energy Demand	Experts refinement	Redundant with *Sum of energy savings caused by Nature-based Solutions*
Economic impacts	New Economic Opportunities and Green Jobs	Public-Private Partnership Activated	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Establishment of new businesses in the area surrounding NBS	Initial refinement	Redundant with *Direct economic activity: Number of new jobs created*
		Direct economic activity: Gross value added to local economy from new business creation	Initial refinement	Redundant with *Direct economic activity: Number of new jobs created*
		Number of subsidies, tax reductions or financial support applied for NBS measures	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Valuation of NBS: Value of NBS calculated using GI-Val	Initial refinement	Too broad, difficult to evaluate empirically
Social impacts	Knowledge and Social Capacity Building	Social learning regarding ecosystems and their functions	Initial refinement	Redundant with *Citizen involvement in environmental education activities*

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MACRO-CATEGORY	SUB-CATEGORY	INDICATOR	EXCLUSION PHASE	RATIONALE
		Awareness of citizens regarding urban nature & ecosystem services	Experts refinement	Too broad, difficult to evaluate empirically
	Participatory Planning and Governance	Policies set up to promote NBS	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Openness of participatory processes	Initial refinement	Redundant with *Proportion of citizens involved in participatory processes*
		Policy learning concerning adapting policies and strategic plans	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Policies Set Up To Promote NBS	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Disaster-risk informed development	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Climate resilience strategy development	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Sense of empowerment: perceived control and influence over decision-making	Experts refinement	Redundant with *Proportion of citizens involved in participatory processes*
		Consciousness of citizenship (sense of belonging)	Experts refinement	Redundant with *Quality of interactions within and between social groups (bridging and bonding)*
	Social Justice and Social Cohesion	Place attachment: Place identity or "sense of place"	Initial refinement	Too broad, difficult to evaluate empirically
		Bonding – quality of interactions within and between social groups	Initial refinement	Merged with *Bridging - quality of interactions between social groups*
		Access to public amenities and services	Initial refinement	Indicator is not specifically related to the effects of NbS
		Amount and accessibility of recreational space	Initial refinement	Redundant with *Accessibility of urban green space and recreational space*
		Availability and equitable distribution of blue-green space	Initial refinement	Redundant with *Accessibility of urban green space and recreational space*
		Safety	Experts refinement	Indicator is not specifically related to the effects of NbS
		Inclusion of different social groups in NBS co-co-co processes	Experts refinement	Redundant with *Proportion of citizens involved in participatory processes*
	Health and wellbeing	PET - Physiological equiv. temperature	Initial refinement	Merged with *Thermal comfort*
		General wellbeing and happiness	Initial refinement	Too broad, difficult to evaluate empirically
		Level of chronic stress (perceived stress)	Initial refinement	Redundant with *Self-reported mental health and wellbeing*
		Estimated years of life lost due to climate and pollution	Experts refinement	Redundant with *Estimated morbidity and mortality associated with climate change and air pollution*
		Self-reported mental health and wellbeing	Experts refinement	Too subjective, difficult to evaluate empirically
	Place regeneration	Proportion of road network dedicated to pedestrians and/or bicyclists	Initial refinement	Indicator is not specifically related to the effects of NbS
		Risk to critical urban infrastructure	Initial refinement	All policy-related indicators have been excluded (beyond scope of the analysis)
		Public transport service	Initial refinement	Indicator is not specifically related to the effects of NbS
		Ratio of land consumption rate to population growth rate	Initial refinement	Indicator is not specifically related to the effects of NbS
		Land reclaimed for NBS	Initial refinement	Redundant with *Land use change*
		Cultural value of blue-green spaces	Initial refinement	Merged with *Recreational value of public green space*
		Proportion of area devoted to roads	Initial refinement	Indicator is not specifically related to the effects of NbS
		Recreational and cultural value of public green space	Experts refinement	Indicator is not specifically related to the effects of NbS

APPENDIX III. – Set of KPIs

NUMBER OF PEOPLE ADVERSELY AFFECTED BY NATURAL DISASTERS EACH YEAR

Macro-category: Environmental impacts
Sub-category: Climate resilience

DESCRIPTION

Count and spatial distribution of people affected by natural disasters. Note: this KPIs could be combined with "Mean annual direct and indirect losses due to natural and climate hazards".

UNIT OF MEASURE	LEVEL	TYPOLOGY
n° of people	City District	outcome

ASSESSMENT METHODOLOGY

The definition of the mean number of people affected each year is given as the proportion of the number of people exposed to disasters that occur at annual frequency by the total population of the area.

INTENT FOR NBS	JUSTICE PRINCIPLES
Assessment of the impact and distribution of natural disasters; Evaluation of the effectiveness of NbS in reducing climate hazards	Rigorous assessment of mitigation and adaptation benefits; People's relationship with land and nature repaired and supported

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- GPSC – Urban Sustainability Framework
- UNECE – Collection methodology for KPIs for smart sustainable cities

STRUCTURAL AND FUNCTIONAL CONNECTIVITY OF URBAN GREEN AND BLUE SPACES

Macro-category: Environmental impacts
Sub-category: Biodiversity enhancement

DESCRIPTION

Structural connectivity is the proximity of blue-green spaces and the infrastructure matrix across a city. Functional connectivity the ability of the landscape to support the movement of organisms through it.

UNIT OF MEASURE	LEVEL	TYPOLOGY
hectares 0-1 index	City District	outcome

ASSESSMENT METHODOLOGY

Natural areas are categorized into separate interconnected patches. The area of each patch is summed, squared and these squares are summed and divided by the total area of natural areas.
Conefor software (or similar GIS tools) can be used to calculate the integral index of connectivity. This represents a method for combining the distance between patches with the threshold dispersal distance of a certain species.

INTENT FOR NBS	JUSTICE PRINCIPLES
Assessment of the impact of NbS in supporting biodiversity enhancement in a district/city	Rigorous assessment of mitigation and adaptation benefits

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- IPBES – The global assessment report on biodiversity and ecosystem services

ANNUAL CO2 EQUIVALENT EMISSIONS

Macro-category: Environmental impacts
Sub-category: Climate resilience

DESCRIPTION

Total amount of CO2 emitted and stored within the study area.

UNIT OF MEASURE	LEVEL	TYPOLOGY
t/y	City District	outcome

ASSESSMENT METHODOLOGY

CO2 equivalent emissions are calculated through the observation of two variables: (1) the total CO2 produced by buildings and vehicular traffic and (2) the carbon storage and sequestration performed by the vegetation.

INTENT FOR NBS	JUSTICE PRINCIPLES
Assessment of the impact of human activities; Evaluation of the effectiveness of NbS absorbing and reducing CO2	Rigorous assessment of mitigation and adaptation benefits

REFERENCES
- Global Covenant of Majors – Common reporting framework
- 8th Environment Action Programme: Measuring progress towards the attainment of the Programme's 2030 and 2050 priority objectives

AIR TEMPERATURE
(reduction of heath island effect)

Macro-category: Environmental impacts
Sub-category: Climate resilience

DESCRIPTION

Measurement of mean and peak daytime temperature, includes the effect of albedo and tree shades as factors affecting air temperature.

UNIT OF MEASURE	LEVEL	TYPOLOGY
°C	District	outcome

ASSESSMENT METHODOLOGY

Ambient air temperature can be assessed through continuous monitoring of temperature, near the NBS intervention area, and evaluation of the maximum daily temperature before and after NBS implementation.
In addition, the temperature is measured in different locations in order to evaluate the impact of vegetation (tree shade) on reducing the heat island effect.

INTENT FOR NBS	JUSTICE PRINCIPLES
Assessment of the impact and distribution of climate change impacts; Evaluation of the effectiveness of NbS in regulating air temperature	Rigorous assessment of mitigation and adaptation benefits

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- Connecting Nature – Nature-based solution evaluation indicators: environmental indicators review

RAINWATER AND GREYWATER CAPTURE AND REUSE

Macro-category: Environmental impacts
Sub-category: Water management

DESCRIPTION

Volume of rainwater or greywater captured and re-used for irrigation or other purposes.

UNIT OF MEASURE	LEVEL	TYPOLOGY
m3/y	Building District	outcome

ASSESSMENT METHODOLOGY

Accurate accounting of rainfall capture (to be re-used) requires use of a water level sensor to measure the volume of water contained within a given rainwater storage unit at any time.

INTENT FOR NBS	JUSTICE PRINCIPLES
Assessment of the efficiency of NbS in reducing impacts of human activities on natural resources	Rigorous assessment of mitigation and adaptation benefits; Regenerative and sustainable economic pathways

REFERENCES
- UNaLab – Performance and impact monitoring of nature-based solutions
- proGIreg – Report on benefits produced by implemented NbS
- Watkin et al. (2019)

COST OF ONGOING GREEN AND BLUE INFRASTRUCTURE MAINTENANCE PLANS

Macro-category: Economic impacts
Sub-category: New economic opportunities and green jobs

DESCRIPTION

Costs incurred to keep the project in good condition or good working order (must include total annual labour costs, land leasing costs, machinery, energy costs, licensing, etc.).

UNIT OF MEASURE	LEVEL	TYPOLOGY
€	Building	process

ASSESSMENT METHODOLOGY

Data can be collected via an economic and labour questionnaire to be distributed to the entities in charge of long-term maintenance of the planned or implemented NBS. Estimation from project financial assessment.

INTENT FOR NBS	JUSTICE PRINCIPLES
Assessment of the long-term costs of NbS; Analysis of the feasibility for NbS to endure in the long term against other possible solutions	Regenerative and sustainable economic pathways

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- Clever Cities - Monitoring strategy in the FR interventions
- proGIreg – Report on benefits produced by implemented NbS

MEAN ANNUAL DIRECT AND INDIRECT LOSSES DUE TO NATURAL AND CLIMATE HAZARDS

Macro-category: Economic impacts
Sub-category: New economic opportunities and green jobs

DESCRIPTION

Expected annual damage (monetary) from hydrometeorological risks.

UNIT OF MEASURE	LEVEL	TYPOLOGY
€	City	outcome

ASSESSMENT METHODOLOGY

Evaluation of change in Expected Annual Damage (EAD) after the implementation of NbS.

INTENT FOR NBS

Assessment of the efficiency of NbS in reducing economic losses caused by climate hazards

JUSTICE PRINCIPLES

Regenerative and sustainable economic pathways

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- UNECE - Collection Methodology for Key Performance Indicators for Smart Sustainable Cities

CITIZEN INVOLVEMENT IN ENVIRONMENTAL EDUCATION ACTIVITIES

Macro-category: Social impacts
Sub-category: Knowledge and social capacity building

DESCRIPTION

Number of educational programs sponsored by schools, universities, municipal recreation departments, local or international not-for-profit organizations, and private entrepreneurs.

UNIT OF MEASURE	LEVEL	TYPOLOGY
n° of educational programs	City District	outcome

ASSESSMENT METHODOLOGY

Scale inventory / questionnaire : add-on items to any survey/questionnaire to collect accounts of EE programs attended in the past year, if any, as well as topic/theme covered; open-ended question(s) can be included to collect information about perceived usefulness, and/or how the knowledge/skills garnered have been put to use, if the case.

INTENT FOR NBS

Evaluation of the social impacts of NbS; Analysis of the impact of NbS on future social transformations

JUSTICE PRINCIPLES

Rigorous assessment of mitigation and adaptation benefits

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- IPBS - The global assessment report on biodiversity and ecosystem services
- LEED - LEED for cities and communities

ESTIMATED MORBIDITY AND MORTALITY ASSOCIATED WITH CLIMATE CHANGE

Macro-category: Social impacts
Sub-category: Health and wellbeing

DESCRIPTION

Prediction of illness and death rates caused by environmental or social factors.

UNIT OF MEASURE	LEVEL	TYPOLOGY
n° cases/y	City	outcome

ASSESSMENT METHODOLOGY

The health response is usually calculated by: $\Delta R = IR \times CRF \times \Delta C \times Pop$
- ΔR is the response as a result of the number of cases;
- IR is the baseline morbidity/mortality annual rate;
- CRF is the correlation coefficient between the risk variation and the probability of experiencing a specific health indicator;
- ΔC indicates the change in risk after adoption of NbS

INTENT FOR NBS

Evaluation of the social and well-being impacts of NbS; Assessment of the efficiency of NbS in reducing health risks

INTENT FOR ICAS

People's relationship with land and nature repaired and supported

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- 8th Environment Action Programme: Measuring progress towards the attainment of the Programme's 2030 and 2050 priority objectives

EXPOSURE TO NOISE POLLUTION

Macro-category: Social impacts
Sub-category: Health and wellbeing

DESCRIPTION

The per cent reduction of noise level measured at the receiver, or the number of inhabitants exposed to noise >55 dB(A).

UNIT OF MEASURE	LEVEL	TYPOLOGY
%	District	outcome

ASSESSMENT METHODOLOGY

Noise reduction can be calculated as:

$$\left(\frac{dB(A)\ level\ after\ NBS\ implementation}{dB(A)\ level\ before\ NBS\ implementation}\right) \times 100 = \%\ change\ in\ noise\ level$$

Or as:

$$\left(\frac{No.\ inhabitatants\ exposed\ to\ noise > 55\ dB(A)}{Total\ number\ of\ inhabitants}\right) \times 100 = \%\ population\ affected\ by\ noise$$

INTENT FOR NBS

Evaluation of the social and well-being impacts of NbS; Assessment of the efficiency of NbS in reducing health risks

INTENT FOR ICAS

Alternatives to appropriation of land for greening and conservation; No land speculation and associated gentrification; No greenwashing and privatization of nature for profit

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- Nature4cities - System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges

LAND USE CHANGE

Macro-category: Social impacts
Sub-category: Place regeneration

DESCRIPTION

Assessment of changes in the urban forms, with specific attention to the reclamation of land for NbS.

UNIT OF MEASURE	LEVEL	TYPOLOGY
%	City District	process

ASSESSMENT METHODOLOGY

Using RS data and/or optical images, the territory can be classified depending on the type of the activities of the population with their morphotypes. The map of functional zonation of the city allows the identification of the optimal level of distribution of ecologically unfavourable, neutral or favourable plots. Moreover, the RS technics can be used to study the ecological state of ecologically favourable plots.

INTENT FOR NBS	INTENT FOR ICAS
Evaluation of both the social effects and the effects on the urban environment of NbS	Alternatives to appropriation of land for greening and conservation; No land speculation and associated gentrification; No greenwashing and privatization of nature for profit

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- Connecting Nature - Nature-based solution evaluation indicators: Environmental Indicators Review

ACCESSIBILITY OF URBAN GREEN AND BLUE SPACE AND RECREATIONAL SPACE

Macro-category: Social impacts
Sub-category: Social justice and social cohesion

DESCRIPTION

Percentage of residents living within acceptable access of the available green and recreational areas.

UNIT OF MEASURE	LEVEL	TYPOLOGY
n° of residents	City District	outcome

ASSESSMENT METHODOLOGY

1. Identify and map arrival points of public green or recreational spaces equal to or greater than 0.5 ha in size.
2. With GIS tools, create a pedestrian isochrone to identify all buildings within 15 minutes walking
3. Using census area or similar data, determine the total number of residents within all the mapped 15 min isochrone

INTENT FOR NBS	JUSTICE PRINCIPLES
Evaluation of both the social effects and the effects on the urban environment of NbS	Alternatives to appropriation of land for greening and conservation; No land speculation and associated gentrification; No greenwashing and privatization of nature for profit

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- UNECE - Collection Methodology for Key Performance Indicators for Smart Sustainable Cities

PROPORTION OF CITIZENS INVOLVED IN PARTICIPATORY PROCESSES

Macro-category: Social impacts
Sub-category: Participatory planning and governance

DESCRIPTION

The proportion of citizens involved in participatory governance and design/planning phases.

UNIT OF MEASURE	LEVEL	TYPOLOGY
%	City District	process

ASSESSMENT METHODOLOGY

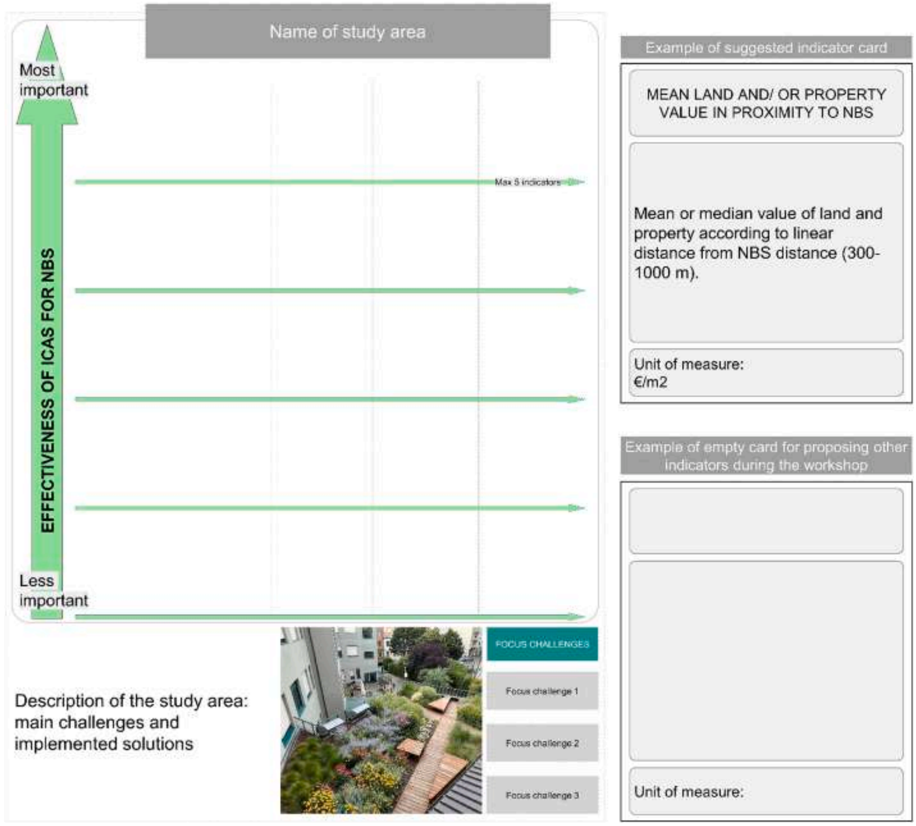
Openness of participatory processes (%) is calculated as

$$\left(\frac{\text{Total number of open public participation processes}}{\text{Population of city}/100000}\right) \times 100$$

INTENT FOR NBS	JUSTICE PRINCIPLES
Evaluation of the social impacts of the planning process of NbS; Analysis of the impact of NbS on future social transformations	Inclusive empowering and participatory schemes; Long-term green inequalities tackled

REFERENCES
- European Commission – Evaluating the impact of nature-based solutions
- ISO 37120:2018 - Sustainable cities and communities — Indicators for city services and quality of life

APPENDIX IV. Example of board and indicator cards to be used during the workshops



Data availability

Data will be made available on request.

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