Identifying the main categories of key performance indicators for nature-based solutions

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Abstract

As the number of people living in urban areas is firmly increasing, more innovative solutions are needed to tackle the accompanying effects of climate change there, such as heatwaves, stormwater concerns or pollution. As these projects are continually developed and their effects are yet to be fully tapped, there is a lack of a coherent monitoring system. This study presents a systematic and comprehensive overview of three of the most recent studies of Sari et al. (2021), Connop (2020) and Elagiry et al. (2019), which list key-performance indicators (KPIs) for nature-based solutions. These indicators are grouped into six major categories, which are further divided into sub-categories. The results of the paper highlight the importance of a general and widely implementable monitoring tool system which is scalable and localizable for different urban settings, making it possible for individual nature-based projects as well as complex urban ecological systems to be well-monitored.

Keywords

Nature-based Solutions (NBSs), Sustainability, Key Performance Indicators (KPIs), Monitoring Tools, Indicator Assessment

1. Introduction

What makes a city liveable is argued by many. One might highlight the level of infrastructure or the proximity of services and opportunities. Jaszczak et al. (2020) argue that the level of liveability is determined by nature itself around us, as it has a positive effect on human well-being. Jaszczak et al. (2020) and da Costa and Kállay (2020) emphasized the importance of nature in urban areas by pointing out the social awareness of nature in urban areas and the beneficial impacts of green areas on the health and overall well-being of individuals. It is highlighted that the global pandemic created a sense of need for the expression of our "biophilic" behaviours (Jaszczak et al., 2020; Tomasso et al., 2021), which can only be fulfilled with the presence of nature and ecological diversity around us. Hence, the arising social recognition of environmental connectedness has given us a unique opportunity to have the willingness for bringing nature back to our everyday urban experiences.

It is projected that the total population living in cities will steeply increase and will reach 68% by 2050. This trend is significant, as in 1950 only 30% of the global population was located in urban areas (United Nations, 2018). Since urbanization is inevitable, and several effects are emerging as well as intensifying; local, urban solutions are needed for addressing these issues.

As with all parts of the globe, the continual urbanization in European cities has led to the increasing number of climate change-induced stress effects, including intensifying heatwaves or concrete jungle effects; the escalating noise, light, or air pollution; flood and stormwater effects. All in all, the cities in the continent are getting more exposed to the severe effects of climate change (Fűr and Csete, 2010; Szabó et al., 2018). These effects have both short- and long-term consequences on human well-being, leading to temporary or acute health issues (da Costa and Kállay, 2020), permanent mental state degradation or induced stress experiences for locals. Due to these effects, not only human well-being is put at risk, but also the level of food, water and energy security, driving to a potential disruption of the economic structure of cities (Faivre et al., 2017). Holistic, systemic approaches are needed that are not tackling these issues with only one solution, but rather apply a cognitive sustainability approach: utilizing the biological and artificial systems with technological solutions to create a more comprehensive web of tools (Zöldy et al., 2022).

Dorst et al. (2019) states that so-called nature-based solutions (NBSs) have the potential to incorporate several disciplines and aspects of urban adaptation processes together, enabling a more holistic, systematic approach. This interdisciplinary and multipartite toolset would allow policymakers to realize and communicate the role and position of nature in urban systems. To be able to implement impactful and sustainable policy measures and regionally suitable and effective green solutions, monitoring results are needed from already executed projects. And evidently, in order to get monitoring results, suitable monitoring processes are required.

Raymond et al. (2017) discussed that the assessments conducted for monitoring purposes only focus on one single area of green urban solutions. A similar conclusion was arrived at with respect to decision making approaches by Zöldy et al. (2022), as they pointed out the lack of holistic, hence cognitive aspects being implemented in urban decision-making processes. Frameworks and monitoring processes have been mainly looking at one of the fields of biodiversity, ecosystem services or other green solutions. As nature-based solutions are such interwoven projects, proper monitoring tools are required in order to allow a cross-sectorial analysis of their impacts instead of a single-sighted managing process. Such broad tools exhibit a complex, intersected system dynamics that requires intricate and detail-oriented monitoring and evaluating processes as well. In their 2018 study, Macháč et al. argued that adaptation measures have difficulties in terms of implementation, as there is not enough knowledge in the topic; and as a result, these measures have a blocking effect on proper monitoring practices for the implemented projects.

As a uniform but still flexible monitoring system for nature-based solutions is required, based on a comprehensive review of the literature, this paper presents a hierarchical system of key performance indicators (KPIs) that are used to monitor nature-based solutions according to three influential studies: Sari et al. (2021), Connop (2020) and Elagiry et al. (2019). The system described here could be used as a starting point for the creation of an internationally accepted monitoring system. Section 2 reviews the relevant literature on the basic concept of nature-based solutions, the role of green areas in cities, and the parameters of nature-based solutions. Section 3 showcases the importance of indices in monitoring processes of green solutions and presents the author's work on the main categories of KPIs for NBSs, mentioning also possible limitations. The suggested system of KPIs is presented in a table in the Appendix.

2. Literature review

This section discusses the different definitions of NBSs, with special focus on the similarities of different approaches. Then the role of green areas in cities is showcased including the sustainability dimensions of NBSs, followed by a short review of the different parameters of NBSs.

2.1 Nature-based solutions

It has been discussed lately whether rapidly growing urban areas can adopt to the severe effects of climate change. Numerous policies, city planning approaches, engineering solutions, and green methodologies have been introduced in order help adaptation measures (Szalmáné Csete and Buzási, 2020; Szlávik and Csete, 2005). One such approach is that of nature-based solutions.

The concept emerged in the last decade, when adaptation practices started to shift from a predominantly engineering-oriented approach to more environmental-based solutions (Cohen-Shacham et al., 2016). It was realized that the increasing number and intensity of urban exposure to climate change effects are not adequately addressable with only technological solutions; rather a better, more complex system is needed to tackle these. A concept emerged that allowed the services provided by nature to do this job. Hence the term "nature-based solutions" was born. As this notion is considerably new, there is no internationally accepted definition, framework, or categorization of the term. Therefore, a comprehensive literature review on the concept is presented in order to provide a broader view on the topic.

The European Commission's (2015) agenda on NBSs lists multiple objectives that can be associated with the green urban solution toolset. The most obvious one is climate change mitigation and adaptation development; additionally, the positive effects of NBSs on risk management and resilience enhancing were highlighted, as well as the development of sustainable urbanization procedures; and lastly, the restoration of degraded ecosystems. Many other sources emphasize the importance of NBSs: Dushkova and Haase (2020) discuss that NBSs have been created to provide an ecosystem services approach inside urban planning strategies and implementations, to completely join in the environmental dimension to socio-economic urban structures, as well as to address current societal challenges in urban areas. Faivre et al. (2017) highlight the importance of NBSs for urban development as a tool for innovation, and encourage the urgent inclusion of these practices for both policymakers as well as practitioners. According to Dorst et al. (2019), NBSs offer a toolkit that has the capability of uniting different disciplines and aspects into a general overview within the concept of urban greening, allowing researchers and policymakers to address climate change challenges in a more effective way. Bush and Doyon (2019) state that NBSs are key elements of resilient urban planning, without which cities would not be able to face the climate challenges. By proposing an integrated system of planning NBSs for urban resilience, they urge the mainstreaming of ecosystem services used in urban planning.

What are the opportunities NBSs can bring to the table that other similar practices, such as green technologies, ecosystem-based adaptation practices or green infrastructure solutions cannot? Dorst et al. (2019) concluded that this is the multifunctionality and the ability to provide solutions to more complex issues due to the broader interpretability of the term “nature-based”. In general, NBSs are such green solution toolsets that offer societal, economic, and environmental benefits in any setting, including urban areas, rural spaces, or agricultural lands.

NBSs are mostly implemented for the adaptation practices to the effects of climate change in urban areas, although an increasing number of sources suggest a rather expansive interpretation. The European Environment Agency (2021) concluded that NBSs are – along with climate change adaptation tools –also risk reduction instruments, allowing urban areas to reduce their disaster threat exposures. Several studies (for example Almassy et al., 2018; Bush and Doyon, 2019; Cohen-Shacham et al., 2016, 2019; da Rocha et al., 2017; Dorst et al., 2019; European Environment Agency, 2021; Giachino et al., 2021; Kabisch et al., 2017; Katsou et al., 2020; Mendes et al., 2020; Seddon et al., 2020; and van den Bosch and Sang, 2017) emphasize the multidisciplinarity and the complex systemic tool trait of NBSs; labelling the term to be an umbrella concept.

While other papers discuss NBSs as tools for urban adaptation, it should be noted that the European Environment Agency (2021) interprets NBSs as an umbrella term, thus all other climate change adaptation and disaster risk reduction practices are considered to be a sub-category under NBSs (Poyraz and Csete, 2021).

2.2 Role of green areas in urban settings

The European Commission’s Horizon 2020 expert group on “Nature-Based Solutions and Re-Naturing Cities” (2015) argues that NBSs are key aspects in bringing sustainability into urban development, as they enhance economic, social, and environmental development simultaneously *(Table 1)*.

Table 1: Sustainability aspects of NBSs services in urban areas.
Source: Author’s table based on data retrieved from Cohen-Shacham et al. (2016), De Vries et al. (2003), Dushkova and Haase (2020), European Commission (2015), and Keniger et al. (2013).

Economy	Business opportunities
	Decrease resource dependencies
	Knowledge-shift
Social	Food and water security
	Disaster risk mitigations
	Health improvements
	Socio-economic development
	Relaxation or therapeutic areas
	Sports activities
	Positive experiences in nature
Environment	Adaptation to urban pollution challenges (air, noise, light)
	Heatwave mitigation
	Water management issues
	Ecosystem-services

As for economic aspects, more and more market players realize the importance of climate change adaptation practices. Consequently, as the awareness of companies and other actors of industries is growing, the interest of the public is rising as well. These shifts in knowledge can lead to policy changing initiatives and a global will to take action. On a less apparent note, economic development is expected from NBS projects in the form of business opportunities, as well as allowing a decrease in the resource dependencies of industries in urban areas (European Commission, 2015).

According to Cohen-Shacham et al. (2016), social challenges that can be addressed by NBSs including adaptation to climate change effects are food and water security, mitigation of disaster risks, and socio-economic development. Furthermore, De Vries et al. (2003) and da Costa and Kállay (2020) add human health improvement here as well. Other social benefits may include creating hospitable areas for relaxation and for therapeutic purposes (Keniger et al., 2013), for active leisure time activities, or increasing the positive experience associated with such an area of the local communities (Dushkova and Haase, 2020).

The beneficiary effects of NBSs on environmental development are straightforward, although they are not fully discovered in their entirety. The adaptive ability of cities to the urban effects of climate change is significant: these urban effects may include air, noise, and light pollution; sudden and severe heatwaves; or stormwater management issues. Alongside with adaptation practices, NBSs provide valuable settings for different ecosystem services. As it has been discussed above, NBSs and ecosystem services are closely interconnected, resulting in an overlapping group of tools.

2.3. Parameters of nature-based solutions

There is an absence of literature related to the operational transparency of NBSs (Cohen-Shacham et al., 2016), which results in the lack of reliability as well as applicational deficiencies of the newly emerging implementation practices. As Cohen-Shacham et al. (2016) have found, the overall goal, the definition, and the principles of NBSs are concepts already in existence in the literature, although there is a significant absence of operational parameters for such projects on a global level. Lapintie (2021) highlighted the need for the embeddedness of such practices into urban planning systems as well as policy making practices, in order to achieve systemic change. The lack of operational parameters results in different implementation methods, a lack of inconsistency of monitoring tools, as well as no standardized indicator utilization for evaluation and examination.

In their more recent study, Cohen-Shacham et al. (2019) found that NBS implementations and frameworks offer higher levels of solutions than other methodologies, as NBSs assimilate with strategies and measures, making it possible to tackle the challenges. The essence of NBSs is the integration with other nature services (Cohen-Shacham et al., 2019), allowing a more comprehensive range of addressed issues. By merging numerous different concepts, a higher implementational impact may be achieved through the improved allocation and scaling-up of NBS projects.

3. Results and discussion

The domain of NBSs is increasing worldwide, making the concept more accepted and considered in urban planning processes, as it does not only provide environmental and ecological benefits, but also significant social and economic advantages (Oen, 2019). At the same time, there are numerous shortcomings of the concept of NBSs, as it is still in its rudimentary form. Kabisch et al. (2016) suggest a stricter monitoring of implemented projects in order to produce so called evidence-based NBS projects in the future. This would result in a more impactful, possibly socio-economically more beneficial outcome of schemes. Alongside with monitoring, the broader inclusion of stakeholders is advised by the research team, in order to make NBSs more adaptable for the complex and administration-heavy governance systems worldwide. Furthermore, Kabisch et al. (2016) highlighted the inclusion of social justice aspects into the transdisciplinary concept of NBSs, making it more inclusive and transparent for social benefits.

Meerow (2019), Chrysoulakis et al. (2021, 2018 and 2015), Ludlow et al. (2016), Spencer and Coye (1988) and a constantly increasing number of other scholars have been searching for proper monitoring tools for NBS projects, with little to no comprehensive solution for the tool. As there are various tools in terms of focus scales (regional or specific), they might work proficiently for individual solutions, while they are not suitable on the European nor global scale. It would be negligent to assume that there is one monitoring tool that fits for all, although a broadly accepted, globally adaptable, and most importantly, scalable monitoring tool is essential.

Besides monitoring, the lack of citizen involvement is alarming. Lorencová et al. (2021) concluded that the lack of awareness of locals as well as the absence of institutional frameworks also raise significant obstacles against climate change adaptation practices in urban areas. They have found that the cooperation of researchers, NGOs and governmental agencies have a major effect on realizing and sustaining these projects. Hence, a broader spectrum of communication about NBSs is needed, including scientific publications, social media announcements, public awareness campaigns, civil society goals, or governmental communication.

Similarly to Lorencová et al. (2021), the European Environment Agency (2021) also highlights the importance of stakeholder involvement in the designing, implementing, and monitoring processes of any NBSs, stating that this approach is the key to raise awareness and to tackle possible disagreements amongst players.

3.1. Data evaluation

The data collected by the Naturvation Project (Almassy et al., 2018) shows that the V4 countries (Poland, Slovakia, Czech Republic, and Hungary) lack the monitoring of these implemented NBSs projects. Only 64 out of 111 projects implemented in these 4 countries have reported in-situ monitoring activity. Investigating the data it became quite evident that there are barely any number of monitoring processes for these NBS projects. This is an enormous inadequacy of these developments, as the lack of these practices results in projects being implemented with possibly no positive impact or even the further estrangement of the ecosystems and their benefits to urban areas.

As mentioned above, it is not only an adverse practice due to the lack of data provided, but mainly owing to the fact that these monitoring practices would enable projects to be more impactful and resourceful, and possibly more economic, as data would be available about the cost benefits of the implemented NBS projects. The return rates of these projects could be lowered, as possible impacts are more accurately pre-measurable with initial data from previous monitoring practices. For this reason, the investigation of present monitoring tools was required. It was found that one of the reasons for the lack of monitoring frameworks in action is the absence of proper indicators. In their 2017 article, Buzási and Csete have highlighted the importance of an indicator-based monitoring system in order to find impactful solutions for urban effects of climate change and to ensure the decision makers, to confidently consider green developments in urban planning.

3.2. Key Performance Indicator approaches

In order to be able to determine the most important aspects of the monitoring toolsets, the KPIs of NBSs need to be defined. KPIs are such tools that allow a rather practical approach towards measuring performance. Warren (2011) discusses them as a “type of language” that allows effective measurements of practices and their effects to their surroundings. In order to provide the most up to date KPI approaches, three publications are going to be presented, published in 2019, 2020, and 2021, respectively. Later in this study, an assessment and possible KPI list will be presented based on the findings of the three studies.

Within the Nature4Cities Project, Sari et al. (2021) investigated the key performance indicators of NBSs and urban climate challenges. They grouped the different indices into five main pools of indicators: climate, environment, resources, social, and economy. They utilized the so-called RACER method: this abbreviation stands for the necessary traits of functioning indices: Relevant, Accepted, Credible, Easy, and Robust. Through this system, Sari et al. (2021) created a list of multi-thematic and multi-scale indicators (UPIs) for urban performance evaluation and monitoring, out of which the KPIs have been selected.

The main goal of Connop (2020) was to create a comprehensive list of KPIs for NBS monitoring in cities. They identified 93 indicators, out of which they have highlighted the 17 most fundamental or impactful ones. Hence only these highlighted 17 indices were included in this investigation. With direct focus on the positive effects of NBSs, they created subgroups for economic, social, ecological and wellbeing benefits. Their study further investigated the locality of the analysed cities, taking a general path and implementing it on a scalable and localized level for each city’s needs and peculiarity.

Elagiry and their team has created the so called GREENPASS tools, which enable the user to assess the effects of NBS projects. These tools also aid planning processes, as they can be used to measure current and possible impacts on a given urban area, by comparing them before and after the green projects (Elagiry et al., 2019). They have collected 28 KPIs that are used to evaluate the performance of aforementioned areas by dividing them into 6 main categories of climate, water, air, biodiversity, energy, and cost.

3.3. Key Performance Indicators

In order to fully investigate the differences and similarities between the indices presented in the three studies, the following five steps were taken: (1) data collection; (2) comparison of all indices; (3) categorization of indices; (4) sub-categorization of indices; (5) assessment of the availability and quality of indices. Appendix A shows the list of KPIs taken from the three sources, categorized and clustered by the author. Six main categories (NBSs; land-use and habitats; pollution and emissions; social; economy; and other) and 20 sub-categories were created (Table 2).

The number of indices listed are quite different in the three sources: Sari et al. (2021) uses 52, Connop (2020) listed 93 (out of which 17 has been used here), while Elagiry et al. (2019) collected 28 of them. It needs to be stated that the number of indices does not necessarily correlate with the quality of them: either too few or too many can be problematic.

Table 2: Main and sub-categories of key performance indicator assessment by author.

NBSs	Blue spaces Blue-green spaces Green spaces
Land-use and habitats	Shannon index and ecosystem Land-use
Pollution and emissions	GHG Air quality and temperature Heat Energy Noise Light Waste
Social	Health Society Accessibility
Economy	Infrastructure Costs

Other	Environment Social Economy	

As mentioned previously, one of the main tasks was to categorize the indices into comprehensible core and sub-categories. As a result of the categorization, six major groupings were set up by categorizing same and/or nearly essentially same indices by the three studies into one category. As an example, for the *Pollution and emissions* main category, under the GHG (greenhouse gases) sub-category came the indices *CO_2 annual carbon sequestration* by Sari et al. (2021), *CO_2 emissions reduced*, *Carbon sequestration rate by tree species*, *Carbon storage/carbon sequestration in vegetation/soil*, *CO_2 emissions reduced* by Connop (2020), and *CO_2 storage score* by Elagiry et al. (2019). The first three categories *(NBSs*, *Land-use and habitats*, and *Pollution and emissions)* are considered to be the environmental core groups, followed by the *Social* and *Economic* categories. Lastly, there is a category for indices that could not be listed elsewhere.

The first category is *NBSs*, which includes the KPIs that are directly connected to the implemented projects themselves. A total of 46 indices were classified here with further sub-divisions of Blue spaces, Green spaces, and the combination of them: Blue-green spaces. The most important similarities in the indices in the Blue spaces group of the *NBSs* category are the consideration of water availability in urban areas, especially water scarcity and the demand thereof. The Blue-green spaces sub-category has only been considered by Connop (2020), highlighting the importance of the interconnectedness of the two systems. They have considered the importance of connectivity of these areas, and the cultural and recreational value they offer.

The next core category is the *Land-use and habitats*, in which two sub-categories are listed: the Shannon Index and ecosystem, and Land-use. Although all the three of the investigated sources consider the Shannon Index, only two of them (Sari et al., 2021; and Elagiry et al., 2019) name it directly, while Connop (2020) itemizes the main elements of it. It is notable also that Connop is the only author to mention the role of pollinators, as they have introduced two indices dealing with this phenomenon. The sub-category of Land-use contains no indices by Elagiry et al. (2019), and only 2 by Sari et al. (2021). Connop (2020), on the other hand, listed 14 of them, focusing on land-use trends, food production, brownfield regeneration practices and urban sprawl patterns.

The third major category of the environmental scope – *Pollution and emissions* – is rather segmented, it is further divided into 7 groups. The sub-category of GHG includes indices from all three of the publications, each focusing on CO_2 sequestration. Air quality and temperature is the largest sub-category, including 23 elements, although the only common index included is air temperature. The other sub-categories include heat, energy, noise, light, and waste related indices. The latter 2 are only considered by 1 publications, respectively: light pollution is highlighted only by Connop (2020), and waste management is included exclusively by Sari et al. (2021).

The *Social* category of the indices was divided into 3 groups: Health, Society, and Accessibility. The former 2 is only included by Sari et al. (2021), who laid great importance on society by the listing of 7 indices here, while others listed none. As discussed previously in the paper, also Kabisch et al. (2016) highlighted the importance of such considerations into NBS implementation approaches. The sub-category of accessibility includes KPIs by both Sari et al. (2021) and Connop (2020), highlighting the importance of the availability of NBSs for everyone.

The group of *Economic* indicators is divided into 2 parts: Infrastructure and Costs. The former category includes KPIs exclusively by Connop (2020), which is due to their great interest in accessibility indices. On the other hand, the Costs subcategory includes only indices from Sari et al. (2021) and Elagiry et al. (2019), with special focus on the investment and maintenance costs, as well as the effects of NBSs on pricing in the related areas.

The last category comprises indices that could not be grouped elsewhere. A similar sub-divisional approach was conducted here as well, with the category having the 3 elements of sustainability: Environment, Social, and Economy. The first sub-group includes indices like albedo or radiation (with only Sari et al. (2021) not utilizing them), the Social category contains KPIs like responsibility or adaptive comfort, while the Economy group discusses indices like leapfrog development index or sustainable practices index.

As with all scientific assessments, inaccuracies, misinterpretations present in the processes are inevitable. That is why it is crucial to highlight the possibilities of such "practices". 3 main biases or potential limitations have been collected to provide a better understanding of the dynamics of the system: bias within the indicators collected, limits of data readiness, and finally, the vicinity aspects of indices assessed.

As for the bias across indices, Sari et al. (2021) claimed that it is challenging to find adequate and all-including indices as (1) the field of NBSs is a wide-ranging toolset with numerous different actors; and (2) this field of science is a relatively new, still emerging discipline with many variables being formulated in the upcoming times. These indices need to be comprehensive, same-level, and inclusive. Hence, deeper research needs to be conducted in the field. It was also argued that the stakeholders might interpret the importance of various indicators differently, which leads to varying lists of KPIs. The diverse group of actors, stakeholders and experts should be able to come to a comprehensive, similar conclusion for a KPI list in order to gain relevant and impactful insights from the monitoring processes.

Concerning data availability, Buzási and Csete (2017) have concluded that in order to utilize the adequate KPIs, multiple characteristics need to be met by the indices. One of these qualities is the availability of data for the given index. It is crucial to utilize indices whose data is either accessible or easily measurable, since their introduction of new data measurements can deter different stakeholders, such as monitoring bodies or policymakers from project implementations.

On the topic of the locality of indices, Farkas et al. (2017) found that indices provided on an international level have great biases across implementations, as indices required for monitoring procedures need to be differentiated regionally due to the territorial differences in different areas. This finding – although it is considerable – is not suitable for real-life measures, as most monitoring bodies do not have the capacity to use individualized indices for each and every project. Furthermore, this would result in an incomprehensive set of data across project monitoring.

4. Conclusion

This study found that the nature-based solution (NBS) toolset is widely considered as an umbrella term by the researchers. It is an interdisciplinary, sustainability-oriented multilateral methodology for urban mitigation, adaptation and disaster risks decreasing measures related to climate change. A comprehensive literature review was conducted to highlight the various characteristics of NBSs, resulting in an overview of the different approaches and interpretations.

It was found that one of the reasons why no proper monitoring solution is globally available is the lack of a comprehensive group of KPIs for NBS monitoring. Three of the most recent articles were investigated to find the similarities and differences between the KPI lists in them. 6 main categories as well as 19 sub-categories were created by the author.

To understand the reality of the NBS implementation and monitoring processes as well as the proper attributes of impactful KPIs, a list of possible limitations was compiled in order to ensure the proper and comprehensive evaluation of data. KPIs related to NBSs can play a pivotal role in urban decision-making processes, enhancing cognitive sustainability in local systems.

As for further research, the list of monitoring tools available for NBS monitoring needs a comprehensive, systemic study. These tools are available and impactful: implementors, researchers, municipalities, NGOs, or residents can utilize them to evaluate the impacts of implemented NBSs, enabling them to carry out more impactful projects in the future, resulting in resourceful adaptation or mitigation tools against the severe effects of climate change.

In addition to the comprehensive research on monitoring tools, further research is needed for the assessment of KPIs. An exploratory data analysis is suggested, for which cluster analysis is highly recommended.

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Appendix

Appendix A. KPIs for nature-based solutions monitoring processes created by the author.

Based on data retrieved from Sari et al. (2021), Connop (2020) and Elagiry et al. (2019).

		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
NBSs	Blue spaces					Blue space areas							
		Water scarcity				Drinking water (surface/ground)	Reduction of drought risk	Water expiration index	Water consumption	Water demand (GI/TCS)	Water demand (GI)	Cost water demand GI/m^2	
		Stormwater quality				Reduction of stormwater treated in public sewerage system (economic benefit)	Water quality	Groundwater quality	Increase greywater and rainwater reuse				
		Total rainfall volume	Peak flow variation			Flood peak reduction/delay	Flood damage (economic)	Rainfall storage/absorption capacity of NBS	Increase groundwater availability	Water storage	Cost invest GI/water storage		
						Increase evapotranspiration				Evapotranspiration			
		Soil biological activity	Soil classification factor	Water detention time		Soil sealing				Sealing Grade	Run-off score		
NBSs	Blue-green spaces					Connectivity of urban green and blue spaces (struct. and funct.)	Cultural value of blue-green spaces	Recreational value of blue-green space					
	Green spaces	Connectivity of green spaces	Urban Green Space Proportion			% of buildings with NBS adaptation	Green space areas	Public green space distribution		Green space			

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
		Normalized Difference Vegetation Index				Community garden area / child capita and in a defined distance	Community garden area / capita and in a defined distance						
						Urban tree health	Urban forest pattern	Total monetary value of urban forests		Leaf area			
Land-use and habitats	Shannon Index and ecosystem	Shannon Diversity Index of Habitats				Index of habitat types	Habitats restored	Targeted habitats		Shannon Index			
						Species diversity	Number of nature species	Species under nature conservation designation					
						Ecological connectivity	Ecological connectivity (eco. connectivity index)						
						Change in ecosystem service provision	% of protected areas (ecologically and/or culturally sensitive	Mapping ecosystem services and spatial - temporal biodiversity legacies	Supporting/increasing biodiversity conservation				
						Increase in pollinators (abundance of pollinators)	Increase in pollinators (habitat)						
Land-use and habitats	Land-use	Biotope Area Factor				Land-use intensity	Land-use mix	Proportion of landscape not in intensive	Land-use change and greenspace configuration				

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
								management					
		Per capita food production variability				Reduction in pesticide use	Local food production	Use of organic fertilizers	Cultivated crops				
						Fragmentation	Ratio of open spaces to build form						
						Brownfield use	Reclamation of contaminated land						
						Population density	Urban sprawl						
Pollution and emissions	GHG	CO_2 annual carbon sequestration				CO_2 emissions reduced	Carbon sequestration rate by tree species	Carbon storage/carbon sequestration in vegetation/soil	CO_2 emissions reduced	CO_2 storage score			
		Avoided GHG emissions				NOx emissions							
Pollution and emissions	Air quality and temperature					Fine particulate matter emissions	Atmospheric pollutant flux	Pollutant fluxes/m^2/year					
		Exceedance of air quality limit value - Local scale				Share of emissions (air pollutants) captured/sequestered by vegetation	Value of air pollution reduction	Annual amount of pollutants captured by vegetation	O_2 production by vegetation				

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
		Common air quality index	Air quality indicators - short term health effects	Air quality indicators: long-term health effects		Air quality change	Air quality index						
		Air temperature	Physiological equivalent temperature	Thermal Comfort score (outdoor)		Air temperature change				Thermal comfort score	Thermal load score	Thermal storage score	Thermal Performance
						Temperature increase / wind shelter				Wind field			
Pollution and emissions	Heat	Heat induced mortality				Tree shade for local heat change				Cost invest GI/Red. Cooling. Degree Hours Building	Cooling Degree Hours Building	Shading Area Factor	Night-time Cooling
	Energy	Energy security	Buildings energy needs	Cumulative energy demand		Air temperature - Energy demand	Energy savings						
	Noise	Day-evening night noise level	Effects of night noise on health			Noise pollution reduction	Noise mitigation by vegetation						
	Light					Light levels at night							
						Increase portion of sky visible from the ground							
	Waste	Specific waste generation	Construction and demolition waste										
		Efficiency of valorisation as a result of recycling process	Material Circulatory Index	Raw material efficiency									

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
Social	Health	Perceived health	Quality of life										
		Number of deaths and missing people											
	Society	Social capital											
		Procedural justice	Segregation index	Percentage of gender violence	Percentage of victimization								
		Recognition	Distributional justice										
	Accessibility	Accessibility				Accessibility of green spaces	Community accessibility	Access to public amenities					
Economy	Infrastructure					Quality of public transport	Length of bike route network	Access to vehicle sharing	Citizen access to public transport				
						Area for pedestrians	Road density	Land devoted to roads	Inundation risk for critical urban infrastructures (probability - economic)				
Economy	Costs	Adjusted Net Saving								Cost invest GI/m^2	Cost invest GI	Cost invest GI/TCS	
										Cost maintenance GI	Cost maintenance GI/m^2		

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
		Housing Pricing Index	Domestic Property Insurance Claims	Gross Value Added in the local Environmental Good and Services sector									
Other	Env.					Albedo				Albedo			
										Radiation			
	Soc.	Responsibility	Capabilities	Adaptive comfort (indoor)		Introduction							
	Additional Indices	Sustainable Practices Index				Climate resilience strategy	Linearity development index	Leapfrog development index					