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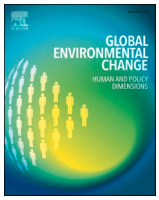

Measuring the contribution of nature-based solutions beyond climate adaptation in cities

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ABSTRACT

Measuring the contribution of urban nature-based solutions (NbS) to climate change adaptation is an essential, though complex, step towards understanding who benefits from them, as well as when, where, how and why. However, urban NbS are also framed as being able to meet multiple objectives relating to biodiversity conservation as well as associated social challenges. The complexity of addressing multiple challenges, combined with conflicting visions of what climate adaptation means at the local level, further burdens the identification of clear and relevant goals, processes and information to track progress (i.e. contributions) towards urban adaptation. To explore and question how current on-the-ground practices address this complexity, we analysed a global dataset of indicators (n = 750 indicators) from 74 NbS projects in 61 cities across 40 countries based on an assessment of the literature regarding information and processes used for evaluating urban NbS for adaptation. This was combined with interviews with local actors who evaluate these NbS projects (n = 15). Our results indicate that current urban NbS projects do not appear to balance climate adaptation with other goals, nor do they uniformly conform to prevailing technical standards of quality of traditional monitoring, evaluation and learning processes. Currently NbS projects tend to primarily prioritise shorter-term high-quality ecological indicators, mostly related to biodiversity, while generally other longer-term social and technical indicators lack quality despite capturing a diversity of potential medium- to long-term contributions of NbS. Various political and social factors that influence the way urban NbS to adaptation are evaluated typically go beyond evaluation purposes and range from using indicators to promote NbS as cost-effective solutions or particular political agendas. The diversity of what makes good information and processes to measure contributions to urban adaptation bolsters calls for establishing processes for flexible, commonly agreed-upon guiding principles. We suggest locally grounded recommendations to help identify fit-for-purpose information and processes to evaluate the potential of urban NbS to address interconnected climate, biodiversity, and societal challenges.

1. Introduction

Nature-based solutions (NbS) are becoming central within international climate and biodiversity governance agendas for their potential role as both climate change adaptation and biodiversity conservation strategies (CBD, 2022; Dodman et al., 2022; UNFCCC, 2022). Though proponents of NbS argue they can be "powerful" approaches to deal with the global climate and biodiversity crisis (Melanidis and Hagerman, 2022), and experiments with their use have emerged across all world regions (Morita and Matsumoto, 2021; Debele et al., 2023; Goodwin et al., 2023; Rawlins et al., 2023), their proven effectiveness in the context of adaptation has long been the subject of debate (Kabisch et al., 2016; Mills-Novoa, 2023). This is especially the case in cities as urban climate adaptation policies and actions often lack clear vulnerability and risk reduction goals and means to prove their progress in meeting them (Olazabal et al., 2019; Dodman et al., 2022). This also relates to what it means to "adapt" in cities, and relatedly what information and processes need to be used to measure progress towards such an objective (Dilling et al., 2019; Singh et al., 2022). Conceptual and practical complexities are particularly acute in the case of urban NbS for adaptation because of

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their framing as strategies with multiple co-benefits beyond climate change action, such as societal development and biodiversity conservation (Dodman et al. 2022).

Numerous frameworks have been developed to clarify how the multiple co-benefits of urban NbS can be measured including and beyond adaptation, for example, human health and climate change mitigation (Raymond et al., 2017; European Commission, 2021). More generally, attention to the interconnected climate, biodiversity and social challenges that shape them has grown. This is referred to as the Climate-Biodiversity-Society, or CBS, nexus (Pascual et al., 2022; Pörtner et al., 2023), and is further reflective of more established trends in sustainability science and practice of taking a systems approach to environmental problems (Pintér et al., 2012). Cities are a unique arena to study the implications of CBS challenges through NbS owing to the interplay of local social, ecological, and technical (SET) dynamics (McPhearson et al., 2022). Implementers of urban NbS are challenged to develop evaluation tools that are relevant to joint CBS challenges and specific SET dynamics in their city.

Identifying relevant information for evaluating the effectiveness of urban NbS towards interlinked climate, biodiversity and societal challenges poses unique hurdles compared to less anthropised landscapes (Van Der Jagt et al., 2023). This is further complicated by the need to operationalise monitoring, evaluation and learning (MEL) frameworks that need to comply with high technical standards of the measurement and reporting of progress (Dodman et al., 2022). However, it is unclear how this complexity can effectively translate into good decision-making as well as how these MEL objectives of relevance and quality can be met. Specifically, understanding what information and processes are good (i.e. more effective and comprehensive) to evaluate urban NbS can help identify capacity-building needs for urban adaptation projects while also providing feedback to both communities of research and practice about how adaptation processes are perceived, evaluated and learnt from.

To contribute to the field, here we use data on current evaluation practices collected from on-the-ground urban NbS initiatives through a mixed-method and interdisciplinary approach, to address three interconnected questions that emerge from the above discussion. First, how relevant is the information currently used to measure the contribution of urban NbS to CBS challenges beyond adaptation? Second, to what extent is this information integrated into high-quality MEL processes? Lastly, how do local urban contexts and actors help explain our findings related to the first two questions?

2. Literature review and conceptual framework

Measuring the contribution of urban NbS to adaptation

The effectiveness of NbS in providing adaptive and other co-benefits is often discussed through (usually quantitative) indicators. Numerous frameworks and guidelines have been developed to identify indicators and methods to measure them (Raymond et al., 2017; GIZ, Unep-Wcmc, and FEBA, 2020; Donatti et al., 2021; European Commission, 2021). Other guiding principles have been developed that identify common concepts that are important to understand progress through the application of NbS generally, though not specifically related to the urban context or adaptation (Seddon et al., 2021). Explicit attempts have been made to identify standardised and universal ideal sets of indicators to evaluate separately the climate (Donatti et al., 2020), biodiversity (Pearce-Higgins et al., 2022), and social (particularly social justice) (Kato-Huerta and Geneletti, 2022) aspects of urban NbS, as well as jointly (Liu, Jay and Chen, 2021; Epelde et al., 2022; Ommer et al., 2022). More generally, international governance processes on adaptation have followed this push towards standardising evaluation of adaptation strategies globally, as seen through the Global Goal on Adaptation emerging from the Paris Agreement (UNFCCC Secretariat, 2022).

However, standardising the information used to evaluate adaptation actions via sets of indicators is controversial. Some detractors criticise the view of adaptation as a "technical solution to a technical problem", highlighting how the complex local realities of cities prevent any standardisation of adaptation goals and thus the information needed to evaluate progress towards them (Chmutina et al., 2023). The technocratic push towards standardisation is also argued to create other risks of homogenising adaptation actions and insufficiently addressing local adaptation needs, potentially exacerbating structural inequalities and maladaptive practices and outcomes (Lecavalier et al., 2023).

Indicators can also be seen as one way of collecting information that can be used to monitor, evaluate, and learn from adaptation actions. Here, we use the term "information" broadly to refer to specific iterations of knowledge gained through the study of the effectiveness of a given adaptation action (Cross et al., 2022). Beyond indicators, there are other approaches to generating information to understand whether desired adaptive benefits have been achieved through NbS. For example, some approaches focus on institutional and other forms of learning for building resilience to climate change (Collier et al., 2023) or adaptation pathways and theories of change, to recognise changes in knowledge, values, and rules within city systems (Colloff et al., 2021). Subjective approaches also exist to capture local perceptions and experiences from the application of urban NbS (McNamara et al., 2020). Recent work advocates for developing commonly agreed-upon guiding principles that define progress by reference to higher-level shared goals that can be particularised using flexible and context-dependent information identified locally, rather than replicating standard approaches (Seddon et al., 2021; Bulkeley et al., 2023). This is a way of "setting standards" rather than "standardising" MEL processes (Bulkeley, 2015, pp. 114–117; Lecavalier et al., 2023).

Creating guiding principles on how to measure progress on environmental challenges is a topic long-researched and debated. As early as the 1990 s in the area of sustainability science and policy, scholars and practitioners have devised different principles to frame best practices for MEL emphasising the importance of a clear vision, a systems approach, or transparency, among others (Pintér et al., 2012). Information systems have also been argued to require salient, credible, and legitimate processes for evaluation and decision-making (Cash et al., 2003). For adaptation specifically, criteria for context specificity and flexibility (Yohe and Tol, 2002), effectiveness, efficiency, equity, and legitimacy (Neil Adger et al., 2005), and consistency, comparability, comprehensiveness, and coherency (Ford and Berrang-Ford, 2016) have been discussed.

Less clear is why, after several decades of discussions on best practices across these different fields, more progress has not been made on MEL for adaptation. Although answering this question may have numerous entry points that go beyond indicator selection, we here focus on how and why certain information is used within MEL processes in the context of urban NbS for adaptation. This entry point responds to urgent questions raised in the literature on why certain parts of the claimed benefits of NbS are given priority over others despite calls they need to be framed and evaluated in an integrated way (Donatti et al., 2020; Pascual et al., 2022; Goodwin et al., 2023).

To answer the question of why more progress has not been made in MEL for adaptation, we propose the use of two guiding principles: *relevance* and *quality*. That is, as NbS are framed as unique strategies for adaptation that provide simultaneous social and ecological benefits, NbS must then also be evaluated using information that is *relevant* to each of these areas simultaneously. In addition, while this defines the scope of the content of evaluating information, selecting relevant information is not sufficient to comprehensively evaluate the contribution of NbS if this information is not expressed within high-quality MEL processes (i.e. *quality)*.

Relevance: the importance of selecting information relevant to urban NbS.

General framing.

Good information to evaluate urban NbS is information that is relevant to cities as SET systems that face specific CBS challenges and must

specifically attribute progress to the implementation of the NbS. We use the word "relevant" here as distinct from salient. Though sometimes used synonymously (Cash et al., 2003) the two terms have been argued to be distinct in that saliency relates more to the objective contextual importance of information, while relevance connects more to the importance of information in a given context that is explained by particular goals or motivations (Pattabhiraman and Cercone, 1990). For example, the concept of salience helps us identify whether urban trees to combat heatwaves are planted in hot parts of a city and are in a stage of their growth cycle where they provide shade and other benefits (i.e., salient information refers to verifiable contextual characteristics of where and when trees are planted). Relevance pushes us to additionally consider whether measuring how many trees are planted (even if they are planted in the right place at the right time) is enough information to know if an NbS is achieving its goals. For example, if it includes the distributional impacts of adaptive benefits among the citýs most vulnerable, or actual reductions in temperatures at street levels in the long term. In short, relevance requires us to consider what and whose interests are at stake in motivating NbS for adaptive purposes, how they are affected by NbS, and provide clear causal links that explain why they create the change needed to meet specific goals.

CBS nexus and SET approach to help identify relevant information.

Climate change, adaptation, and re-naturing cities do not impact urban systems in uniform ways. Using SET system theory to analyse urban decisions and interventions is useful to clarify *what* and *whose* interests are prioritised and who is benefitting from those interventions (Tozer et al., 2020; McPhearson et al., 2022). For example, urban greening may provide benefits to residents through lower temperatures (social dimension), opportunities for biodiversity to thrive (ecological dimension), and reduce impact on stormwater systems during heavy rainfall events (technical dimension), each of which has unique requirements for conceptualisation, prioritisation, and, also, measurement (McPhearson et al., 2022; Van Der Jagt et al., 2023).

Further, conceptual advancements on the CBS nexus are useful to identify *whether* and *how* NbS is addressing climate change, biodiversity loss, and social challenges such as social injustices (Baldwin-Cantello et al., 2023). For example, addressing increasing storm surge due to climate change may be done through foreshore revitalisation using native species (i.e. biodiversity challenge) in a way that benefits the most vulnerable (a social challenge). These challenges may then be evaluated using information such as the number of people benefited or damages to property avoided (i.e., social or technical information related to climate), increases in species abundance or richness (i.e., ecological information related to biodiversity), or the distributional impact of the NbS on identified vulnerable groups (i.e., social information related to social challenges).

In the context of adaptation through NbS, there is ongoing debate about how these climate and biodiversity stress (CBS) challenges share numerous drivers, feedbacks, and impacts, often resulting in blurred boundaries between them (Pascual et al., 2022; Pörtner et al., 2023). Nonetheless, there are numerous conceptual distinctions and methodological decisions that help highlight their unique areas of focus. For example, climate challenges addressed by urban NbS can be framed as the type of climate vulnerability being addressed, categorised as either (1) reducing risk exposure at the scale that a population or area is affected by climatic risks; (2) reducing risk sensitivity in terms of the magnitude at which a given population/area is affected or; (3) supporting adaptive capacity as related to the level of preparedness that the population/area possess to respond to climatic risks (Seddon et al., 2020; IPCC, 2022). Additionally, how indicators may relate to addressing biodiversity challenges, for example, can be seen as whether indicators measure the way a given NbS restores, protects, or helps manage the ecosystems involved, or the degree to which it creates novel ecosystems (Chausson et al., 2020; Seddon, 2022). Lastly, addressing social challenges is often connected to whether indicators measure the NbS contribution to issues of social justice, understood to include procedural (i.e., how stakeholders are included or not in decision-making processes), recognition (i.e., how the different values, perspectives, and needs are incorporated into project designs), and distributive justice (i.e., how the project addresses potential trade-offs in the distribution of benefits and burdens relating to its implementation) (Goodwin et al., 2023). Furthermore, centring social challenges in the context of justice makes explicit whether or not NbS account for the potential for maladaptive social consequences (Colléony and Shwartz, 2019; Cousins, 2021).

The overlap in terminology requires us to provide examples to help clarify how theory on the CBS nexus and SET systems can complement each other to advance scientific and practical approaches to understanding the contribution of NbS to cities beyond adaptation. For instance, social information in the SET dimension could include, how many people benefit from a given NbS intervention. Social information relevant to the CBS nexus could then further include how many people benefit from an intervention disaggregated by gender, racial or ethnic identity, and economic status, among other intersectional characteristics (Amorim-Maia et al., 2022; Pörtner et al., 2023). Similarly, although in some uses of the term, "ecology" (e.g. in SET theories) may cover concepts of both climate and biodiversity (as typically the case within the CBS framework), their usage here more relates to the connection of more basic information about urban ecology (e.g., number of trees planted within an NbS) with more contextual, issue-specific information (e.g., reduction of ambient temperatures on streets (climate), changes in species richness (biodiversity). The combination of both areas of theory is complementary in that it connects the *what* and *who* (SET theory) to the *how* (CBS nexus) in framing what can be relevant within the MEL of NbS with primarily adaptive benefits.

Process and progress information

Information used to evaluate urban NbS must be relevant in that it clearly attributes benefits achieved to the implemented NbS. This must include a causal explanation of *why* the implementation of the specific NbS contributes to its stated goals, and *when* it does so (i.e., over the short, medium and long-term) (Dumitru et al., 2020). This is often addressed by identifying and connecting what are termed "process" and "progress" indicators. Starting from the planning and initial implementation stage, process indicators include "inputs" (i.e., resources applied to the project, e.g., "money invested in project") that are leveraged to create the intended shorter-term "outputs" of the project (i.e., activities and projects that result from the action, e.g., "number of trees planted"). These must be connected to longer-term progress indicators that summarise the intended goals to be met through the project, including both "outcomes" (i.e., changes in behaviour as a result of the activities, usually medium-term, e.g., "temperature reduction on street level"), and "impacts" (i.e., longer-term changes in social, ecological, or technical dimensions of the city, e.g., "reduction in hospitalisations during heatwaves") (Hale et al., 2021). Including both shorter-term process indicators and longer-term progress indicators is essential to ensure that both MEL processes and information used within them are forward-looking, thereby attempting to account for the inherent uncertainty in how present actions will affect future climate impacts (which themselves are deeply uncertain) (Nightingale et al., 2022).

Our focus is not on prescribing what information must be included in MEL frameworks. Instead, we emphasise defining what constitutes good information and effective evaluation processes for NbS in a way that is flexible and sensitive to specific contexts. Used as an analytical framework, this understanding further helps identify which CBS challenges, SET dimensions, and casual connections of process and progress are underrepresented in evaluation practices and why. This kind of approach based on guiding principles, rather than prescriptively defining standardised indicators, is emerging in local practice as a way to balance the need for locally-relevant information with the desire to develop shared visions for understanding progress in urban adaptation through NbS (Bulkeley et al., 2023).

Quality: Embedding relevant information into high-quality MEL processes

Defining what information and processes are good to evaluate urban NbS further requires consideration of the *quality* of those MEL processes they are embedded within. For this, it is necessary to first evaluate the overall level of detail with which the information is translated into indicators. This relates to the level of generality and degree of quantifiability of the indicators used, as highly detailed indicators ideally provide unambiguous and quantifiable elements to be measured (Arnott et al., 2016).

There is debate over the specific characteristics and processes required to create high-quality information for evaluation in research and practice (Olhoff et al., 2018; Pringle and Leiter, 2018). However, applied research highlights several best practice criteria that are important to assess. These criteria cover practical considerations such as setting quantifiable units and targets for measurement, that is repeated over the course of the project, and identifies clear roles for collection and reporting of data in a way that follows identified best practice in that field (if applicable) (Goonesekera and Olazabal, 2022). Finding a way to operationalise these criteria has been highlighted as key to improving MEL practices specifically for urban adaptation (Dodman et al., 2022).

Other research highlights additional considerations that go beyond information and how it is used. For example, flexibility has been highlighted as crucial for learning from monitoring and evaluation processes and adapting to changing needs and climate impacts during a project, but is often overlooked in practice (Ensor and Harvey, 2015; Huang and Harvey, 2021; Dekens and Harvey, 2024). We acknowledge that the quality of learning within MEL may require other criteria than those discussed here. However, as discussed above we focus on the informational components of MEL and so specific discussions of the quality of learning goes beyond the scope of this article.

3. Data and methods

The data.

To identify urban NbS with adaptive co-benefits, we sourced secondary data drawn from an existing systematic mapping exercise which collected data on 216 urban NbS to climate adaptation from online databases containing information on urban NbS (Goodwin et al., 2023). The results of this mapping are available freely online (Goodwin et al., 2022). To identify urban NbS projects with MEL experience, we identified projects from that dataset that made some reference to the use of indicators evaluating progress towards their goals using the documentation initially catalogued by Goodwin et al. (2023). This included the web pages within each database that describe the project, as well as supporting documentation linked to the database and found through further internet searches (e.g., MEL and other project reports). A subsample was generated that included all projects that made some reference to indicators. In this filtering process, indicators were defined as any piece of information that was used, according to the sources consulted, to evaluate whether the NbS was on track to address a given problem. This resulted in the selection of 74 NbS projects in 61 cities from 40 countries (see Supplementary Information 1 (SI1) for a description of the documentation protocol, and Table 6, Supplementary Data 1, for the list of NbS projects included in the sub-sample).

Indicators were extracted for processing and content analysis (n = 776). To do this, first, the text contained within the landing pages of each of the 74 projects was analysed, along with any associated documentation to identify any information that related to measuring progress towards the project's goals. Second, those passages of text containing measurement information were broken down into individual indicators which were extracted into a spreadsheet. Most indicator descriptions were extracted verbatim as they were referenced in the source. Some were slightly reworded to maintain a consistent format (see Fig. 1 and Supplementary data 1). In all cases, the extraction of information was guided by the same selection process, i.e., any information that was referenced in the source material that was provided to give an indication of progress towards the projecťs stated goals. This could include information explicitly listed as "indicators" within MEL frameworks, or those that were referenced in a more narrative form.

Content analysis.

Content analysis was performed on indicators through a process of closed systematic coding. Codes were developed from the conceptual exploration of *relevance* and *quality* as explained in Section 2 (see Table 1 for a complete list of codes and their meaning). Because of the adaptation focus of the study, only those indicators referring specifically to adaptation or both adaptation and mitigation goals were analysed (iv in Table 1). Some of the information used was collected as *meta*-data, e.g. the location of the project, while other information was analysed interpretively, as detailed below (either "direct" or "inferred", in Table 1). Note that all categorical codes (i.e., (a)-(e) in Table 1) are mutually exclusive. This choice was especially important for CBS challenges which were separated into individual code groups, as many indicators could potentially address different challenge areas simultaneously. Assigning separate codes for CBS challenges allowed this overlap to be reflected in the data analysis. The full dataset of analysed indicators is available in Supplementary Data 1 and online https://doi.org/10.5281/zenodo.8263080.

Quantitative analysis — principal Component analysis and clustering

Principal Component Analysis (PCA) and k-means clustering were used to identify key components of *relevance* and *quality* that differentiate NbS projects, and then grouped projects according to these differences at project level (i.e., a comparison of the distribution of each code per individual NbS project). This allowed for a more detailed analysis of underlying trends among projects of the degree to which they

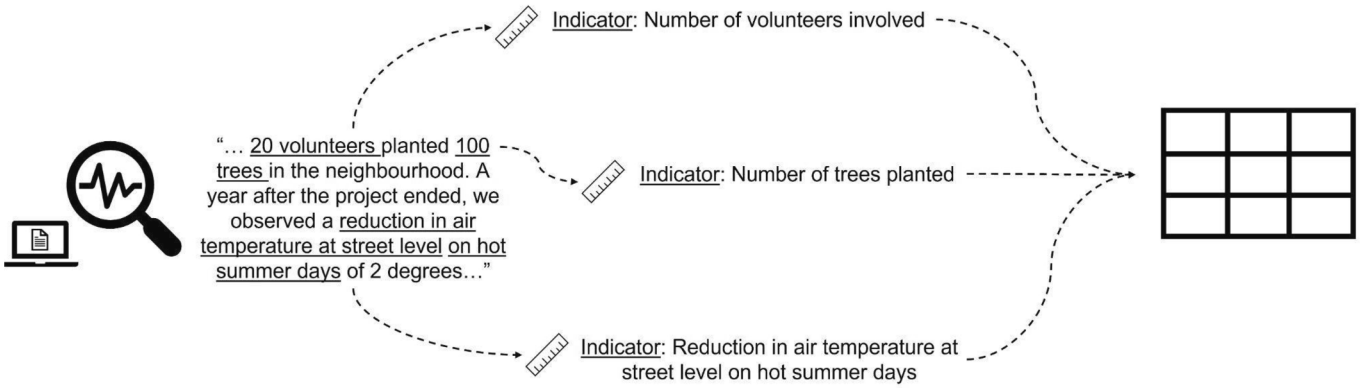


Fig. 1. The process of indicator extraction from the online sources of data listed in Goodwin et al (2022 & 2023) which included web pages describing NbS projects, as well as other supporting documentation either attached to the database or found through web searches.

Table 1
Codes included in the analytical framework used to evaluate information used to measure the contribution of urban NbS, adapted from Goonesekera & Olazabal (2022) (added or adapted variables or definitions are marked * in column Code).

	Attribute	Code	Description and example	Collection method
i	Descriptive	Name	The name of the indicator given in the documents analysed, e.g., "area of mangroves planted".	Direct
ii		Adaptation measure (if applicable)	The specific name of the adaptation measure that the indicator relates to (if multiple, and if relating to "adaptation")	Direct
iii		Scope	Whether the indicator is related to a specific measure of the NbS project ("**specific**") or related to the entire project generally ("**general**").	Direct
iv		Climate action domain	The main area of climate action the indicator is related to (whether the indicator is tracking progress to "**adaptation**" goals, "**mitigation**" goals, "**both**" of these, or "**general**" i.e. non-specific relation to either)	Direct
a	Relevance	Dimension*	Whether the indicator is related to **social** (e.g., social relationships, economics, politics, or governance), **ecological** (e.g., environmental or biophysical components of cities), or **technical** (e.g., built physical and other infrastructure and related systems) dimensions of city systems.	Inferred
b		Climate challenge addressed*	Which form of climate change vulnerability did the indicator relate to addressing or developing (i.e., **risk exposure**, **risk sensitivity**, or **adaptive capacity**).	Inferred
c		Biodiversity challenge addressed*	In which way did the indicator relate to biodiversity challenges (i.e., ecosystem **restoration**, **protection**, **management**, or **creation** of novel ecosystems).	Inferred
d		Social challenge addressed*	Which forms of social challenges did the indicator relate to, with a specific emphasis on how social justice issues are managed (i.e., **procedural** justice, **recognition**, or **distributive** justice).	Inferred
e		Type	Whether the indicator is related to an **input**, **output**, **outcome**, or **impact**. **Input** refers to materials and resources (e.g., money, time, assets) that are provided and measured. **Output** refers to the immediate product or the result created using inputs (e.g., number of trees planted, people trained). **Outcome** refers to the short to medium-term results resulting from outputs (e.g., increased climate risk awareness). **Impact** refers to long-term changes in the city's social, ecological, and technical dimensions (e.g., reduction in hospitalisations following heat waves).	Inferred
f	Quality	Level of detail	A classification of the overall level of detail of the indicator as **low** (relating to ambiguous overall goals), **medium** (if elements of the indicator are identified without a clear way of measuring them), or **high** (if the indicator contains clear elements that are measured, often with clear units and methods).	Inferred
g		Unit of measurement	Whether the indicator included a specific unit of measurement (e.g., m2 of trees planted) (**yes/no**)	Direct
h		Timeframe	Whether there was a specific timeframe identified for repeated measurement of the indicator (e.g., after the first, third and fifth year of the project) (**yes/no**)	Direct
i		Target	Whether a target is set in relation to the indicator (e.g., that 100 m2 of coral is to be restored), and whether that target is met or not (**yes/no**)	Direct
j		Data source	Whether the source of data to be collected about the indicator is disclosed (e.g., national census data, surveys conducted) (**yes/no**)	Direct
k		Monitoring provider	Whether an individual/body/organisation is identified as responsible for measuring the indicator (e.g., specific government departments, or other collaborating organisations) (**yes/no**)	Direct
l		Reference guidelines	Whether reference guidelines are provided for how indicators are selected, e.g. if they are applicable standards for establishing indicators that are to be followed (e.g., IUCN NbS Global Standards) (**yes/no**)	Direct
m		External reporting acknowledged	Whether the indicator is to be reported to another body or organisation in relation to MEL (e.g., regional or national governments) (**yes/no**)	Direct

are selecting information relevant to NbS and embedding these within quality MEL processes. This specific combination of methods has been similarly applied in the context of understanding NbS or MEL, especially to identify typologies of NbS approaches (Zingraff-Hamed et al., 2020; Castellar et al., 2021), or to cluster indicators of climate change adaptation and resilience (Goonesekera and Olazabal, 2022; Mahmood et al., 2022). For a full account of methodological choices made in the PCA and clustering process, see Supplementary Information 1.

Qualitative analysis — semi-structured interviews and narrative analysis.

Semi-structured interviews were conducted with key actors from a selection of 14 of the NbS projects analysed (n = 15, as two informants were identified for one project, totalling 13 h of interviews and 133 pages of transcripts). Informants were selected based on a mix of purposive and strategic sampling (Patton, 2014, p. 230), accounting for their experience in the evaluation of their NbS project as well as a diversity of regional representation and NbS/actor types across the data set. All interviews were transcribed and analysed as data in addition to the notes and observations recorded. The interviews were used to triangulate what key actors perceive to make good information and quality processes when evaluating their own projects (Flick, 2018). This data is crucial for addressing our third research question and links the first two by showing how local contexts and actors inform and influence the concept of relevance and quality as we have defined them.

Two specific open-ended questions were asked during interviews: (1) what was the process for selecting the indicators used to evaluate the project, and (2) how were these indicators useful to understand the contribution of the project to achieving the established goals. A narrative analysis was conducted on the information from the interviews that summarised the different viewpoints (narratives) about what makes good information to evaluate urban NbS, and whether this related to relevance and quality or other considerations not covered by our approach (Charmaz, 2014).

Narrative analysis was chosen to analyse interviews because of their storied nature. This form of analysis is often applied in this way to understand the human dimension of otherwise seemingly technical processes behind the development of urban NbS (Neidig et al., 2022), and to further reveal the influence of contextual factors such as power dynamics in decision-making (Melanidis and Hagerman, 2022). That is, we found that the answers to the questions asked elicited detailed recounts of the Informants' recollections of the events surrounding the precipitation of the project and the MEL process, their place in it as protagonists, and what they learned as a result, which followed a narrative form. The latter reflections further allowed us to capture learning about MEL that resulted from the experience of Informants (Dekens and Harvey, 2024). The narrative analysis allowed us to also shape the locally-embedded discourse behind choices for indicators and processes of evaluation (Creswell, 2007; McAllum et al., 2019). Our aim with this approach was to formulate causal explanations between local contextual factors (e.g., the worldviews of actors responsible for MEL, their role, etc), the indicators chosen to evaluate the quality, and the MEL processes they were embedded within (Neuman, 2014, p. 56). We coded interviews through open (inductive) coding to contrast the closed (deductive) coding approach of the qualitative methods used and was performed in NVivo release 1.7.1 (see SI1 for further details of the interview and coding process).

4. Results

4.1. Limited scope of evaluation of current urban NbS

The data show how some urban NbS co-benefits receive more attention and tend to be measured more often than others (Table 2). While indicators also tend to target social over other dimensions of city

Table 2
Distribution of codes at the aggregate level (i.e., across the full set of 750 indicators).

Code group	Individual code	Distribution (% of total)	Example
Type	Inputs (Process)	2 %	"Budget allocated to biodiversity."
	Outputs (Process)	60 %	"Key stakeholders trained in flood risk management, urban climate change resilience and territorial planning."
	Outcomes (Progress)	27 %	"Reduction in work days missed in the last 30 days due to flooding."
	Impacts (Progress)	11 %	"Reduction in 10-, 50-, and 100-year return flood risk."
Dimension	Social	50 %	"Key stakeholders trained in flood risk management, urban climate change resilience and territorial planning."
	Ecological	38 %	"Increase in species richness."
	Technical	12 %	"Length of primary drainage system put in place."
CBS Challenge	Climate	46 %	
	Adaptive capacity	*23 %*	"Number of fire hazard warning drills conducted annually." "Area undergoing uncontrolled burns."
	Sensitivity	*17 %*	"Drainage channels cleaned at least once per year before rainy season in project area."
	Exposure	*5 %*	
	Biodiversity	37 %	
	Restoration	*17 %*	"Ecosystem services and natural resource assets maintained or improved under climate change and variability-induced stress." "Number of trees planted in vertical forests." "Number of municipalities with operational land register in place."
	Novel ecosystems	*10 %*	"Area of reserve created."
	Ecosystem management	*7 %*	
	Ecosystem protection	*4 %*	
	Social (justice)	19 %	
	Distribution	*8 %*	"Number of homes built (disaggregated by social housing)." "Percentage of children and parents surveyed who thought the road felt safer."
	Recognition	*7 %*	"Grievances raised by stakeholders are addressed and closed."
	Procedure	*4 %*	

systems, they more often relate to climate and biodiversity challenges, and omit to evaluate whether these benefits are provided in a way that is socially just (in terms of distribution, recognition, or procedure). As seen in Table 2, most indicators are related to process (i.e. input and outputs), meaning that current MEL processes for urban NbS focus on short-term results while failing to link these to longer-term progress goals (i.e. outcomes and impacts).

Connecting the different codes on relevance (Fig. 2), indicators tracking outputs mostly relate to social and ecological dimensions. Regarding progress indicators, indicators relevant to the social dimension more often relate to short- and medium-term outcomes, while ecological indicators track longer term impacts. Indicators relevant to technical dimensions were generally underrepresented, though were mostly outputs. These results add nuance to the aggregate findings in Table 2 by identifying how indicators of short-medium term benefits (inputs and outputs) focus more on social challenges, while there remains a lack of evidence on the longer-term impacts of urban NbS except on those related to ecological dimensions (outcomes and impacts). Evidence relating to the technical benefits of NbS remains lacking overall.

Most indicators were relevant to the climate and biodiversity CBS challenges, rather than social ones. These results suggest that, with the exception of climate benefits, MEL practice on urban NbS is siloed in terms of how social and biodiversity benefits are evaluated. Social (justice) and biodiversity benefits are not often connected transversally to different SET dimensions of cities. In terms of quality, although the NbS analysed often articulated detailed indicators and clear units of measurement, MEL of urban NbS lack many of the metrics of quality we analysed, notably visible processes for data collection, target setting, and external reporting (Table 3).

4.2. Types of current MEL practices

The PCA identified several codes relating to both relevance and quality that were more important in differentiating and grouping projects according to their MEL practices. Projects can be differentiated according to the proportion of their indicators that identified (1) units, (2) monitoring providers, (3) data sources, (4) level of detail, (5) outputs, (6) relation to ecological dimensions, (7) relevance to biodiversity challenges. Clustering the data accounting for the influence of these codes allowed us to better identify key differences among the NbS projects. Based on different configurations of the PCA and clustering, three clusters (k = 3) were chosen that best represented the data (see Supplementary Information 1).

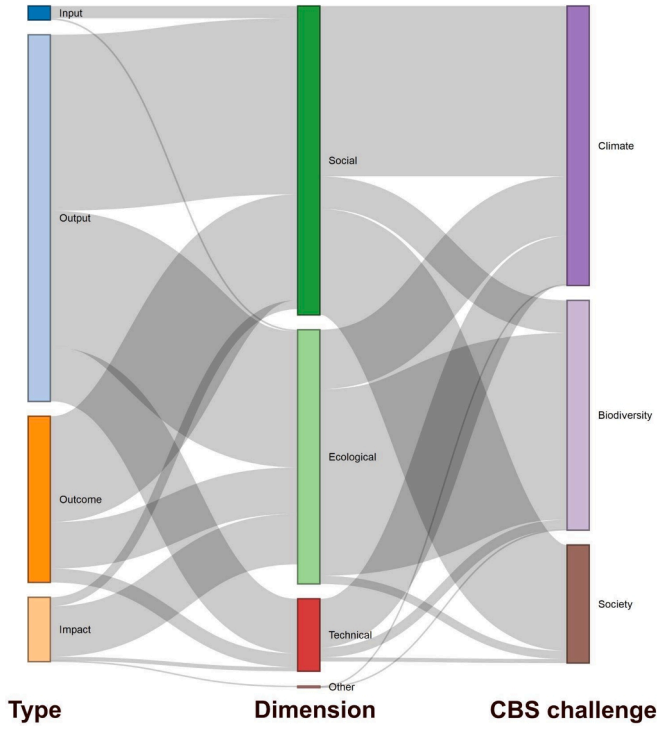


Fig. 2. Sankey diagram displaying the connections between type of indicator, SET dimension, and CBS challenges (n = 750). Relative bar length indicates the overall distribution of each code among the indicators analysed, with the grey bars indicating the overall correspondence between each group of codes.

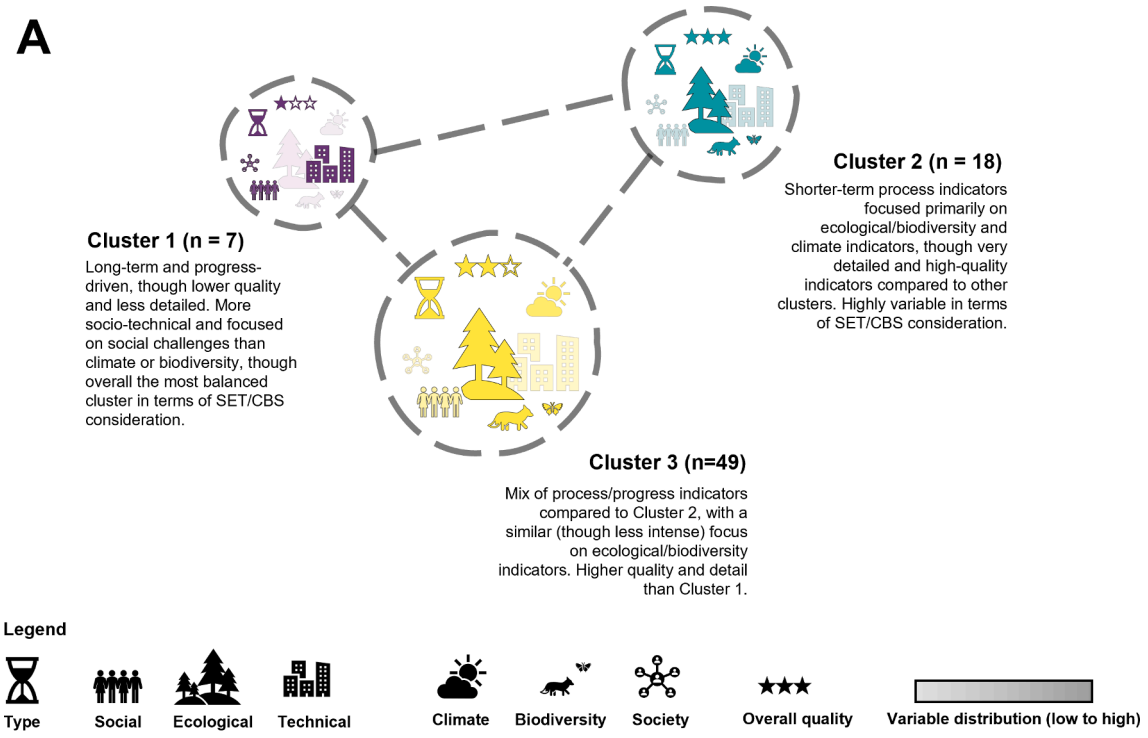
Table 3
Aggregate distribution of MEL quality.

Code	Distribution (% of total)
Detail	
High	78 %
Medium	7 %
Low	15 %
Unit	80 %
Timeframe	37 %
Target	39 %
Data source	54 %
Monitoring provider	72 %
Reference guidelines	36 %
External reporting	12 %

The first cluster (represented in Fig. 3A in purple, n = 7) contains projects with indicators that reported higher proportions of longer-term progress (i.e. outcomes and impacts). They relate more heavily towards social and technical indicators and mainly address social justice challenges, especially progress towards recognition. Biodiversity challenges focus more heavily on measuring the restorative potential of NbS, while adaptive benefits show a similar association towards adaptive capacity as in other clusters. However, overall, this cluster shows the most balanced consideration of different SET indicators and CBS challenges. It also has the lowest proportions of all identified measures of quality (e.g. level of detail, use of units, timeframes, setting targets). An example of these trends can be seen in the Singapore Green Plan, which included important forward-looking social indicators such as "retain low incidence of environment-related infectious diseases", though nonetheless did not appear to meet other metrics of quality based on publicly available information at the time of analysis.

The second cluster (shown in Fig. 3A in green, n = 18) is the opposite of the first in several ways: it has the highest average proportion of more detailed process indicators (rather than less detailed progress indicators), focusing much more heavily on ecological indicators that respond to biodiversity and climate challenges. Evaluation of biodiversity challenges focuses more on a mix of indicators relating to ecosystem management and restoration over the creation of novel ecosystems and ecosystem protection. This cluster also shows the least balanced consideration of SET and CBS codes, as ecological indicators and biodiversity outcomes were in much higher distribution than other codes in these groups. Social justice challenges measured within this cluster are related mostly to distributional aspects. Projects in this cluster embed these indicators in higher-quality MEL processes than others. These patterns are well-reflected, for example, in the strategic environmental plan of Milan (Italy), including emblematic projects like the *Bosco Verticale*, which has a sharp focus on area-based ecological outputs (e.g., area/number of trees planted, etc).

The third cluster (shown in Fig. 3A in yellow, n = 49) could be placed between the extremes of the first and second clusters in several respects. It evidences moderate levels of detail similar to the second, though these were slightly more related to progress indicators (impacts) as with the first cluster. Indicators used by projects in this cluster are marginally more social in terms of the dimensions of cities they targeted (again with a focus on distributional justice), though they responded more to biodiversity and climate, rather than social, challenges, as identified in Section 4.1 above. Compared to other clusters, indicators measuring



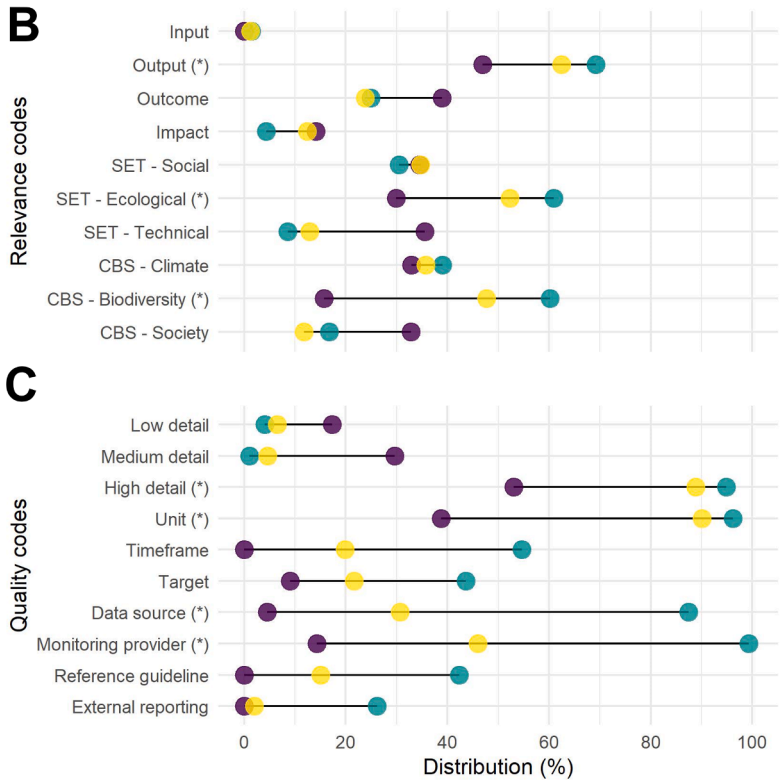


Fig. 3. Representation of the key features that differentiate the first (purple), second (green) and third (yellow) clusters of indicators across all analysed NbS projects (A). The hourglass represents the type of indicators reflecting short-term (input, output), to longer-term (outcome, impact) objectives, with the other symbols identifying the different components of relevance analysed. Overall quality is estimated by the star symbols, with one being low quality, and three high quality. Most prominent codes are shaded. The bigger the cluster area, the higher the number of projects meeting cluster characteristics. Below, a lollipop chart is given illustrating the average difference in the distribution of each code (y, including (B) relevance and (C) quality code) between each of the clusters (x, as an average percentage of the distribution of each code per project within the cluster). Marked codes(*) are those that were identified through the PCA as being the most influential to the formation of principal components and the resulting clustering. The length of the line between them is a function of their difference (i.e. the longer the line, the larger the difference in average values between the clusters). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

progress towards biodiversity challenges relate more to evaluating restorative benefits along with evaluating the emergence of novel ecosystems, rather than the focus on management seen in Cluster 2. Indicators within this cluster are more evenly distributed between different SET dimensions and CBS challenges. Except for the disclosure of units, this cluster lay also between the first and second on average in terms of indicator quality, generally involving lower quality MEL processes compared to the second cluster. An example is the Modderfontein Reserve in Johannesburg (South Africa) which more evenly identifies a collection of social and ecological indicators that cover short-term outputs, but further includes medium to long-term outcomes and impacts, tracking the changes in user type and diversity over time (social) and species compositions (ecological).

The emergence of these different clusters aligns with the results at the aggregate level discussed previously (c.f. Sections 4.1 and 4.2). These results overall show that current MEL practice for urban NbS does not appear to be successfully integrating the evaluation of co-benefits across different CBS challenges and SET dimensions. Rather, current MEL practice focuses on a siloed set of benefits. However, in terms of quality characteristics, we observe a more diverse practice; this is normally connected to the type of benefits that are being considered (e.g., social are less detailed and long term while ecological are more detailed and short term).

4.3. Narratives behind current MEL practices

Four main narratives emerged from the interviews (n = 15 interviews across 14 projects). The narratives could be differentiated based on whether they perceived relevance and quality to be important considerations in what makes good information and processes to evaluate urban NbS. Narratives were not mutually exclusive in the responses of informants as they often contributed to the development of multiple narratives (see Supplementary Figure 5 in SI1). These narratives are summarised by reference to the following statement headings that describe what Informants believed to be the purpose of indicators within the project that in turn determined what made good information and processes to evaluate their project.

Indicators as a proof of concept

For some Informants (n = 4), the use of indicators is essential to creating a proof of concept that NbS projects are a preferable approach to addressing CBS challenges facing their city. It was further important for them that the indicators they chose were relevant to a diversity of SET dimensions and CBS challenges they face (Fig. 4), and, further, that they were technically credible (i.e., that they were embedded in high-quality MEL systems): "*we need to bring information* […] *in such a way that we can produce good quality technical information that can be used to subsidise and justify the implementation of* [more NbS]" (Informant #13). Relevant and good quality indicators were both determined by scientific and technical standards regarding the individual NbS type (e.g., rain gardens, river bank naturalisation): "*I selected these indicators because they were very commonly used indicators in my reference papers, purely from a scientific view*." (Informant #9).

The importance of selecting a diversity of types of information relevant to different SET dimensions and CBS challenges, and embedding these in high-quality MEL processes, was often motivated by the Informant's desire to further promote the use of NbS as a urban climate adaptation strategy: "… *a lot of organisations are saying we need to gather the evidence to show that* [NbS] *are a low-risk investment.*" (Informant #7). Informants also highlighted the danger of promoting NbS in this way, especially to financial institutions, for the fear that selecting relevant and quality indicators would be replaced by indicators that are merely "sellable": "[those responsible for developing indicators] *want to sell the monitoring and the consultancy, that is why they are not going to measure very complex things*." (Informant #15).

In summary, in this narrative, Informants chosen indicators need to be both relevant to a variety of SET dimensions/CBS challenges and be

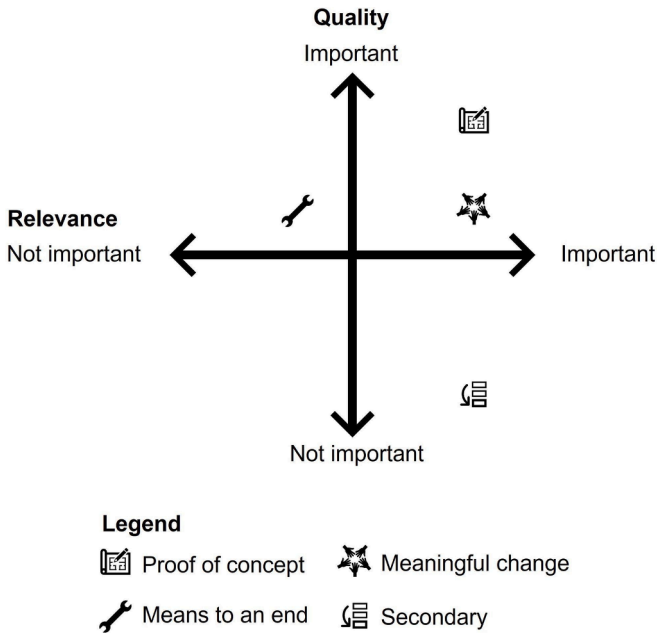


Fig. 4. A visualisation of the relative importance of relevance and quality in informing what makes good information according to the four narratives that emerged from the analysis.

embedded in high-quality MEL systems. In this way, this narrative aligns with our approach to defining relevance and quality: indicators selected within MEL systems ought to relate to local CBS challenges and SET dimensions of cities that adhere to identified best practices. This narrative conceptually aligns with the way indicators were used in Cluster 2, which focused more on technically sound (though ecological) indicators.

Indicators as a means to an end.

Another narrative explicitly de-emphasised the importance of indicators for the sake of project evaluation (n = 5) and saw them instead as a means to achieving other (non-evaluation related) goals. For example, regarding the reporting of municipal and national governments or financial institutions using data collected from indicators as a way to justify expenditure on adaptation projects to citizens or shareholders, often in development projects within collaborations between the Global North and Global South. These indicators were usually based on simple quantifiable outputs which can more easily be communicated to a non-expert audience: "…*this* [well-being] *has to be recognized by decision-makers for example. That more green space within the city, green roofs, green facades, do increase well-being and health* […] *and I think it's not something that is recognised.*" (Informant # 6) This was further noted in the international development sector, describing the mismatch in donor expectations: "…*it's difficult now for people to understand we are trying to build a system that eventually will help the country to develop. It's much less "sellable"*." (Informant #10) In this way, indicators were also used as valuable information towards learning, as they provided a basis to reflect on whether the project was implemented well, or whether other information or adjustments to the project were necessary.

Local beneficiaries of donor funding further highlighted the discomfort of this mismatch in expectations, noting how they found themselves in positions where they had to measure indicators they did not have a say in developing: "… *for the growing and conservation of the forest, they* [project implementers] *just want to plant the trees to make their annual report. And we are planting the trees for the environment, for climate change and everything.*" (Informant #11). Though they acknowledged indicators used for reporting and imposed by donors did not hold as much meaning locally, complying with their measurement was nonetheless used as a way to secure funding into the future: "…*you accept*

whatever they give you [and] *utilise every last penny in the project, so that the next year, they themselves know that this is a good organisation and* […] *they give* [funding] *to you.*" (Informant #11). In other cases, indicators were used as a political tool to hold others accountable: "… *now the government needs to follow this information. Before, they could allege they did not know, but now you do know because there is an official report made by a public officer.*" (Informant #2).

Considerations other than relevance or quality came also into focus. For example, social (i.e., securing funding for projects to implement projects) and political (i.e., being held or holding others politically accountable) considerations emerged as defining factors in this narrative. Relevance and quality considerations were secondary to other social or political goals, and were only useful insofar as they served those goals: "*This goal has been set publicly by the former mayor and […] then is very much about numbers and how do you get these numbers…*" (Informant #8).

In summary, in this narrative, good information to evaluate urban NbS is defined by the value of the information to achieve social and political goals with less emphasis on the relevance and quality of MEL information and processes. The use of information in this way creates a conflict between those deciding what information should be measured and those tasked with measuring it, both locally and internationally, especially in collaborations between the Global North and Global South. In this narrative, indicators and MEL processes serve social, political, and economic purposes beyond how we conceive relevance in the context of CBS challenges and SET dimensions of cities. In addition, quality standards further depend more explicitly on who holds economic or social power, rather than strictly technical or other standards.

Indicators as an approximation of meaningful change.

Most informants (n = 12) mentioned that indicators were mainly used as an approximation of the kind of meaningful change they sought to achieve through the specific NbS project. This way, relevance was chosen over the quality of MEL processes: " … *we purposely chose those indicators because we wanted to measure that the* [flood reduction] *system that we built is there. You cannot do it piece by piece because otherwise, it's not sustainable. You can declare that the infrastructure, the output, is there, but not the outcome. So that was why we designed it that way … it's a system indicator.*" (Informant #5).

The unique contribution of this narrative to the discussion of how relevant and quality indicators are chosen is the diverse local social, political, and ecological contexts that constructed what meaningful change meant in each context. History and the experience of local communities are critical processes in this decision-making process: "*given the nature of South Africa's history with the apartheid system … the department started to investigate how it could get more involved in biodiversity or open space management by working together with local communities or bringing marginalised communities into projects…*" (Informant #6).

Several respondents spoke instead of the personal, felt experiences that could be used as information to understand the development of their project in the city. These were indicators that guided and motivated their actions: "*People will trust us, our organisation. I will feel it everywhere we go. They tell us: 'Thank you'*" (Informant #1). Others noted the personal relationships that motivated using indicators to evaluate the project: "… *because I am a citizen of the city, I want to tell my girls, based on that data, those are the successes…*" (Informant #15). These experiences, though relevant, were often measured informally because it was perceived by informants to be difficult to identify processes to formally evaluate them. Instead, they came from informal contact with beneficiaries, highlighting the importance of building relationships through MEL processes: "*we looked for verbal cues from the people on how they perceive their microclimates… they reported that the microclimate was improved, and they felt like it was fresher*" (Informant #4).

In summary, in this narrative, good information and processes to evaluate urban NbS were intimately connected to a variety of social and political factors, spanning history, culture, and personal and collective felt experience based on relationships with less emphasis on high-quality MEL processes. In doing so, this narrative focuses on the process of discovering what CBS challenges and SET dimensions of cities are relevant to measure. However, in opposition to our conceptualisation of quality in MEL processes, more focus was placed on the personal, felt experience of local beneficiaries, rather than technical standards. Conceptually, this narrative reflects some of the patterns of indicator use seen in Cluster 1, as they relate to longer-term social measures of project success (outcomes and impacts) that may be more difficult to measure according to prevailing technical standards.

Indicators as secondary considerations.

Other informants (n = 3) disputed whether indicators and MEL processes could produce good information to evaluate NbS at all. Instead, they pointed that all that projects should focus on is ensuring a "good process" of providing project inputs and outputs: "… *that is how we work here, the process precedes the project.*" (Informant #2). Importantly, in this narrative, a "good process" of providing inputs and outputs is fundamentally participatory even before a project is conceptualised: "*You don't start the project by planning, you start by dreaming.* […] *Then you have to bring people together to dream. Once you dream, because when you dream you connect, you're not doing something alone.* […] *Then you go* […] *from planning to executing, from executing […] to monitoring, evaluation. Fantastic. But you also don't stop there. Then there's the celebration,* […] *because you're doing something beautiful together.*" (Informant #2) For these Informants indicators were only potentially useful as proxies for the quality of both MEL and implementation processes, however flexible processes were more important to be able to implement learnings in continuous adjustments within the NbS project.

This way of taking local, collective action was contrasted to what was described explicitly by informants as the "European" or "Western" way of implementing projects: "*This is a very different approach to what you guys usually do in Europe. You bring technicians, you make a very fine project, you make a public call, you make a selection, you execute it, you then monitor it and evaluate it…*" (Informant #2). Under this view, MEL frameworks need to be understood as tools, rather than ends in themselves, and what progress towards adaptation means within NbS projects needs to be re-considered by those designing and implementing them. In defining progress, Informants were inspired by their understandings and experiences working with Indigenous people's worldviews that emphasise reforming not only the way to connect as people through collective action (i.e., dreaming together) but also the natural world, moving away from the dominant technocratic approach to evaluating adaptation: "*The new progress needs to look back*" (Informant #14). Any information ultimately used to evaluate projects must nonetheless be relevant to the local context, as: "…*the goal is not the number, the goal is the impact*" (Informant #3).

In summary, this narrative challenges the idea that indicators could make good information to measure progress within the evaluation of urban NbS. It instead emphasises ensuring "good processes" behind project implementation that are fundamentally inclusive and sensitive to the local context. Rather than relating to process indicators as we have defined them (i.e., inputs and outputs), the processes Informants spoke about referred more broadly to ways of doing both adaptation and MEL. This narrative conflicted the most with our approach to conceptualising good information to evaluate urban NbS, as here, quality MEL processes are defined entirely based on the quality of participation and co-creation of the project itself above any formal technical standards. However, this narrative more closely aligns with our conceptual focus on local, context-specific CBS challenges and SET dimensions of cities being integrated within evaluation processes.

5. Discussion

Based on the results obtained here we reflect on how certain kinds of information relevant to understanding progress through urban NbS are left out of current MEL practices. Following this, we discuss how good

information is conceptualised for communities of research and practice, especially based on current efforts towards standardising information to evaluate urban NbS for adapting to climate change.

The connection between process and progress.

Our analysis suggests that current urban NbS projects struggle to develop high-quality social and technical indicators of adaptation, prioritising ecological indicators to assess progress towards addressing biodiversity challenges, and similar trends have been observed beyond the urban context (Donatti et al., 2020; Cross et al., 2022). This is a common challenge in adaptation strategies more generally, as the definition of social challenges and what information should be used to track progress depends on who defines those challenges in the first place (e.g., whether citizens, municipal governments, scientific experts, etc) (Dilling et al., 2019; Feldmeyer et al., 2019). The dangers of insufficiently considering the social implications of NbS, particularly, have been documented in cities in the Global North (Anguelovski et al., 2018; Aznarez et al., 2023) and Global South (Anguelovski et al., 2019; de Souza and Torres, 2021). Comparatively, ecological indicators have a history of standardisation and pursuit of objectivity and, while still not settled, may have clearer pathways towards measurement and contextualisation to climate change adaptation in the ecological sense (Pearce-Higgins et al., 2022). We thus posit that a lack of integration of especially the social and technical dimensions, is a key challenge to achieving transformative change (McPhearson et al., 2021; Palomo et al., 2021) In this regard, we provide novel nuance to previous findings by revealing which kinds of social (justice) considerations are largely missing from MEL processes, mostly recognition (i.e., incorporating multiple forms of knowledge) and procedural justice (i.e., creating space for meaningful public participation). Our results further contrast with how co-benefits from urban NbS are framed in the current scientific literature that has been found to overly focus on anthropocentric benefits (Pineda-Pinto et al., 2022).

Specifically relating to adaptive benefits, while previous studies point out that NbS are more often framed to reduce exposure to climate hazards (Goodwin et al., 2023), indicators analysed in our study more often measure progress towards improving adaptive capacity. This may point to a lack of current practical evidence and measurement practice of how NbS are contributing directly to reducing climate impacts, reinforcing the argument of a generalised lack of capacity and guidance to track progress towards adaptation goals (Olazabal, et al., 2024).

In terms of current ways of evaluating NbS in the context of adaptation and biodiversity challenges, we posit that there is a clearer focus on evaluating restorative benefits. Across the groups of projects, a stronger focus on restorative benefits was identified within the first cluster, which further contained projects more keenly focused on evaluating forms of social justice (recognition, procedure) less frequently observed in other clusters. This leads us to hypothesise that there may be a connection between restorative practices and these forms of social justice that concern multiple forms of knowledge. We also note that the evaluation of novel ecosystems was further concentrated in the largest cluster (Cluster 3), which also contained a more balanced evaluation of different components of the social and climate challenges considered in our study. This then suggests that the current practice of establishing novel ecosystems in cities may hold some promise in addressing different dimensions of social and climate challenges facing cities more equally.

Local social and political factors to define what "good" information is for evaluation

The narrative analysis showed that what makes good information and processes for evaluation was not limited to scientific understandings but rather was defined by numerous local social and political factors. Diverging purposes, expectations and uses of evaluation information were shown to create conflict locally and internationally revealing how MEL processes can become yet another iteration of global inequality and power imbalance in the specific context of urban NbS, a problem common to both urban and non-urban NbS (Woroniecki et al., 2020; Rochell, Bulkeley and Runhaar, 2024). Voices from the Global South that shaped several of these narratives noted the potential power of information when formulated and collected in a grass-roots way. This approach did not prescribe what progress meant or how it should be measured before project implementation. On the other hand, they highlighted how indicators, in general, could become a burden when external standards not sensitive to local needs are imposed. These perspectives support existing calls for decolonising research agendas and fostering learning from experiences with urban NbS in the Global South and Indigenous knowledge systems (de Souza and Torres, 2021; Johnson, Fisher and Parsons, 2022), especially in light of the Indigenous knowledge systems found inspiring in several of the narratives that emerged from the interviews.

Other studies have highlighted key determinants of the success of MEL systems in tracking whether NbS are providing adaptive and other benefits. For example, collaboration with research partners has been highlighted as a key factor for MEL success (Oakes et al., 2022). Our study supports this argument but expands the understanding of collaboration. For example, the *proof of concept* narrative referred to collaboration with actors with technical expertise and the means to provide technical resources (monitoring stations, etc) to ensure the success of MEL. Narratives that focused on *meaningful change* and that understood evaluation and indicators to be *secondary considerations* instead pointed to ongoing and inclusive collaboration with project beneficiaries and project managers. Key actors in this regard went beyond those with scientific expertise, and included for example community leaders and local technical staff that were able to maintain personal contact with the project over time. This further connects with other studies that identify key actors that enable successful MEL practices as those that span both scientific/technical and local management expertise and can act as a bridge between different forms of knowledge (Cross et al., 2022) and that maintain a connection to the project after implementation (Mills-Novoa, 2023). The emphasis on the importance of flexibility and opportunities for learning within several of the narratives further signals the importance of these components of MEL processes for NbS as adaptation strategies (Huang and Harvey, 2021; Dekens and Harvey, 2024).

Reporting at different governance levels.

Results of the analysis highlighted the difficulties and risks in developing a common set of indicators in practice given the diversity of perspectives regarding what is good information for evaluating adaptation as well as adaptation needs. They further suggest that what makes good information and processes for reporting to higher levels of governance may not be equally good at the local level. Relying only on high-level indicators for measurement that are not adapted for local use risks insufficiently accounting for how local climate impacts are experienced and understood locally (Chmutina et al., 2023), although they may provide a useful starting point for cities struggling to get started with MEL processes (Lecavalier et al., 2023). Our results bolster calls for establishing processes that set commonly agreed-upon guiding principles for locally identifying good information and processes to evaluate urban NbS, as was attempted here, instead of developing out-of-the-box solutions for cities (Singh et al., 2022; Bulkeley et al., 2023). Concepts of relevance and quality and the CBS and SET frameworks have helped us to preliminarily identify key areas where evaluation is lacking, though cross-referencing them with local experience, priorities, and informational needs was critical as it offered several additional considerations that shape what good means locally and that were not visible from the literature, as highlighted elsewhere (Nalau et al., 2024).

Our findings on the need for consideration of both local social and political factors and scale in creating useful MEL processes that are fit for purpose support previous calls in research and practice, including in sustainability policy analysis (Pintér et al., 2012), environmental conservation and management (Rempel et al., 2004), and climate adaptation (Leiter, 2021). We further hypothesise about the main reason why creating MEL systems that are fit for purpose is a lingering challenge in the field of adaptation despite decades of echoing calls. In this regard,

our results (the interviews in particular) point to issues of imbalances of power and agency. Beneficiaries and local actors (those most affected by climate change, and who are intended to be helped by NbS) appear to lack power and agency in deciding how adaptation goals are set and how progress is measured toward them. Meanwhile, those with the power to decide may have other objectives than evaluation alone, diverting their attention to other political ends that may not serve the interests of beneficiaries or otherwise reinforce existing biases towards technocratic understandings of the purpose of adaptation MEL (Olazabal, et al., 2024). We think that future research should address how issues of power and agency can be resolved within adaptation MEL so that information and processes to evaluate the contribution of urban NbS to adaptation and beyond respond to the needs of beneficiaries, whether human or more-than-human (Nightingale et al., 2020).

6. Conclusion

Measuring the contribution of urban NbS was explored here by reference to concepts of *relevance* and *quality* that were used to clarify who benefits from the approach as when, where, how and why. Operationalised within a quantitative analysis, and framed under the CBS nexus and SET dimensions, these concepts enabled us to identify *what* and *whose* interests are currently underrepresented in current MEL practice (social, and technical) as well as *how* (by lacking a social justice perspective), and that temporal and causal connections (*when* and *why*) between process and progress are often lacking.

Integrating local perspectives through a narrative analysis helped us make sense of the quantitative findings and highlighted how different local priorities mediate what information is relevant to measure and how it should be embedded into MEL processes. This expanded our original framing and the scope of factors that define good information and processes for MEL, revealing how MEL processes serve a diversity of social and political purposes that are currently not captured in how the practice is understood in current research.

Based on these findings we identify the following areas for improvement in MEL practice for urban NbS. First, local capacity-building efforts should focus on introducing the full range of potential CBS challenges that NbS can help address in cities, spanning all SET dimensions. Additional attention is particularly needed on how social justice challenges can be addressed and how progress in this area can be measured and recognized through MEL. Second, greater recognition is required to the diversity of perspectives and informational needs of local actors in terms of what information is important to measure and what barriers exist in reporting progress. Scientific and technical concepts of what makes good information ought to be informed and verified by on-the-ground experience. Special attention also needs to be paid to the role of power relations in how MEL systems and their governance structures are designed and implemented. Third, current processes seeking to standardise information should focus on cultivating inclusive processes for identifying guiding principles for what can make good information and processes for this purpose, rather than developing prescriptive lists of indicators to be universally applied to evaluate the contribution of urban NbS to adaptation and co-benefits. Lastly, given the lack of comparative studies between NbS in urban versus non-urban settings, future research could focus on shedding light on a) which of the issues discussed here are most pressing across the different settings and, based on these findings, and b) whether these learnings are applicable and useful to global development discussions on the selection of indicators and metrics for adaptation to climate change and on practices to measure progress.

We believe these locally-grounded areas for improvement can help advance MEL for adaptation. In day-to-day practice, they can contribute to identifying fit-for-purpose indicators and processes to evaluate the potential of urban NbS to address interconnected climate, biodiversity, and societal challenges. In this line, we call for transdisciplinary approaches that bridge multiple forms of knowledge in assessing MEL for adaptation.

CRediT authorship contribution statement

Sean Goodwin: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Marta Olazabal:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Antonio J. Castro:** Writing – review & editing, Supervision. **Unai Pascual:** Writing – review & editing, Supervision, Funding acquisition.

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.

Data availability

Data generated or analysed during this study are included in this published article (and its supplementary information files) and online repositories (https://doi.org/10.5281/zenodo.8263080).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2024.102939.

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