Impact of Nature-Based Solutions: A Summary Eindhoven

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About UNaLab

The UNaLab project is contributing to the development of smarter, more inclusive, more resilient and more sustainable urban communities through the implementation of nature-based solutions (NBS) co-created with and for local stakeholders and citizens. Each of the UNaLab project's three Front-Runner Cities – Eindhoven (NL), Genova (IT) and Tampere (FI) – has a strong commitment to smart, citizen-driven solutions for sustainable urban development. The establishment of Urban Living Lab (ULL) innovation spaces in Eindhoven, Genova and Tampere supports on-going co-creation, demonstration, experimentation and evaluation of a range of different NBS targeting climate change mitigation and adaptation along with the sustainable management of water resources. The Front-Runner Cities actively promote knowledge- and capacity-building in the use of NBS to enhance urban climate and water resilience within a network of committed partner cities, including seven Follower Cities – Stavanger, Prague, Castellón, Cannes, Başakşehir, Hong Kong and Buenos Aires – and the Observers, Guangzhou and the Brazilian Network of Smart Cities. Collaborative knowledge production among this wide network of cities enables UNaLab project results to reflect diverse urban socio-economic realities, along with differences in the size and density of urban populations, local ecosystem characteristics and climate conditions. Evidence of NBS effectiveness to combat the negative impacts of climate change and urbanisation will be captured through a comprehensive monitoring and impact assessment framework. Further replication and up-scaling of NBS is supported by development of an ULL model and associated tools tailored to the co-creation of NBS to address climate- and water-related challenges, a range of applicable business and financing models, as well as governance-related structures and processes to support NBS uptake. The results of the project will be a robust evidence base and go-to-market environment for innovative, replicable, and locally-attuned NBS.

Partners

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1. NATURE-BASED SOLUTIONS FOR URBAN CHALLENGES

Nature-based solutions (NBS) have emerged as an umbrella concept that encompass and build upon previous concepts that aimed at actions for enhancing climate change adaptation (CCA) and disaster risk reduction (DRR). These concepts include but are not limited to Ecosystem-based Adaptation (EbA), low-impact development (LID) and sustainable urban drainage systems (SUDS), ecological engineering, green infrastructure and ecosystem services. The distinguishing feature of NBS is simultaneously providing economic, social and environmental benefits and co-benefits. Many definitions of the NBS concept have been developed over the years, including those by IUCN and European Commission and the latest definition by the UN.

> *"… actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits." - Fifth Session of the United Nations Environment Assembly (UNEA-5)*

The lifecycle of an NBS project comprises six equally important steps or phases (Figure 1). The lifecycle begins with a framework identification phase, which will be adopted first in the project, and which will drive the implementation of the next actions. The following phases of identifying the relevant NBS given the identified urban pressures and challenges and the key performance indicators (KPIs), and developing a monitoring scheme to capture the change from the baseline conditions – are crucial for evaluating the NBS performance and impact. Once the monitoring scheme is defined and monitoring equipment is tendered, a prolonged period of NBS monitoring begins. The monitoring outputs are continuously reviewed to assess NBS performance and impact, and to ensure the soundness of the equipment and the methods of data acquisition. Ideally, NBS monitoring should span several years for critical evaluation of NBS performance and impact to support future development proposals. Several phases of the NBS project lifecycle directly contribute to the NBS Knowledge Base, which can be perceived as a collection of good practices regarding NBS implementation across the EU Member States.

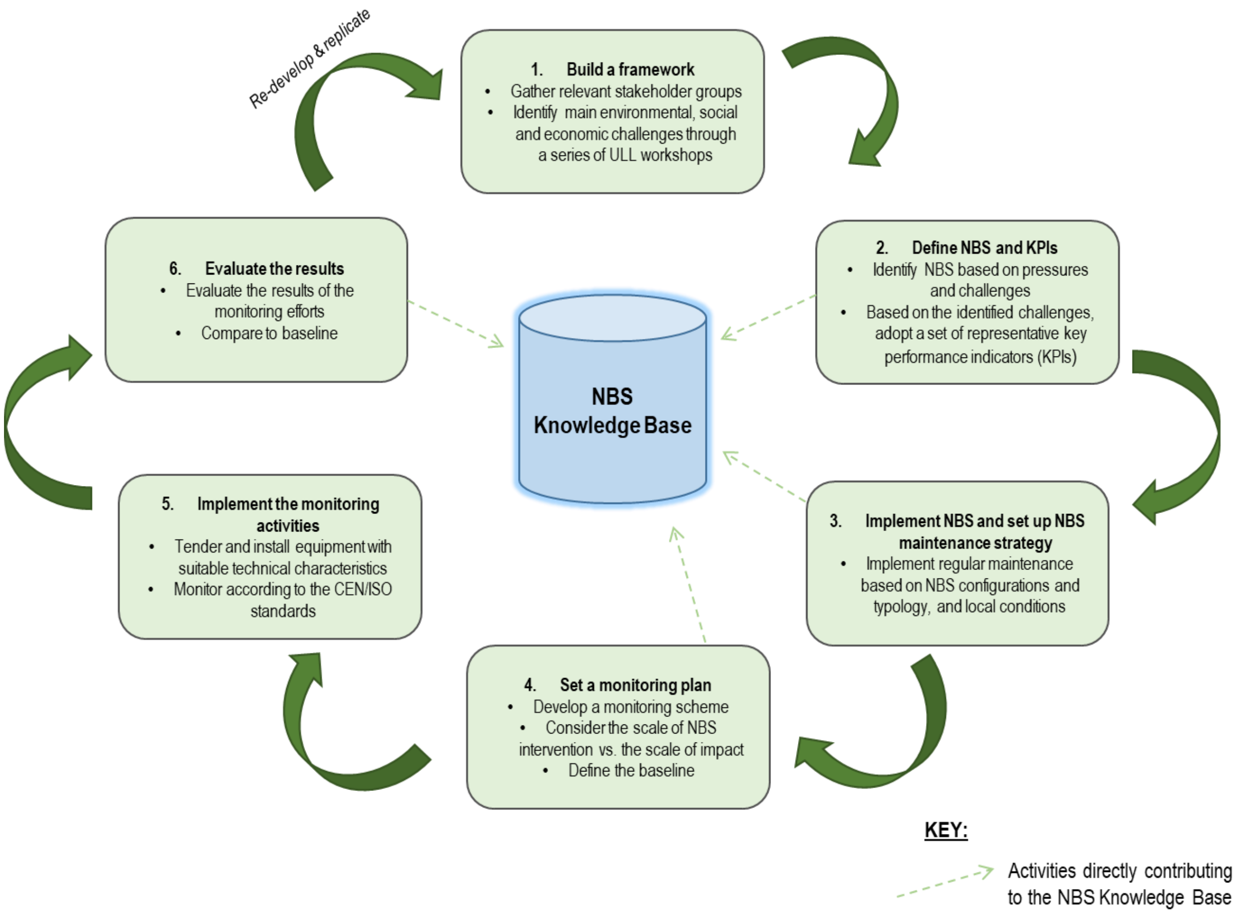


Figure 1. Lifecycle of an NBS project.

This publication presents a high-level summary of the highly detailed *Impacts of NBS Demonstrations*. The report aims to provide the key messages and outcomes of the NBS monitoring process and impact assessment produced within the UNaLab project for each of the UNaLab front-runner city. This report provides only the key messages – for an extensive evaluation the reader is referred to the complete *Impacts of NBS Demonstrations* publication (Roebeling et al., 2023).

The knowledge, data and its evaluation and resources developed throughout the UNaLab project aim to serve as a reference for the NBS practitioners and other involved parties in developing, executing and evaluating the NBS projects in different socio-economic and climatic contexts. The list at the end of this report provides references for further reading.

2. NATURE-BASED SOLUTIONS CO-MONITORING AND IMPACT ASSESSMENT

In times of rapid urbanization and anthropogenic climate change, urban areas face an increasing number of extreme weather events and other environmental burdens such as water and air pollution. NBS are associated with distinct impacts on ecosystem services and improvement of a range of environmental aspects hindered by urban growth. However, a selection of NBS to address the identified challenges and pressures should demonstrate its impact and indicate whether the anticipated outcomes are achieved, including monetary and environmental targets, to consolidate the future investments into wider NBS implementation. Monitoring is one of the central factors determining the success of the NBS impact assessment as it provides quantitative and qualitative evidence of the impact generated by the NBS interventions.

The UNaLab tools that complement the co-developed holistic framework for nature-based solution (NBS) initiation in front-runner cities (FRC) follow the Plan-Do-Check-Act (PDCA) adaptive management cycle (see Dubovik et al., 2020). Monitoring and impact assessment of NBS forms part of the PDCA-cycle (Check), and aims to provide quantitative and qualitative evidence of the impact generated by NBS.

Monitoring and impact assessment of NBS comprises several steps that are equally important for the development of a holistic monitoring and impact assessment strategy (Figure 2). Once the NBS have been (co-) defined (Plan; Do), these steps include the identification the representative key performance indicators and establishment of the baseline – thereby accounting for the scale of impact which will dictate the scale of monitoring. In turn, the data acquisition mode needs to be defined such that it allows to capture the impact in terms of its temporal and spatial resolution, and granularity. Finally, the evaluation framework determines the thresholds and the overall evaluation scheme of the NBS performance and impact.

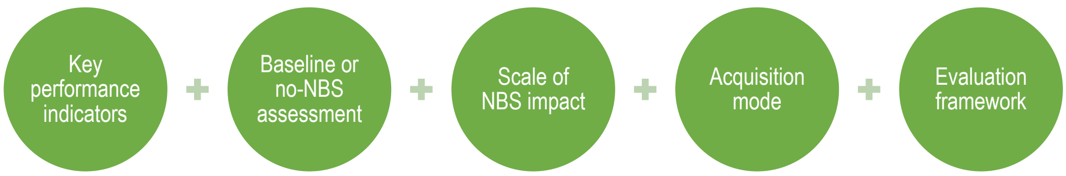


Figure 2. UNaLab monitoring and impact assessment strategy (source: Dubovik et al., 2020).

Co-definition of **NBS performance and impact indicators** can be viewed as an intermediate step between setting the goals and targets and formulating a sound plan for NBS monitoring (Figure 3). The first and foremost requirement for the NBS performance and impact indicators is to reflect the targets and objectives set in the beginning of NBS co-creation process. In co-identifying indicators with stakeholders, it may be beneficial to limit the number of indicators by assembling a local expert group (familiar with the local challenges) who will recommend a narrowed list to further the discussion.

There are numerous NBS performance and impact indicators, and selecting them can be challenging for an inexperienced person. The Task Force 2 handbook *Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners* (Dumitru & Wendling, 2021a) and its *Appendix of Methods* (Dumitru & Wendling, 2021b) alone collects more than 400 recommended and additional indicators over 12 key societal challenge areas:

1. Climate Resilience
2. Water Management
3. Natural and Climate Hazards

4. Green Space Management
5. Biodiversity Enhancement
6. Air Quality
7. Place Regeneration
8. Knowledge and Social Capacity Building for Sustainable Urban Transformation
9. Participatory Planning and Governance
10. Social Justice and Social Cohesion
11. Health and Wellbeing
12. New Economic Opportunities and Green Jobs

Indicators of NBS performance and impact should be selected to reflect both primary benefits as well as any associated co-benefits.

It is equally important to **establish baseline** – a pre- or no-NBS situation for understanding the reference conditions and quantifying the actual impact or change in indicators with-NBS. Baseline measurements either occur prior to NBS implementation (pre-NBS) and/or occur in a similar reference area without NBS (no-NBS). In addition, baseline data can be derived from spatial and non-spatial historical and statistical data. Modelling can also be used to derive reference (baseline) conditions.

On data outputs

Granularity is different from *accuracy*, the degree of correctness of the outputs with respect to the true value, and from *precision*, the accuracy when the observations are repeated.

Instead, *resolution* is a specification of *granularity*, and it indicates the size of the minimum unit/area in a data output (e.g., spatial data).

Once the monitoring scheme is defined and set, establishing the **appropriate data acquisition** means will ensure careful data collection at relevant scales. A number of data acquisition options exist that could be employed for NBS performance and impact monitoring. Means of measurement refers to whether data is obtained through in-situ observations, statistical and legacy data, remote sensing and earth observations, citizen science initiatives and/or modelling. Finally, data collection equipment needs to be selected based on precision, accuracy, resolution, detection limits, sampling frequency, sensitivity, units of measurement, data transmission or retrieval, device unit cost, device calibration, device maintenance schedule, device lifetime and operational environment.

On monitoring scales

The choice of scale and resolution/granularity is subjective and is typically informed by prior experience, but they should not be selected arbitrarily or haphazardly. Careful considerations for the suitability of scales and their interactions will produce the most reliable outcomes.

Considerations of the **scale of NBS monitoring** and the **frequency** of recorded data are of outmost importance requiring an understanding of the spatial and temporal impact of NBS at which the impact can be measured. Given the multiple ecosystem functions, services and values provided by NBS, multiple spatial and temporal scales need to be defined in accordance with the selected indicators. Multiple monitoring data can be combined to yield information on a broader scale and, alternatively, modelling data can provide approximations and projections for a larger scale or various NBS.

NBS are essential elements in some of the **major European and global policies and strategies** that shape and direct the actions at building the structural, environmental and social resilience. European policies and the current development agenda generally support the implementation and uptake of NBS, and some directly mention NBS as means for achieving certain goals. International policies may not directly mention NBS but they all focus on CCA and DRR which is inherent to all NBS activities.

NBS **impact assessment framework** is the essential step when targets and objectives are evaluated against the measured performance during the NBS monitoring stages (Figure 3). Impact assessment identifies causalities and aids in determining the supporting or additional interventions necessary for achieving the goals. This makes the NBS implementation process cyclical enabling the adaptive management cycle of every NBS project.

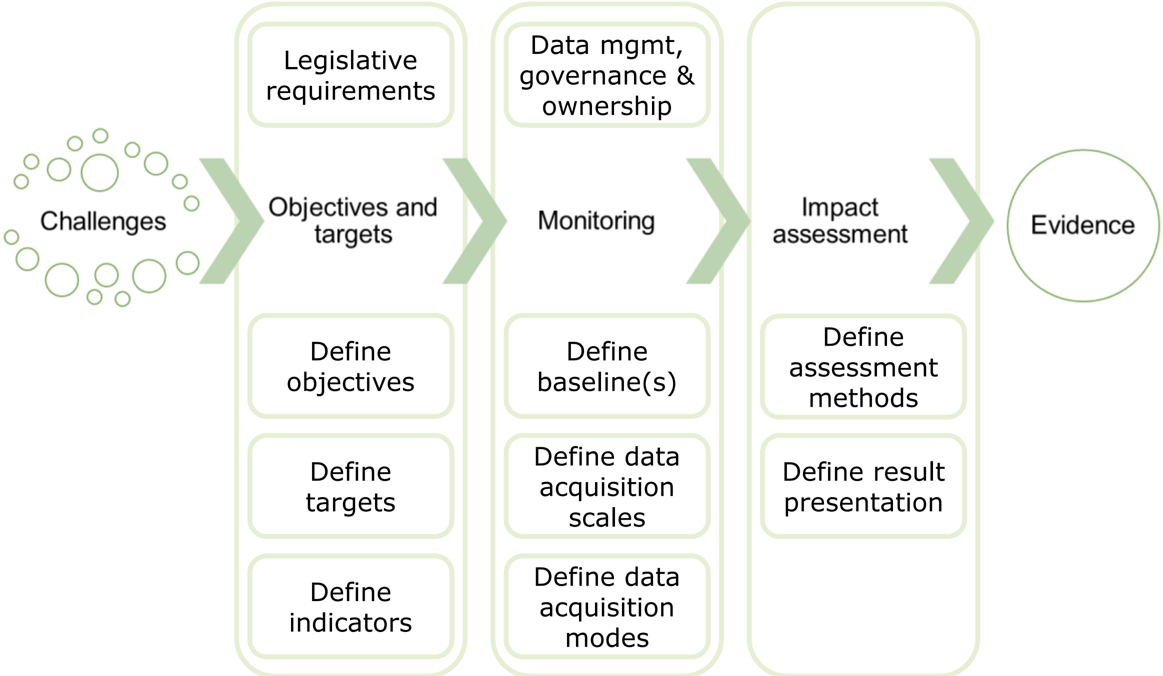


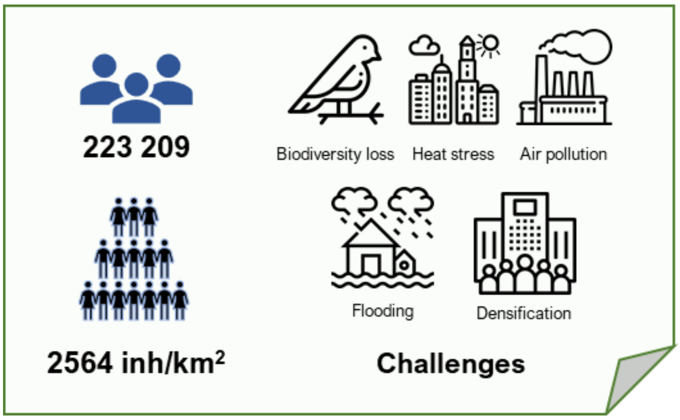
Figure 3. Framework for co-definition of NBS performance and impact indicators and assessment protocols (based on Dubovik et al., 2020).

The UNaLab project used a highly participatory approach to produce evidence of NBS impact, including co-creation, co-development, and co-monitoring activities. In the NBS impact assessment process in the UNaLab front-runner cities first involved co-definition of NBS performance and impact indicators in an interactive way with a wide range of local stakeholders. After co-definition of indicators, the UNaLab front-runner cities iteratively co-developed the monitoring and evaluation strategies together with project partners and other technical experts to assess NBS performance and associated impacts in a cost-effective way.

The UNaLab approach to co-development of the monitoring strategy relied on a diverse group of participants, in terms of cultural and educational background and needs. Deep stakeholder engagement was important for identifying the local challenges and monitoring and evaluation needs and capabilities. The selection of suitable performance and impact indicators and identification of the monitoring needs were facilitated through engagement of a wide range of experts during NBS monitoring and impact assessment planning.

NBS impact assessment in UNaLab was facilitated by the development of an ICT platform and other NBS monitoring and evaluation tools developed by UNaLab project partners. Automated collection of NBS monitoring data from IoT sensors complemented by manual entries supports long-term NBS monitoring and impact evaluation.

3. IMPACT OF NATURE-BASED SOLUTIONS IN EINDHOVEN



The City of Eindhoven (51°26′N 5°29′E) is located in the southern Netherlands. The city has a high population density, which is exacerbated by lack of green spaces and high temperatures in the dense urban area. Eindhoven sought to implement NBS that are versatile and, combined with supporting measures, can deliver multiple benefits.

The City of Eindhoven has selected multiple locations for NBS implementation, predominantly in the city centre, that represent a range of different urban characteristics. The focus of the NBS demonstration in Eindhoven is on effective integration of blue (water), green (flora) and grey (built environment) areas, focusing on urban challenges such as biodiversity, heat stress and air pollution, and flooding.

Eindhoven city centre
1. Vestdijk
2. Clausplein
3. Nutsbedrijven radio Eindhoven (NRE)
4. Waagstraat
5. Bilderdijklaan
6. Willemstraat
7. Dommelstraat & H.Boexstraat
8. Oude Stadsgracht
9. City Hall (Stadhuis)

Outside the city centre
10. De Grote Beek

Figure 4. NBS demonstrations in Eindhoven.

Heat stress

Heat stress was evaluated via the Physiological equivalent temperature (PET) which models the thermal conditions of the human body in a physiologically relevant way. PET is calculated from data obtained by mobile weather stations and sensors placed at 1.1 m, the average height of the centre of gravity of the human body in several locations of Eindhoven. The overall trend is that NBS decrease the PET relative to the reference measurement except for the NRE green façade that exhibits both decreasing and increasing results.

NRE	Stadhuis	Waagstraat	Clausplein	Vestdijk
-2.5%	-0.2%	-18%	-20%	-1%
+6%	-4%	-0.8%	-2%	-24%

Figure 5. Physiological Equivalent Temperature (ºC) calculations for two measurements per each NBS as compared to a reference site based on temperature and ambient conditions measurements in Eindhoven (based on monitoring data over a 10-minute period).

Additionally, the effect of NBS interventions on decreasing the temperature of the surrounding environment and buildings was evaluated with thermal cameras outputs (Figure 6). Thermal camera images indicate that NBS tend to have lower surrounding temperatures as well as providing shade (Figure 6a-b and g-h) and reduce temperature of the building (Figure 6e-f),

(a)

(b)

(c)

(d)

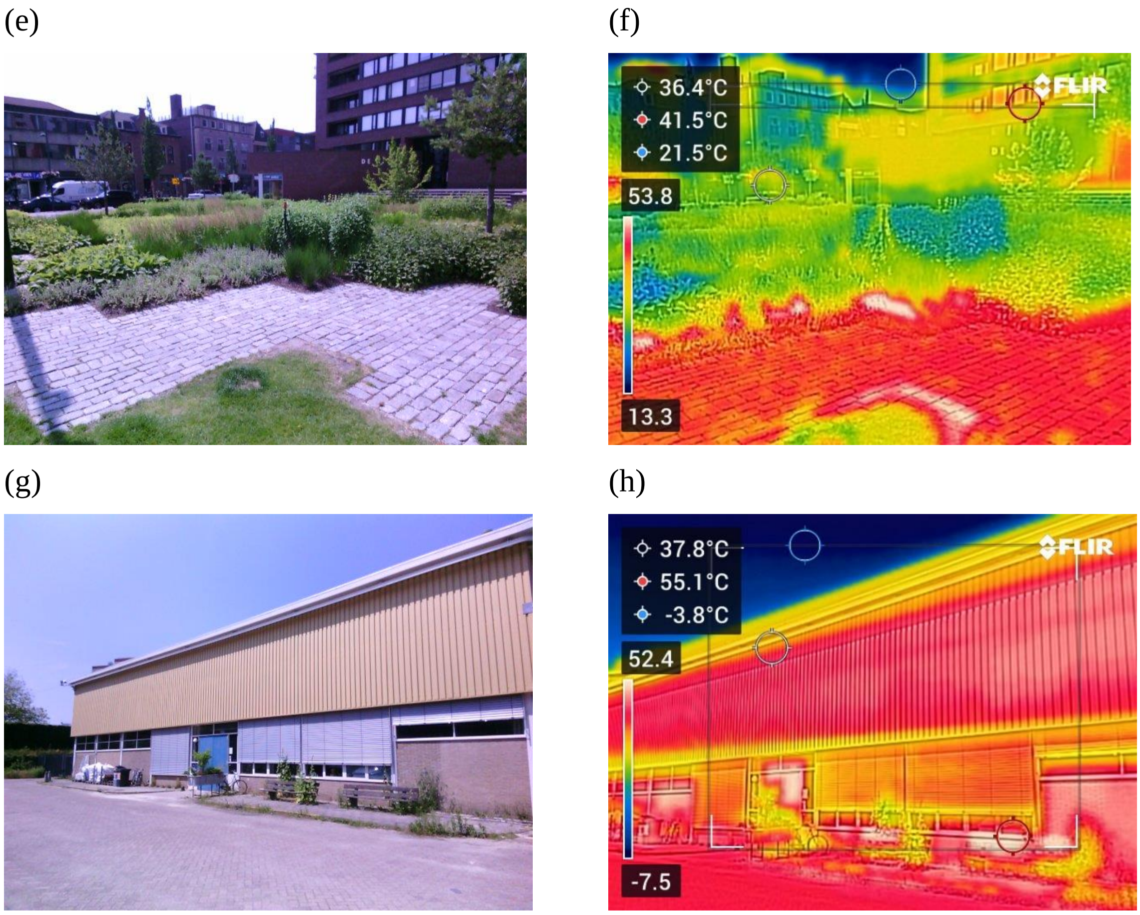


Figure 6. Thermal photos of NBS demonstrations in Eindhoven: (a)–(b) Vestdijk, (b)–(c) Smalle Haven, (e)–(f) Clausplein and (g)–(h) a reference building.

Water management

Ability of NBS to alleviate floodwaters was assessed via measuring their infiltration capabilities and rates. Infiltration rate data (mm/h) have been collected across various streets in Eindhoven (NL) for several NBS (including infiltration planter, bio-swales and green strips), using the Full Scale Infiltration Test (FSIT) method.

Figure 7. Infiltration rates of nature-based solutions across various streets in Eindhoven.

The highest infiltration values were observed for green strips (Clausplein), followed by bio-swales (in particular in Vestdijk) and infiltration planters (Boexstraat) as the soil media ensures high water permeability (Figure 7). Variation in infiltration rates across bio-swales is mainly explained by differences in soil type (e.g., sand or clay) and soil moisture. NBS, thus, contribute to infiltration capacity as compared to surfaced areas – thereby reducing pressure on the sewage system and decreasing flood risk.

Green space accessibility and distribution

Green space accessibility refers to the area influenced by the proximity to green and blue areas that has positive impacts on quality of life and general wellbeing. Figure 8 highlights that NBs implementation results in an average 34.6% increased green space per capita, with individual neighbourhoods seeing increases ranging from 3% to over 90%. Figure 9 shows the effects of NBS on green space accessibility in two central neighbourhoods in Eindhoven, which are neutral to positive depending on the neighbourhood. This indicator is conditioned by the scale of the selected solution, as well as where it is implemented. The results show that improvements can be achieved using these methods, as shown in the Eindhoven results where, in some cases, a new green space became available to an additional 25% of the residents.

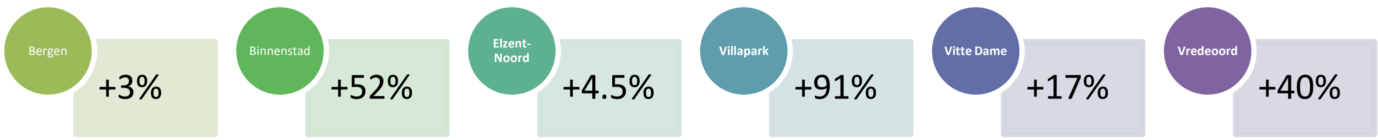


Figure 8. Change in area of green space per capita (m^2/capita) after implementation of nature-based solutions by neighbourhood in Eindhoven.

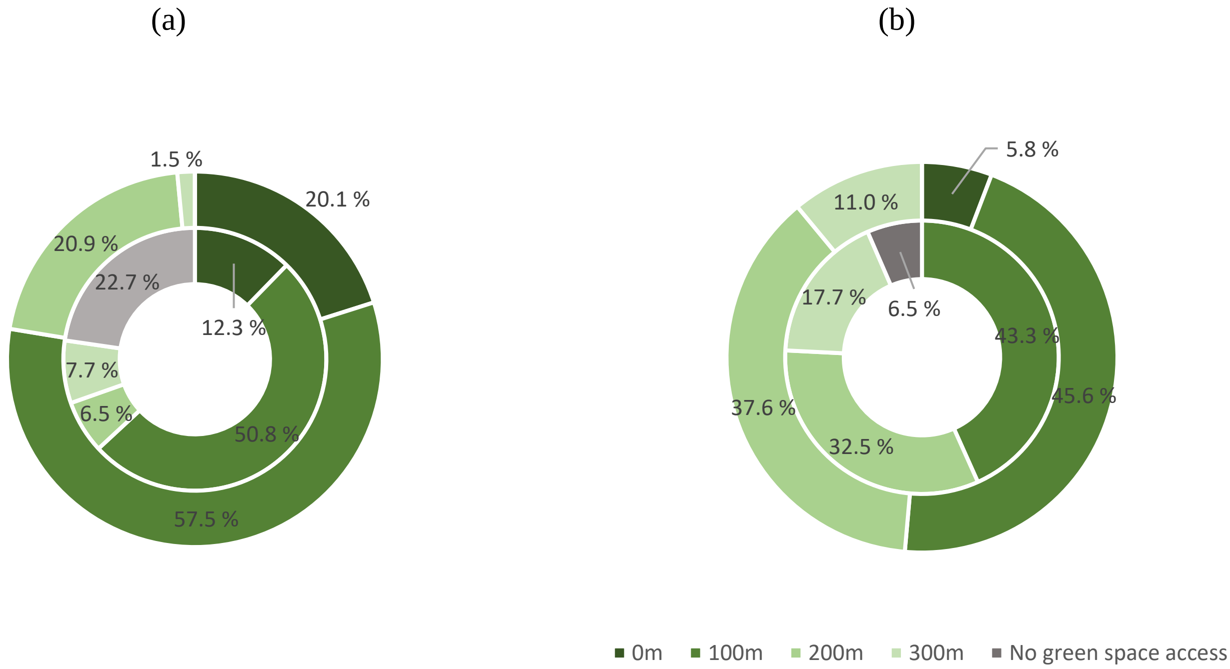


Figure 9. Share of people living with access to urban green space in (a) Binnestad and (b) Villapark neighbourhoods in Eindhoven. Outer circle represents the situation with NBS and inner circles without.

Biodiversity

A monitoring campaign was undertaken to determine the number of native plant species within the different NBS demonstration sites of Eindhoven as well as two control sites for comparison (Figure 10). NBS can create suitable habitats for native species to thrive in urban contexts. Eindhoven species counts show that NBS can foster native plant species in numbers ranging from 3 to 59 (average 17) depending on the design and placement of the solution, and this could account for 21% to 88% (average 54%) of all species present at the location. The control sites yielded a very uneven distribution of native species counts, so a proper comparison requires more extensive investigations.

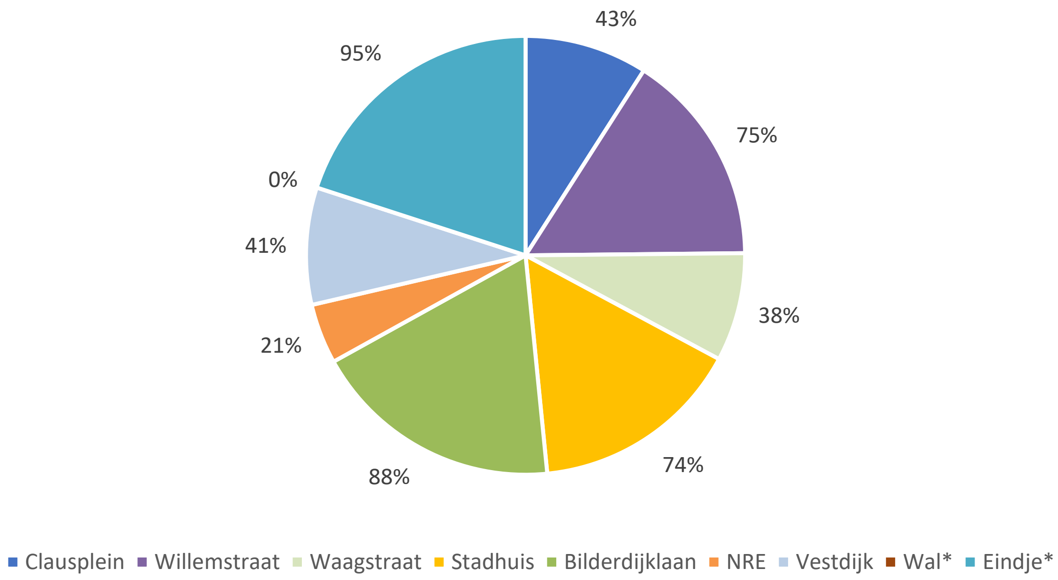


Figure 10. Number of native plant species as a proportion of all plant species observed in Eindhoven NBS and control sites (Wal and Eindje, marked with an asterisk).

Shannon Diversity Index (H), which indicates the broader diversity of the species in a community, was determined for the situation with NBS and without (control site) based on biodiversity surveys from the second half of 2020 to the first half of 2022 (Figure 11).

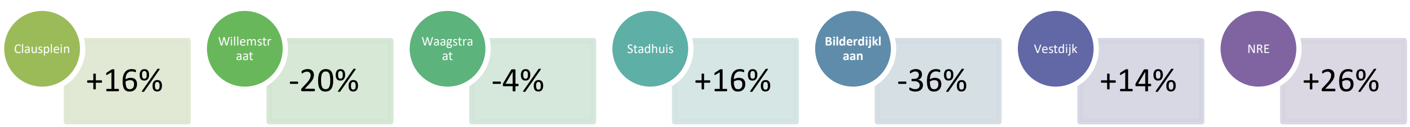


Figure 11. Species diversity change after NBS implementation as compared to two control sites in Eindhoven.

NBS positively contribute towards biodiversity in urban areas. Values from Eindhoven monitoring show increases that can be as high as 26% when compared to control sites (Figure 11), although some locations saw a reduction as well which could be attributed to specific conditions of the locale and not necessarily to the NBS itself. It should also be noted that the choice of control site will also affect these comparisons.

4. CONCLUSIONS

Synthesis of the measured and potential performance and impacts of NBS in UNaLab front-runner cities shows that NBS have the capacity to simultaneously address several societal challenges, depending on their geographical location as well as type, size and location of implementation. In particular, they have a noteworthy positive impact on green space management; a small positive impact on climate resilience, natural and climate hazards (flooding), biodiversity enhancement, air quality, and new economic opportunities and green jobs; and an indecisive impact on water quality management and place regeneration.

In Eindhoven, NBS had a variable impact on heat stress and not pronounced impact on temperature of surrounding areas and buildings. Infiltration was enhanced in areas with greater vegetation and unsealed surface area coverage. The impact on biodiversity was variable – both decreasing and increasing trends had been observed. NBS implementation increased the access and distribution of public green spaces – from a moderate to a considerable change in green spaces area per capita.

Based on the experiences and outcomes of NBS implementation and monitoring in the UNaLab FRCs, it was possible to draw some joint conclusions summarised in Laikari et al. (2021). The three UNaLab FRCs supported the fact that frequent monitoring is an essential element of NBS implementation, future planning and replication, and concluded that it also aids in identifying and detecting issues related to NBS functioning and supports in solving them. In addition, monitoring is a cross-cutting topic and the division of responsibilities for NBS monitoring should be clearly emphasised already during the planning stages. Finally, the planning stage should include the definition of the data management strategy, data governance, and ownership of data between municipal units generated throughout NBS monitoring.

5. FURTHER READING AND RESOURCES

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