Report on assessment methodologies for planning and monitoring GHG emission reductions through Urban Greening and Naturebased Solutions

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Summary

This deliverable is aimed at assessing the reduction of GHG emissions through the use of urban Nature-based Solutions (NBS). It is the outcome of sub Task 2.2.3, focused on assessment methodologies for planning GHG emissions reduction through the use of urban NBS, including impact monitoring with respect to emissions reduction.

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Report on assessment methodologies for planning and monitoring the reduction of GHG emission through the use of urban Nature-based Solutions

Deliverable 2.6

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Abbreviations and acronyms

Acronym	Description
AFOLU	Agriculture, Forestry and Other Land Use
AQP	Air Quality Pollutants
BECCS	Biomass for Energy and Carbon Capture and Storage
CDR	Carbon Dioxide Removal
DACCS	Direct Air Carbon Dioxide Capture and Storage
EU	European Union
GHG	Greenhouse Gas
KPI	Key Performance Indicator
MEL	Monitoring, Evaluation and Learning
NBS	Nature-based Solution
SUP	Sustainable Urban Plans
RUP	Renaturing Urban Plans
WP	Work Package

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Summary

This deliverable is aimed at **assessing the reduction of GHG emissions** through the use of urban Nature-based Solutions (NBS). It is the outcome of sub Task 2.2.3, focused on assessment methodologies for planning GHG emissions reduction through the use of urban NBS, including impact monitoring with respect to emissions reduction.

The potential of **Nature-based Solutions (NBS)** in the achievement of climate neutrality in cities is twofold: (1) as key elements to compensate GHG emissions that cannot be reduced from some sources (up to 20% by 2030, as recommended by the EC Info Kit for Mission Cities), thus, acting as carbon sinks that collect and stores CO_2 directly from the atmosphere, resulting in "negative emissions"; and (2) because of their potential in the reduction of energy consumption and carbon emissions, mainly in the built environment, mobility and transport and circular economy (water, mainly stormwater) areas.

The **current practice** around assessment methodologies for planning GHG emissions reduction through the use of urban NBS is assessed through an analysis of the main **frameworks of NBS indicators**. Such frameworks include relevant publications, EU initiatives and EU projects on NBS.

It is also necessary to highlight the importance of the NBS in relation to the **co-benefits** that can be achieved with their deployment. They contribute in a positive way to the better performance of the cities and other implemented innovative technologies, such as climate resilience, health, social, economy, resource efficiency and biodiversity. This is assessed in a **qualitative** way, taking the list of NBS developed within WP10 (NBS Thematic Area, which is included in the Knowledge Repository in the NZC Portal) and the list and classification of co-benefits, developed also under WP10.

Then, a **list of the NZC KPIs for the evaluation of NBS interventions** in cities is provided. It is divided into **key indicators and additional indicators**, and further details of all of them can be consulted in the *Handbook Evaluating the impact of nature-based solutions: Appendix of methods*; the publication developed by representatives of 17 EU-funded NBS.projects and institutions as the EEA and JRC, as part of the European Taskforce for NBS Impact Assessment.

Finally, **examples of Case Studies** in which urban NBS have been implemented and from which some indicators have been calculated to estimate their impact quantitatively are presented.

Keywords

Nature-based Solutions (NBS); GHG emissions, Indicator, Key Performance Indicator (KPI), impact assessment.

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1 Introduction

One of the key objectives of NetZeroCities is to offer a better understanding of how cities can monitor and evaluate performance, how they can assess the progress made along the path to climate neutrality, analyse achievements and enable learning for all local stakeholders as well as for other cities. This objective defines Work Package 2 (WP2) on "Impact Metrics and MEL". As part of WP2, **Task 2.2** "NetZeroCities indicator sets" is aimed at developing a science-based set of indicators enabling the assessment of climate, environmental and socio-economic impact of cities' climate neutral action plan, as well as its replication and scaling potential, in terms of GHG emissions reduction.

Within this context, (sub) **Task 2.2.3** is focused specifically on the assessment methodologies for planning GHG emissions reduction through the use of urban NBS, including impact monitoring with respect to emissions reduction.

1.1 Aim and scope of the report

The **Info Kit for Mission Cities published by the Joint Research Centre (JRC)[1]** in late 2021 addressed, among other things, what EC understands by climate neutrality in cities, which consists of reducing the GHG emissions from all sectors and sources within the city's boundary. These sectors include: emissions from combustion of fossil fuels in all buildings and facilities (known as 'stationary energy'), emissions from combustion of fossil fuels for all vehicles and transport, emissions arising from the consumption of electricity and district heating/cooling, emissions arising from waste generated within the city boundary, emissions from changes in land use, as well as emissions from chemical processes in industry. Indicators for measuring such emissions reduction are divided into three scopes, and covered in Deliverable 2.5 *Identified climate impact indicators based on existing indicators review.*

Besides the elements defined as part of the climate neutrality definition, the Info Kit includes some guidance on how to deal with **residual emissions and offsetting**. It also recognises that, although cities are required to reduce all sources of GHG emissions to the extent feasible, there may be certain emission sources (e.g. specific industrial processes) that depending on their local circumstances cannot be fully mitigated by 2030 due to technological or financial constraints. So, **compensating for any 'residual emissions' will be possible**, to an extent, to account for those emissions sources which cannot be fully eliminated.

To ensure that cities achieve maximum emission reductions within their territory, the Mission recommends as a guideline to aim for a level of **'residual emissions' within the city boundary in 2030 that does not exceed 20% of the baseline GHG inventory**, with the possibility that the remainder could be accounted for **using carbon sinks or credits**. A net-zero emission balance must be achieved by 2030, between direct reduction and offsetting of residual emissions, meaning the amount of GHGs emitted from a city territory is completely neutralised.

The Info Kit includes also the two ways for a city to deal with its residual emissions in order to achieve net-zero:

- **Carbon sinks**: removals through natural and technological solutions within the city boundary. It collects and stores CO_2 directly from the atmosphere, resulting in "negative emissions". There are two potential options for carbon sinks:

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- – **"Natural sinks"** refer to the planting of trees or other conversions of land use. These are accounted for as part of the 'AFOLU' sector of the GHG inventory (Deliverable 2.5).

- – **"Technological sinks"**, known as Biomass for Energy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Dioxide Capture and Storage (DACCS) technologies, can be used to sequester CO_2 permanently (locked away in geological formations).

- • **Carbon Credits**: from outside the city's boundary and subject to certain rules and restrictions to be able to credibly demonstrate a city's climate neutrality (i.e. using formal credits/certificates verified and/or validated under rigorous standards by certified third-party auditors).

Having all this into account, this report is aimed at assessing the reduction of GHG emissions through the use of urban Nature-based Solutions (NBS), which can be either by offsetting residual emissions, carbon sequestration, capturing and storing, or through complementary solutions applicable mainly in buildings, stormwater management and transportation that help the savings in energy and carbon.

Nature-based Solutions are this special group of solutions with a different scope or aim, focused on the compensation of emissions (sequestration of emissions, capturing or storing), but also very much related to a wide range of associated **co-benefits**, such as climate adaptation, biodiversity, social health and wellbeing (air quality), etc.

To address specific challenges more effectively, such as Climate Change Mitigation and Water management, it is necessary to incorporate them into Sustainable Urban Planning (SUP) in cities. In this line, several H2020 projects are aimed at developing a methodology principles, bases and focus on **Renaturing Urban Plans (RUP)** as a way to renaturing-cites with NBS.

The implementation of RUP also contributes to the creation of new market opportunities for European companies and fosters citizen insight and awareness of the importance of urban resilience measures among other aspects as health and wellbeing must always prevail.

Due to their specific context and relation to climate change mitigation (mostly not direct), it is **difficult to measure the performance or impact of urban greening and nature-based solutions**. It is particularly difficult to try to measure energy efficiency KPIs in relation to NBS, such as "Energy and carbon savings from reduced energy consumption", which could be calculated through different methods, for example through direct measurement and comparison with the performance before and after the NBS implementation, or through estimation of energy demand, although both are quite "abstract" or less tangible than we can expect from other solutions implementation.

In general, this is one of the most common **barriers** to the implementation of Nature-based Solutions: the difficulties to demonstrate with proper and accurate data the positive impacts and benefits of their implementation due to the many variables that affect to implementation and conservation of its. Therefore, the prioritisation of indicators that a city wants to address is crucial to be able to carry out an adequate data collection protocol, and thus adequately plan, evaluate and monitor the impact and performance of these solutions.

All in all, the document draws from numerous EU projects on Nature-based Solutions (NBS) such as EKLIPSE[2], Nature4Cities[3], CitieswithNature[4], Connecting Nature[5]; URBAN GreenUP[6], and similar European initiatives (e.g. NBS Impact Evaluation Taskforce[7]). Emerging assessment methods are

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[2] https://eklipse.eu/

[3] https://www.nature4cities.eu/

[4] https://citieswithnature.org/

[5] https://connectingnature.eu/

[6] https://www.urbangreenup.eu/

[7] European Commission, Directorate-General for Research and Innovation, *Evaluating the impact of nature-based solutions: a handbook for practitioners*, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/244577

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researched and evaluated, considering potential inputs from global practices, and drawing from extensive work emerging on climate resilience references to NBS.

> The present report describes the **current practice** around **assessment methodologies** for planning GHG emissions reduction through the use of urban NBS. The report includes as well the impact monitoring concerning emission reduction. Given the numerous already well-defined methodologies which include a great and wide list of NBS indicators, the report focuses on making the most **adequate selection of KPIs to recommend to cities when implementing NBS** with a focus on achieving climate neutrality (both through their potential for energy and carbon savings and through the offsetting of GHG emissions). The document includes also a **qualitative assessment of the co-benefits** that can be achieved through the implementation of urban NBS, which have a significant impact on the case of urban NBS.

Thus, this **list of NBS** assessed builds upon the NBS Taxonomy developed in WP10 (already included in deliverable 10.1 *Taxonomy of Thematic Areas* and further elaborated and refined in *deliverable 10.2 Catalogue of solutions and co-benefits*), where all solutions are listed and included as resources (in the form of Factsheets) into the NZC Knowledge Repository. From that D10.2, we are also taking the **classification of co-benefits**.

1.2 Structure of the document

The document is structured into three main sections:

- **Section 1** introduces the document, its aim and scope, as well as its structure and connection to other Tasks and Work Packages.

- **Section 2** delves into the state-of-the-art of EU projects and similar EU initiatives or publications on urban NBS assessment. It is structured into two sub-sections:

  - **Section 2.1** focuses on the state-of-the-art assessment of existing NBS indicators frameworks;

  - While **Section 2.2** performs a qualitative assessment of the co-benefits (as defined and classified in the NetZeroCities project –WP10) to which urban NBS contribute.

- **Section 3** delves into the main indicators for assessing the planning and monitoring of GHG emission reductions through the use of urban NBS.

  - **Section 3.1** includes the NZC indicator set for assessing the impact of NBS for climate neutrality. They are classified into two groups: the key or most important ones from other additional ones that might be relevant for advanced cities that are keen on or relying on these solutions.

  - **Section 3.2** provides indicative Case Studies in which urban NBS have been implemented and indicators have been calculated to estimate intervention impact.

- Finally, a section of **Conclusions** is added at the end of the report, as well as a **References** section, which consolidates the references added as footnotes across the report.

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1.3 Connection to other Tasks and Work Packages

Below the connections between Task 2.2.3 and other Tasks and Work Packages of the project are presented:

- Strong link with prior **Task 2.1** "Setting-up a MEL framework", mainly with **D2.2** "Inventory of existing MEL methodologies" where relevant existing MEL methodologies developed in EU projects and other initiatives was compiled and assessed.

- Link to the other subtask in **Task 2.2** "NetZeroCities indicator sets", where in sub-task **2.2.1** the overarching indicator framework is set based on the outputs from the other sub-tasks in T2.2: **st2.2.2** – climate impact indicators (scope 2 indicators), **st2.2.4** – evaluation framework for Social Innovation Action Plans, and **st2.2.5** – relevant indicators for capital and finance needs.

- Link to **Task 2.3** "Standards and interfaces for data collection", which will analyse data sources to support the measurement of the KPIs defined in previous Task 2.2.

- Link to **Task 2.4** "Monitoring, evaluation, learning and reporting", which will set the framework for and enable evaluation of the CCCs and of the Climate action plans, Social Innovation action plans, pilots and replication potential of the solutions.

- Strong link and alignment needed with **WP1**, mainly with **Task 1.5** "Cohort support for Social Innovation and Climate Action Planning", where the assessment and evaluation framework set within T2.2 will be key input.

- Link with **WP10**, mainly with **Task 10.1** "Taxonomy of thematic areas", from which the taxonomy set for the Nature-based Solutions thematic area is a key input for the definition of challenges in the present report. There is also a link with the **Task 10.2** "Analysis of solutions, co-benefits and barriers to adoption", where the mentioned taxonomy was refined due to feedback from JRC and has been taken into account for the list of solutions presented in this document; as well as the definition of the list and classification of co-benefits for the NZC projects.

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2 Assessment of urban NBS

The assessment of urban Nature-based solutions in this report, as mentioned in the previous section, is done with a view to achieving climate-neutrality in EU cities, both for Mission Cities aimed at developing the Climate-neutral City Contract (and its subsequent Action and Investment Plans) or for Pilot Cities aimed at implementing technical and non-technical solutions.

Thus, we need to take into account that the potential of urban NBS in climate neutrality is twofold:

- As key elements to **compensate GHG emissions** that cannot be reduced by 2030 (e.g. from specific industrial processes, from historically protected buildings in which is very difficult to perform any retrofitting, both through active or passive measures, etc.).
- For their potential in the **reduction of energy consumption and carbon emissions**, mainly in the built environment, mobility and transport and circular economy (wate and waste) areas.

In addition to these two main aspects of urban NBS about climate neutrality, the great potential of NBS in terms of **co-benefits** should also be highlighted.

NBSs are thus assessed through a **set of key indicators** set by NetZeroCities that come from the literature review, and through a qualitative assessment of the **associated co-benefits** that such solutions may have.

The solutions analysed in terms of their associated co-benefits are the ones defined within the WP10 taxonomy on Nature-based Solutions thematic area, which are uploaded in the form of individual Factsheets to the NetZeroCities Portal, in the Knowledge Repository (https://netzerocities.app/knowledge).

In addition, indicative **examples (case studies)** are gathered in this report to showcase how cities have been implemented urban NBS and indicators have been calculated to estimate intervention impact.

For a **successful implementation of urban NBS**, and thus achieve the expected impacts and co-benefits, it is important to **take into account several interactions of NBS with its broader social, environmental and climatic context**. Although vegetation is used to improve air quality, it is also affected by the poor air quality in different ways. Ozone and other pollutants can lead to acid rain that harms tree leaves, stressing trees and overall changing the chemical and physical composition of the soil.

Understanding this dual effect is important to maintain any diverse and healthy ecosystem that will result in improved human health and well-being and also biodiversity health and well-being. BObserved biodiversity will depend directly on the quality of the greenery.

The rhizosphere is the narrow region of soil or substrate that is directly influenced by root activity and associated soil microorganisms and constitutes a unique physical, biochemical, and ecological environment, through this it is estimated that 5 – 21%[8] of all photosynthetically fixed carbon is eventually transferred to the rhizosphere.

Restoring and preserving biodiversity overall at the soil level helps to increase carbon sequestration of NBS and other green areas. Also, having a good diversity of plants will ensure energy savings as it can act as a screen by reducing the surface area by several degrees and reducing wind speed by the order of 65-75%, reductions in wind speed can reduce the dispersion of pollutants, which will tend to increase local pollutant concentrations

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[8] Bais, H.P., Loyola-Vargas, V.M., Flores, H.E. et al. *Root-specific metabolism: The biology and biochemistry of underground organs.* In Vitro Cell.Dev.Biol.-Plant 37, 730–741 (2001). https://doi.org/10.1007/s11627-001-0122-y

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2.1 State-of-the-art assessment of existing urban NBS indicators frameworks

Following Table 1 presents the main frameworks of indicators used to assess and evaluate urban NBS. They are classified by including the **title and year**, as well as the **link** to access to it; if they have been developed as part of an **EU project, publication, or other initiative**, together with the **authors**. Table 1 also includes a **short description** of it's the main purpose of the frameworks, the **internal structure or dimensions** in which the framework organises the indicators, its **adoption level** (i.e. if it has been adopted/applied by cities or if it is just a theoretical piece of work/ methodology; as well as in terms of ease for cities to adopt it), and a brief **evaluation** with respect to the **relevance of the framework to the NetZeroCities** project (mainly related with the existence of climate impact indicators).

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Table 1: Assessment of relevant indicator frameworks for urban greening and NBS

Framework	Type & Authors	Description	Internal structure/ Dimensions	Adoption level	Evaluation for the NZC
Evaluating the Impact of NBS: Handbook and Appendix of Methods (2021)[9]	Publication. Authors: Representatives of 17 EU-funded NBS-projects and institutions such as the EEA and JRC, as part of the *European Taskforce for NBS Impact Assessment*	The Handbook provides a comprehensive NBS impact assessment framework, with a robust set of indicators and methodologies to assess the impacts of NBS across 12 societal challenge areas.	12 societal challenge areas: Climate Resilience; Water Management; Natural and Climate Hazards; Green Space Management; Biodiversity; Air Quality; Place Regeneration; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance; Social Justice and Social Cohesion; Health and Well-being; New Economic Opportunities and Green Jobs.	Applied. It offers a wide and comprehensive framework of NBS indicators with enough information and well-classified, which makes it easy to adopt.	Very relevant. It includes evaluation of impacts of NBS, standardized methods of assessment, state of play in urban implementation and evaluation frameworks, as well as dimensions related to climate change.
EKLIPSE impact evaluation framework to support planning and evaluation of nature-based solutions projects (2016)[10]	EU initiative. Authors: EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas	EKLIPSE developed an impact evaluation framework with a list of criteria for assessing the performance of NBS in dealing with challenges related to climate resilience in urban areas. It includes also an application guide for measuring how NBS projects fare against the identified indicators in delivering multiple environmental, economic and societal benefits; and makes recommendations to improve the assessment of the effectiveness of NBS projects, including the identification of knowledge gaps according to the criteria presented in the impact evaluation framework.	10 climate resilience challenges: Climate adaptation and mitigation; Water management; Coastal resilience; Green space management; Air quality; Urban regeneration; Participatory planning and governance; Social justice and social cohesion; Public health and wellbeing; Potential economic opportunities and green jobs.	Applied. It provides relevant and legitimate evaluation framework, which allows it to be used effectively.	Very relevant. It includes evaluation of impacts on NBS and climate-related indicators. In addition, it is constantly updated, a reference site, as well as challenges on climate resilience.

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[9] European Commission, Directorate-General for Research and Innovation, *Evaluating the impact of nature-based solutions: a handbook for practitioners*, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/244577
[10] https://www.eklipse-mechanism.eu/apps/Eklipse_data/website/EKLIPSE_Report1-NBS_FINAL_Complete-08022017_LowRes_4Web.pdf

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Framework	Type & Authors	Description	Internal structure/ Dimensions	Adoption level	Evaluation for the NZC
URBAN GreenUP indicator framework (2023)[11]	**EU project**. <u>Authors</u>: Partners in the URBAN GreenUP project (https://www.urbangreenup.eu/)	It has defined a set of KPIs (Key Performance Indicators) used to assess a defined methodology for city renaturing, as well as to assess the demonstration cities for the diagnosis and baseline. The methodology is based on main challenges and goals from EKLIPSE Mechanism framework. It provides a detailed definition of the KPIs. It also elaborates a methodology for Re-Naturing and evaluation of NBS Scenarios.	The framework is structured under the same 10 challenges as *EKLIPSE* (see above).	**Applied**. It is detailed enough (also due to the need of measure the indicators in the demo cities).	**Relevant**. It includes climate-related indicators, and they are measured in the demo cities to evaluate the impact of the implementations (so, ensuring they are quantifiable, measurable and recent).
Nature4Cities Urban Performance Indicator framework (2019)[12]	**EU project**. <u>Authors</u>: Partners in the Nature4Cities project (https://www.nature4cities.eu/)	Nature4Cities built a framework of Urban Challenges to consider to develop a clear and coherent indicator system. Starting from literature review for the Urban Challenges selection (including EKLIPSE), then plenty of different existing frameworks were analysed, summarised and structured together. To keep the structure as simple as possible, the EKLIPSE framework was adduced to be the base for it.	5 main topics containing the Urban Challenges and Urban Sub-Challenges are defined: <u>Climate</u>: Climate issues & Water management and quality <u>Environment</u>: Air quality & Biodiversity and urban spaces & Soil management <u>Resources</u>: Resource efficiency <u>Economy</u>: Green economy <u>Social</u>: Public health and well-being & Environmental justice and social cohesion & Urban planning and governance & People security.	**Theoretical**. It contains a vast number of indicators, although well classified and with enough detail to be calculated (necessary to decide the most relevant ones to each case).	**Relevant**. It offers a wide indicator framework, well classified and detailed, which includes climatic and emissions aspects.

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[11] https://www.urbangreenup.eu/resources/deliverables/

[12] https://www.nature4cities.eu/post/nature4cities-defined-performance-indicators-to-assess-urban-challenges-and-nature-based-solutions

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Framework	Type & Authors	Description	Internal structure/ Dimensions	Adoption level	Evaluation for the NZC
Connecting Nature NBS evaluation indicators: Environmental Indicators Review (2020)[13]	**EU project**. <u>Authors</u>: Partners in the Connecting Nature project (https://connectingnature.eu/)	It is a review of core and recommended evaluation indicators for evaluating the benefits, co-benefits, and trade-offs associated with Nature-based Solutions indicators. The review comprises the indicators scoping co-production exercise done in the project in collaboration with the three front-runner cities.	All indicators are environmental related, and they are divided into Core indicators and Feature indicators.	**Applied**. The three front-runner cities in the project operationalised these indicators on their exemplar projects. Indicators are detailed enough.	**Something relevant**. It offers a wide set of indicators related to environment, well detailed, although most of them are most related to the co-benefits than to GHG emission reductions.
UNaLab Performance and Impact monitoring of NBS (2019)[14]	**EU project**. <u>Authors</u>: Partners in the UNaLab project (https://unalab.eu/)	It is first and foremost a handbook for practitioners. It summarises the classification and mode of action of nature-based solutions (NBS), the selection of key indicators of NBS performance and impact, design of a NBS monitoring scheme.	Divided directly by indicator category: Carbon Emissions Temperature Flood Vulnerability Drought Vulnerability Water Quality Green Space Management Biodiversity Air Quality Urban Regeneration Participatory Planning and Governance Social Justice & Social Cohesion Health and Well-Being Economic Activity & Green Jobs	**Applied**. The three front-runner cities in the project monitored and evaluated their implemented NBS' effectiveness with those indicators.	**Relevant**. It offers a complete indicator framework, well classified and detailed (incl. sources of data), which has a specific category on carbon emissions.

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[13] https://connectingnature.eu/nature-based-solution-evaluation-indicators-environmental-indicators-review
[14] https://unalab.eu/en/documents/d31-nbs-performance-and-impact-monitoring-report

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Framework	Type & Authors	Description	Internal structure/ Dimensions	Adoption level	Evaluation for the NZC

CLEVER Cities Monitoring and Evaluation Framework (2018)[15] and Monitoring Strategy (2020)[16]	**EU project.** <u>Authors</u>: Partners in the CLEVER Cities project (https://clevercities.eu/)	Assessment of NBS impact by establishing and implementing a robust, long-term and integrated yet locally-adaptably co-monitoring framework. The approach for KPIs definition is linked to a co-design process.	Different KPIs were selected for each city around the following challenges:
			    Health and well-being
			    Sustainable development
			    Social cohesion and environmental justice
			    Citizen security
				Applied. The three front-runner cities in the project monitored their actions with their defined KPI framework.	**Not too relevant.** It does not focus on any environmental or carbon emissions indicator.

GROW GREEN Monitoring Strategy for Nature-based Solutions impact assessment in cities (2021)[17]	**EU project.** <u>Authors</u>: Partners in the GrowGreen project (https://growgreenproject.eu/)	Outlining of key components to build a robust Monitoring Strategy for cities to assess the impact of Nature-based Solution (NBS) projects.	Indicators set around cities challenges: <u>Climate adaptation and mitigation</u>: Heat stress, Water management flooding, Water management scarcity, Carbon emissions. <u>Urban Environmental Quality</u>: Water quality, Access to nature, Air quality, Noise quality, Biodiversity. <u>Urban Challenges</u>: Social cohesion, Social Justice, Human health and well-being, Inclusions and equality, Stakeholder participation, Connectivity/accessibility, Rapid growth densification.	**Theoretical.** It is meant to provide guidance to the stakeholders facing the challenge of implementing NBS in cities on how to monitor and assess the impact of NBS.	**Relevant.** It offers a well-structure guide and indicator set around main challenges, including carbon emissions.

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[15] https://clevercities.eu/fileadmin/user_upload/Resources/181130_D.4.1_Monitoring_Framework_TEC.docx.pdf
[16] https://clevercities.eu/fileadmin/user_upload/Resources/CLEVER_D4.3_Monitoring_Strategy_in_the_FR_interventions_vF2.pdf
[17] https://growgreenproject.eu/wp-content/uploads/2021/11/GrowGreen-Summary-sheet-007-v02.pdf

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2.2 Assessment of urban NBS co-benefits

Urban Nature-based Solutions have a relevant role in the achievement of the climate neutrality in cities, also due to their several co-benefits that contribute in a positive way to the better performance of the cities and of the other implemented innovative technologies. They are indirect impacts related to other areas that are also important for cities and that should be not forgotten when addressing the net zero emissions: climate resilience, health, social, economy, resource efficiency and biodiversity.

The following Table 2 shows the complete categorization done in the NZC project (WP10 – D10.2 *Catalogue of solutions and co-benefits*) of the co-benefits that solutions might have.

Table 2: Co-benefits categories classification by NZC – WP10

Climate resilience	Climate adaptation	• Reduce risk to natural and climate hazards • Enhance stability of the urban infrastructure
	Climate mitigation	• Reduce GHG emissions • Reduce energy needs • Increase access to clean, affordable and secure energy • Increase carbon sequestration capacity
Health	Environment	• Improve air quality • Reduce noise pollution • Reduce hot spots/urban heat islands • Reduction of road danger
	Well-being	• Enhance attractiveness of the cities • Healthier and more attractive lifestyles • Better physical activity of individuals • Better access to living areas
Social	Inclusion	• Social cohesion • Social capacity building • Enhance citizen participation, connectivity and community
	Education	• Improve access to information • Raise awareness/behavioural change • Increase skill development • Improve access to job opportunities
Economy	Local and global connection	• Boost local business (km 0) • Proximity economy • Sharing economy
	Entrepreneurship and innovation	• Increase employment rate and jobs • Increase technological readiness • Decrease future maintenance costs
Resource efficiency	Waste efficiency	• Better waste management • Promote the materials cycle
	Water efficiency	• Better water quality • Better water management
	Food efficiency	• Sustainable and resilient food systems • Reduce food waste
	Land use	• Improve land use management • Improve soil health

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Biodiversity	Greater biodiversity	• Species increase • Pollinator increase • Increase ecological connectivity • Reduce risk of epidemics • Reduce ecological footprint • Green awareness

This list of co-benefits has a close relation with the societal challenge areas defined by the EC Handbook: Evaluating the Impact of NBS, where the indicators to evaluate them are set (seeee Figure 1 below). This means that, although complex and difficult for data to be obtained, the defined co-benefits can be measured and evaluated also in a more quantitative way, in the form of defined indicators as per the relation established.
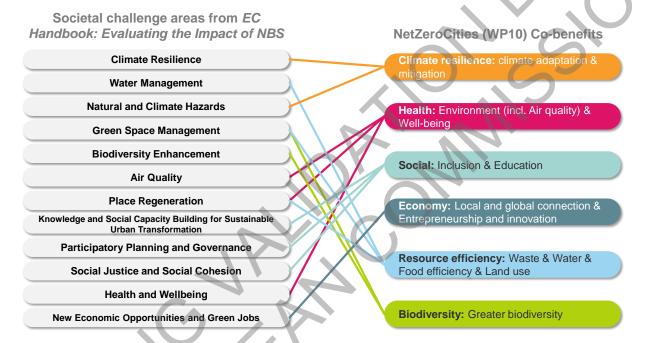

Figure 1: Relation between the societal challenge areas from the *EC Handbook: Evaluating the Impact of NBS*[18], where quantitative indicators are set, with the NZC Co-benefits

The indirect positive impacts of urban NBS in the co-benefits areas are explained in the following paragraphs, and are summarized in Table 3.

NBS has potential to contribute to **climate mitigation** by indirectly reducing GHG emissions through passive solutions that reduce the energy needs, such as the shading effect of vegetation that keeps the solar radiation off the building (and thus reducing the need of cooling in summer), or by creating a thermal mass "buffer" that prevents against daily fluctuations (thus blunting the effect of temperature swings during the peak of the heating and cooling seasons), but also through evapotranspiration, which is the loss of water through evaporation and transpiration that contributes to humidifying the air, therefore cooling it. All in all, urban NBS reduce therefore the need for air conditioning in summer (**reduction of energy needs, and thus the GHG emissions**) without increasing the need for heating in winter. Direct

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[18] European Commission, Directorate-General for Research and Innovation, *Evaluating the impact of nature-based solutions: a handbook for practitioners*, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/244577

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contribution is offered through the **carbon sequestration** potential of NBS, since green areas absorb carbon dioxide and increase the supply of oxygen.

According to the study carried out by Casal-Campos et al. (2013)[19], in which eight case studies are reviewed, there is a close relation between the elements considered for the life cycle assessment (LCA) of the carbon footprint associated with green infrastructure (GI) and other NBS for different LCA configurations. This is shown in Figure 2 below, and sets a clear relation with the benefits from NBS in terms of CO_2 reduction.

GI life cycle stages	MATERIALS	CONSTRUCTION	OPERATION	DECOMMISSION
Carbon sources	Extraction, processing and transport of raw materials to site.	Transport of equipment and labour to site. Energy/fuel used for construction activities. Construction waste disposal.	Transport of equipment, materials and labour to site. Energy/fuel used for maintenance activities. Maintenance waste disposal.	Transport of equipment and labour to site. Energy/fuel used for demolition activities. Waste disposal.
Opportunities to reduce the carbon footprint of GI	Sourcing of materials (local manufacturers, eco materials, etc.)	Low-carbon construction methods and design.	Low-maintenance design. Carbon sequestration. Avoided emissions from new grey infrastructure. Reduced pumping and treatment of combined sewer flows. Energy benefits from flooding or diffuse pollution mitigation. Reduced heat island effect, enhanced building insulation, etc.	Easy-to-remove design. Reusable/recyclable materials. Adaptable design.
Carbon category	Embodied Carbon		Operational Carbon	End-of-life Carbon
LCA boundaries	*Cradle-to-site*	*Cradle-to-built asset* *Whole life cycle carbon assessment (UKWIR approach)*		*Cradle-to-grave*

Figure 2: Summary of the elements and activities commonly considered for the life cycle assessment (LCA) of the carbon footprint associated with green infrastructure (GI) for different LCA consigurations. *Source: Casal-Campos et al. (2013)*

With respect to **climate adaptation and disaster risk reduction**[20], urban NBS work with and enhance nature to restore and protect ecosystems and to help society adapt to the impacts of climate change and slow further warming. NBS typically entail coastal zone protection, wetland restoration, river/floodplain restoration, agroforestry, close-to-nature forestry, (peri)urban greening and soil protection. They can also deliver services such as erosion control, drought and flood prevention, carbon sequestration, cooling and wildfire prevention. E.g. planting trees that thrive in coastal areas (known as mangroves) reduces the impact of storms on human lives and economic assets, provides a habitat for fish, birds and other plants supporting biodiversity. And wetlands reduce flood risk by holding excess water.

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[19] Casal-Campos, Arturo & Fu, Guangtao & Butler, David (2013). *The whole life carbón footprint of Green infrastructure: A call for integration*. NOVATECH Conference at Lyon, France. https://www.researchgate.net/publication/265786761

[20] European Environmental Agency, *Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction*, 2021, doi: 10.2800/919315. https://www.eea.europa.eu/publications/nature-based-solutions-in-europe

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With respect to **environmental benefits**, certain plants have a great impact on **improving air quality**, as they remove air pollutants and smog from the atmosphere, as well as protect from harmful UV rays. They eliminate certain gaseous pollutants, which are permanently absorbed via their stomata (ozone and nitrogen oxides), and absorbed in the fatty elements of the cuticle (PCBs, dioxins and furans). The particles are intercepted at the surface of the leaves, particularly if the leaves are rough, hairy or waxy. This interception is temporary, as these particles can be released back into the atmosphere, be washed away by rain or fall to the ground together with the leaves and twigs. It should also be noted that the positive effects described above can be partly counterbalanced by negative effects, inter alia: emissions of volatile organic compounds (isoprene, monoterpene) by certain species, reduction of wind speed which can lead to an increase in the concentration of pollutants locally, or emissions of allergenic pollens. For this reason, careful planning and implementation of greening is recommended.

Vegetation can also moderately reduce **hot spots and urban heat island effect**, as it creates a cooling effect around it. **Noise pollution** is also improved as vegetation can reduce noise level by human ear by more than 50%.

Urban NBS have also related co-benefit of **well-being**, **enhancing attractiveness of cities**, since green areas create aesthetically beautiful environment in the cities. Urban carbon sinks can create an interconnected network of green spaces that sparks interest in citizens and harmonized the negative impacts of urban expansion, which is also related with the enhancement of green mobility.

In terms of **social inclusion**, urban NBS create a green space network that support busy city life, improving health, prosperity and happiness of citizens. With respect to **economic** co-benefits, urban NBS can create economic opportunities by leading to higher land prices for the properties in the proximity. Nonetheless, this is also considered a risk for gentrification if greening is not equally distributed also in low income neighbourhoods.

Urban NBS have also potential for **resource efficiency**, mainly related to the improvement in the **land use** management. Some of the urban NBS are also related to circular economy (such as community composting, or sustainable urban drainage –SUD- systems), that contribute effectively to the **waste efficiency**, with on-site waste recycling and reuse, or with a more sustainable and resilient food system (**food efficiency**), since compost can be used to promote individual or community kitchen gardens, while reducing dependency on external food supply.

Urban NBS with emphasis on water management can increase water storage, infiltration and attenuate floods, contribute to the **water efficiency**, by achieving a better water management, by offering the possibility to displace the water to dry areas when there are floods, allowing community to collect fresh water during rainy seasons for later use during drought and dry spells, or by providing a water balance in case of extreme or irregular weather.

Biodiversity is also one of the main co-benefits from NBS. Urban nature-based solutions enhance biodiversity and **pollinator increase** with enhanced green areas, with which an instant improvement in biodiversity is observed. This contributes to soil moisture content enhancement and improved nutrient cycle, thereby impacting the surrounding flora and fauna. Vegetation and green areas contribute to a significant increase in the number of animal and plant species (e.g. birds, insects, mammals, lichens), which the habitat for shelter, reproduction or food. They also are important to create **green awareness** in citizens of native green species and the value of vegetation.

Table 3 presents the **qualitative assessment** of the different co-benefits defined in the project by different nature-based solutions. In particular:

- Solutions (NBS) are assessed in terms of scale. Although it is a qualitative assessment, it is crucial to have into account the **scale of application** of the different interventions, for a better idea of the impact of the different co-benefits. In this case, the scale of application has been divided into metropolitan, urban (city level), streetscape, district and building level.

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- **Co-benefits** are assessed per solutionaccording to the classification previously shown in Table 2. They are evaluated with a **two-colour code** to have a more detailed analysis though still qualitative. Dark green is for the co-benefits that the implementation of the urban NBS will provide "for sure" around it; while light green is to highlight other possible co-benefits that the NBS can provide as well if it is implemented adequately and with favourable conditions.

The literature resources provided in Table 1 offer semiqualitative through to fully quantitiative methods for assesing these co-benefits. The present report does not aim to reproduce them – rather it focused on KPIs that relate to emissions' reduction (see Section 3).

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Table 3: Matrix for the assessment of urban NBS solutions co-benefits

Urban Nature-based solution (linked to Nature-based Solutions in Knowledge Repository: https://netzerocities.app/resource-2644)	SCALE OF APPLICATION					CO-BENEFITS												
						Climate resilience		Health		Social		Economy		Resource efficiency				Bio-diversity
	Metropolitan	Urban	Streetscape	District	Building	Climate adaptation	Climate mitigation	Environment (incl. Air quality)	Well-being	Inclusion	Education	Local and global connection	Entrepreneurship and innovation	Waste efficiency	Water efficiency	Food efficiency	Land use	Greater biodiversity
Urban carbon sink (urban forestry)	■	■	■			■	■					■			■		■	■
Smart-soils and Phytoremediation	■	■												■	■			
Pollinator and verges spaces	■					■					■			■		■		■
Vertical mobile gardens		■	■	■	■	■		■					■					
Shading structures		■	■	■	■	■												
Floating gardens	■					■									■			■
Green filter area		■	■	■	■	■								■			■	
Urban garden bio-filter for improved air quality	■	■	■			■		■					■	■			■	
Green resting areas, parks and urban forests, parklets	■	■				■		■	■								■	
Cooling trees	■	■	■	■		■												
Green corridors for active and cooler mobility	■	■	■	■		■		■									■	
Community composting				■	■							■		■		■		
Hard-drainage flood prevention	■	■	■			■									■		■	
Grassed swales and water retention pounds	■	■						■							■			■
Floodable park	■						■	■										■
Green pavements: hard drainage pavements		■	■	■													■	
Sustainable Urban Drainage (SUD) systems	■	■	■												■			
Water irrigation and maintenance technologies	■	■	■	■	■										■			
Constructed wetland	■					■		■							■		■	

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Urban Nature-based solution (linked to Nature-based Solutions in Knowledge Repository: https://netzerocities.app/resource-2644)	SCALE OF APPLICATION					CO-BENEFITS												
						Climate resilience		Health		Social		Economy		Resource efficiency				Bio-diversity
	Metropolitan	Urban	Streetscape	District	Building	Climate adaptation	Climate mitigation	Environment (incl. Air quality)	Well-being	Inclusion	Education	Local and global connection	Entrepreneurship and innovation	Waste efficiency	Water efficiency	Food efficiency	Land use	Greater biodiversity
Rain gardens	■	■	■			■	■	■		■			■		■		■	■
Green roof					■	■		■					■		■		■	■
Green swales and green façades		■	■	■		■		■	■				■		■		■	
Climate smart greenhouses			■	■		■				■	■				■	■		

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3 NZC indicator for assessing reduction of GHG emissions through the use of urban NBS

As final step in this report and as main outcome from the literature review (state-of-the-art in section 2.1), this section includes the list of indicators for the Mission Cities related to the assessment (planning and monitoring) of the reduction of GHG emissions through the use of urban Nature-based Solutions. The evaluation of NBS can vary depending on the societal challenge that it sets out to address, in this case: **climate change mitigation.**

The list of indicators is divided in two levels: the **key indicators** and the **additional indicators**. Primary indicators are those that are essential to evaluate when seeking climate neutrality, while the additional ones are recommended for cities that put emphasis on the implementation and deployment of urban NBS.

According to the *Handbook Evaluating the impact of nature-based solutions: a handbook for practitioners*[21], a proper assessment and evaluation of the targeted impacts from NBS is needed in a way that is relevant and useful firstly to immediate end users and secondly to inform broader policy processes. Therefore, the development of monitoring and impact assessment plans must consider some universal principles:

- Be scientifically sound,
- Be practical and straight-forward,
- Use reference conditions and baseline assessment,
- Align with policy principles and reporting obligations,
- Be based on a transdisciplinary approach.

The handbook also establishes a classification of indicators, together with Donabedian (1966)[22]:

- **Structural indicators (S)**: resources and infrastructures in place to achieve the planned goals (people, materials, policies and procedures). These indicators will be most useful during the planning of the NBS.

- **Process indicators (P)**: efficiency, quality or consistency of specific procedures employed to achieve the desired goals. These ones can be applied to the management process (meanly during periods of intense activity) and are most useful to evaluate the methods used for the NBS cooperative aspects (co-create, co-implement and co-manage).

- **Outcome indicators (O)**: accomplishments or impacts focussed on the end result of NBS actions.

The indicators can be used not only to establish the final results/outputs but can also be used for and the evaluation of baseline conditions which will ultimately inform NBS implementation (e.g. an example of a baseline can be the green space area per population density).

The different outcomes can be calculated through measurements collected over time to illustrate the long-term impacts of NBS and be able to distinguish the changes directly attributed to NBS actions and

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[21] European Commission, Directorate-General for Research and Innovation, *Evaluating the impact of nature-based solutions: a handbook for practitioners*, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/244577

[22] Donabedian, A., 'Evaluating the quality of medical care', The Millbank Memorial Fund Quarterly, Vol. 44, 1966, pp. 166-203.

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those that are not. The election of a "control site" where no NBS actions will be implemented, will help to do the distinction.

According to different types of NBS, different indicators can be established. The most widely adopted NBS typology **proposes grouping** them based upon their **primary objective of function and by the level of ecosystem intervention** as follows[23]:

Table 4: Classification of NBS in typologies according to their objective and level of ecosystem intervention

NBS Type	Intervention in ecosystems	Objective	Characteristics
Type 1	**Minimal or no intervention**	Maintaining or improving the delivery of ecosystem services within and beyond the protected ecosystems	Include protection and conservation strategies, **urban planning strategies**, and (environmental) monitoring strategies
Type 2	**Extensive or intensive**	Developing sustainable, multifunctional ecosystems and landscapes in order to improve delivery of ecosystem services relative to conventional interventions	Various sustainable management practices
Type 3	**High intensive**	Design and management of newly-created ecosystems	Newly-created ecosystems. The most 'visible' solution

3.1 Indicators definition

The selection and implementation of the NBS is done on the basis of previously defined objectives, which should cover the impacts experienced by the NBS. To this end, progress must be assessed at different temporal and spatial scales by use of indicators. These indicators must have a certain degree of flexibility to be able to adapt to the different and broad scenarios that characterise the NBS, which means that in certain cases, cities will have to adapt them to their specific context. The results obtained should allow users to distinguish between changes that are directly attributed to the actions of the NBS and those that are not. The choice of a "control location" where no NBS actions are applied will help to make the distinction.

Table 5 and Table 6 below present the **most relevant indicators that are related to the reduction or offsetting of GHG emissions through the use of NBS. These are sourced directly from the** Handbook.

These are mainly linked to *Climate Resilience* as the central challenge, and address:

* the direct impacts of NBS on GHG emissions via carbon storage and sequestration in vegetation and soil;

* indirect impacts of NBS on avoided GHG emissions from various activities, through the provision of passive cooling, insulating and/or water treatment;

* and impacts of NBS on temperature and human comfort.

The following Table 5 and Table 6 summarise the **key and additional indicators by NZC project to assess urban NBS interventions**. Tables below (Table 5 and Table 6) include the indicator name,

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[23] Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W.W., and Le Roux, X., 'Nature-based solutions: New influence for environmental management and research in Europe', GAIA, Vol. 24, No 4, 2015, pp. 243-248.

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source, definition, required data, data frequency, and the level of expertise required to calculate/understand the KPI.

This list of indicators will be further analysed jointly with the rest of KPIs being developed under the other deliverables within Task 2.2 and finally reported under D2.4 final version.

For the following indicators, further details (i.e. most detailed description and definition, the measurement procedure and tool, scale of measurement, data source –if any-, required data, data input type, data collection frequency, level of expertise required, as well as connect with the SDGs and other info) can be consulted in the Appendix of methods of the *Handbook Evaluating the impact of nature-based solutions: Appendix of methods.*

Finally, cities developing specific NBS interventions (e.g. bioswales, rain gardens, etc.) which substitute or complement a carbon intensive piece of grey infrastructure, can also account for the avoided carbon emissions embedded in materials, construction and operations. Life Cycle Analysis would be required to calculate avoided emissions. Examples are provided in the next section.

Table 5: NZC key indicators for the assessment of urban NBS *(Source: Handbook Evaluating the impact of nature-based solutions: a handbook for Practitioners & Appendix of methods)*

Indicator	Source	Definition (incl. units)	Required data	Data frequency	Level of expertise required
Total carbon removed or stored in vegetation and soil	UNaLab project	Total carbon removed or stored (tonnes/ha/y or similar units)	C storage to be determined from either carbon storage and sequestration in soil or carbon storage and sequestration in vegetation indicators	Annually	Low – requires the ability to determine C storage from other metrics and follow the calculation procedure
Avoided greenhouse gas emissions from reduced building energy consumption	UNaLab project	CO_2 emissions related to building energy consumption (direct via, e.g. residential combustion and indirect via, e.g. electric heating and cooling) with and without NBS implementation (kWh/y and t C/y saved)	Information about building energy sources and electrical energy use, as well as supplemental energy sources such as district heating and local combustion for heating.	Annually (to enable tracking of changes to C storage and sequestration with time before and after NBS implementation)	Low – requires ability to follow the calculation procedure and to convert different units of energy to kWh of energy to achieve the total energy consumption.
Mean value of daily maximum temperature (TX_x)	CLEVER Cities and GROW GREEN	Mean of the daily maximum temperatures (ºC) observed during specific time period, either for a specific year or over a specific period of years.	A time series of air Tº data (measured in ºC) – Monthly calculated	At least hourly measured (normally, sensors collect data every 10 minutes)	Sensors must be calibrated and located in the same place during all measurement period.
Mean value of daily minimum temperature (TN_n)	CLEVER Cities and GROW GREEN	Mean of the daily minimum temperatures (ºC) observed during specific time period, either for a specific year or over a specific period of years.	A time series of air Tº data (measured in ºC) – Monthly calculated	At least hourly measured (normally, sensors collect data every 10 minutes)	Sensors must be calibrated and located in the same place during all measurement period.
Heatwave incidence	CLEVER Cities and GROW GREEN	Several indicators are proposed to represent heatwave events: • **Heatwave number (HWN):** 90th percentile of TX or the 90th percentile of TN. • **Heatwave frequency (HWF):** 90th percentile of TX or TN • **Heatwave amplitude (HWA):** 90th percentile of TX or TN	A time series of air Tº data (measured in ºC) – Monthly calculated	Sensors collect data every 10 minutes or daily	Sensors must be calibrated and located in the same place during all measurement period.

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Table 6: NZC additional indicators for the assessment of urban NBS *(Source: Handbook Evaluating the impact of nature-based solutions: a handbook for Practitioners & Appendix of methods)*

Indicator	Source	Definition (incl. units)	Required data	Data frequency	Level of expertise required
Total carbon storage and sequestration in vegetation	UNaLab project	Total amount of carbon (tonnes) stored in vegetation, described per unit area and unit time.	Data on extent of vegetation cover & characteristic of vegetation, land use, air quality data, and meteorological and other local information for modelling.	Annually (to enable tracking of changes to C storage and sequestration with time before and after NBS implementation)	Moderate – requires understanding the C storage concept, and ability to combine and apply allometric equations and modelling tools
Annual carbon storage and sequestration in vegetation	Nature4Cities project	The annual carbon sequestration is a commonly used indicator of the global climate regulation ecosystem service of different vegetation types. Measured in tC/ha/year	Measured data of biomass size and basic climatic data (average temperatures and sum of precipitation, length of vegetation period)	At least before and after the project's implementation	Low – relatively easy to understand
Carbon storage score	Nature4Cities project	The CSS (Carbon Storage Score) describes the total amount of stored CO_2 within the vegetation and soil of a project area.	Project area and NBS typology	One to several times in planning and optimization processes	Low – easy to understand for planners and decision makers
Measured soil carbon content	UNaLab project	Total amount of carbon (tonnes) stored in soil per unit area and unit time.	Site characteristics, including maps of soil type, topography, and vegetative cover. Average soil bulk density (in kg/m^3).	Annually, including at a minimum measurement before and after NBS implementation	Low to Moderate – field sampling Moderate – combustion analysis in laboratory conditions High – soil sample pre-treatment for determination of organic C content
Energy use savings due to NBS implementation	URBAN GreenUP project	The KPI is calculated converting into energy savings the benefits already considered by means of other KPIs. Therefore, all the NBS that provide an ecosystem service which has a direct link to an energy saving or the ones that generate electricity themselves are considered.	Measured at the level of the related demo sites. Defined conversion factors.	Annually	Technical/ Expert

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Indicator	Source	Definition (incl. units)	Required data	Data frequency	Level of expertise required
Carbon emissions reduction from building energy saving – cooling	URBAN GreenUP project	It estimates the reduction in carbon emissions associated with energy savings for cooling by multiplying the reduction in energy consumption (in kWh) by 0.537. the 0.537 multiplication factor is derived from carbon intensity for grid electricity: 0.537 kg/kWh (Defra/Carbon Trust).	General information about area of investigation and local green infrastructure/ NBS. Energy consumption of building to be compared with baseline.	Individual assessments. At least before and after the project's implementation	Technical/ Expert
Energy and CO_2 emissions savings from reduced volume of water entering sewers	URBAN GreenUP project	The estimated decrease in energy use and associated CO_2e emissions due to implementation of NBS (increase in land surface vegetation).	Land use and land surface cover characteristics for the area under examination; local rainfall data (yearly mean rainfall); water treatment unit costs, including energy use.	Individual assessments. At least before and after the project's implementation	Technical/ Expert
Universal Thermal Climate Index (UTCI)	UNaLab project	The UTCI is the air temperature that would produce under reference conditions the same thermal strain as the actual thermal environment. In other words, the UTCI is the reference environmental temperature causing strain.	Air temperature (ºC), Mean radiant temperature (degrees Kelvin), Water vapour pressure (hPa), Relative humidity (%), Wind speed at a height of 10m (m/s).	Frequency as desired. UTCI can be calculated frequently with measurement intervals determined by weather data acquisition.	Low to Moderate
Thermal Comfort Score (TCS)	Nature4Cities project	The TCS gives a weighted information of the mean PED on face level. PET classification describes the mean thermal comfort, which allows to understand and compare the thermal comfort of any given are with ease.	PET (physiological equivalent temperature) at face level; project area (incl. geopositioning); NBS typology.	One to several times in planning and optimization process	Low –easy to understand for planners and decision makers
Physiological Equivalent Temperature (PET)	UNaLab project	Biophysiological equivalent temperature expressed in ºC or K according to international standard calculation method.	Energy balance of the human body, heat flows through the body and clothing	Annually, including at a minimum measurement before and after NBS implementation	High – it requires ability to follow the calculation procedure and units, and to critically evaluate the results

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Indicator	Source	Definition (incl. units)	Required data	Data frequency	Level of expertise required
Urban Heat Island (UHI) incidence	UNaLab project	Urban Heat Island (UHI) effect denotes an urban area that is significantly warmer than its rural or undeveloped surrounding areas. Expressed and evaluated as temperature (°C)	Hourly temperature measurements	Annually, including at a minimum measurement before and after NBS implementation	Low
Thermal Storage Score	Nature4Cities project	The TSS (Thermal Storage Score) describes the stored energy in urban materials on a standardized heat day.	Air temperature, incoming shortwave radiation (direct & diffuse), physical parameters of surfaces and materials, project area (incl. geoposition), NBS typology	One to several times in planning and optimization process	Low –easy to understand for planners and decision makers
Thermal Load Score	Nature4Cities project	The TLS (Thermal Load Score) describes the mean difference (Delta K/°C) between the hourly average In- and Out-flow Air temperature of an area, from the ground to the roof level over the day (typical heat day).	Project area (incl. geoposition), NBS typology, hourly air temperature of instreaming air body over a day, hourly air temperature of outstreaming air body over a day	One to several times in planning and optimization process	Low –easy to calculate and understand for planners and decision makers
Estimated carbon emissions form vehicle traffic	UNaLab project	Vehicle traffic emissions are the fraction of GHG emissions that can be affected by nature-based solutions in the urban environment. CO_2 emissions related to vehicle traffic (t C/y).	Fuel consumption data or travel distance data. In a community-scale study, only travel distance represented by amount of traffic measurement are seen feasible	Annually, including at a minimum measurement before and after NBS implementation	Low – requires ability to follow the calculation procedure

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3.2 Examples: Case Studies on NBS impact indicators

The following Tables (Table 7, Table 8 and Table 9) present indicative Case Studies in which urban NBS have been implemented where and indicators have been calculated to estimate intervention impact. For each Case Study a brief description of the specific NBS is described along with with its emissions reduction related calculated impacts. The relation between their calculated impacts with the indicators proposed by NZC in the present report is established.

Table 7: Case Study 1

Case Study: Using rainwater for tree-based cooling on Garibaldi Street (Lyon, France)	
https://www.tdag.org.uk/uploads/4/2/8/0/4280686/garibaldi.pdf	
Garibaldi Street is a **major thoroughfare** running through Lyon's city centre. Regeneration was initiated in the 1990s, and is now entering into a second, more ambitious phase expected to turn the six-lane road into a people-friendly green street that will also serve economic regeneration. The 2.6km project drastically re-allocates space between highway users. Pedestrians, cyclists and buses now have the lion's share. The scheme features extensive tree planting, designed to provide shade and manage surface water runoff from the footways and cycle paths. A structural "skeleton" growing medium is being used underneath footways and cycle paths to maximise the rooting volume: this creates a bridge allowing the roots of trees planted in continuous trenches to access the open soil provided in nearby linear landscape verges collecting rainwater. This includes an underpass repurposed as a rainwater harvesting cistern receiving stormwater runoff from the footways, the cycle tracks and the bus lanes when they are not subject to winter treatment. The rainwater harvested is used for street cleaning and for irrigation of the trees during the summer so as to maximise the cooling they deliver through evapotranspiration.	**Monitoring** (over two summers) demonstrated significant microclimate **impacts**: • **Ambient summer temperatures reduced** on average by 1.78 ºC (August 2017) and 2.33 ºC (August 2018) • At times, **cooling effect** reaching up to 8 ºC • Impact in terms of user comfort: **UTCI (Universal Thermal Climate Index)**, a physiologically-based approach based on human heat balance models, is -9 ºC (equivalent to a lowering of the "perceived" temperature by 9 ºC).

Related indicators:
- Mean value of daily maximum temperature on average reduction of temperatures over summer
- Urban Heat Island (UHI) incidence → cooling effect in city
- Universal Thermal Climate Index (UTCI)

Potentially additional indicators:
- Modal shift from car use to micro-mobility
- Control site: modal shift in streets with mobility infrastructure with no associated NBS, compared to street redesign with tree shading

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Table 8: Case Study 2

Case Study: Eco-City Augustenborg – Redevelopment Project (Malmö, Sweden)
https://www.researchgate.net/publication/311588074_Nature-Based_Solutions_in_Urban_Contexts_A_Case_Study_of_Malmo_Sweden

	Impacts:
Augustenborg is a **residential neighborhood** in Malmö originally developed in the 1950s, but by the 1970s degenerating conditions had led to residents moving away. In 1998, the City of Malmö began to regenerate Augustenborg as an "eco-city", working with residents to create a socially, ecologically, and economically sustainable settlement. This urban renewal effort focused on enhancing green and blue infrastructure, installing NBS. The Augustenborg neighborhood has historically been vulnerable to floods. Stormwater was handled by a combined sewer system that handled both sewage and runoff, which overloaded in periods of heavy rainfall, causing basement flooding and sewage to enter watercourses. Such floods were predicted to grow more frequent as warming climate leads to increased rainfall, adding a climate change component to an annual pressure. In addition to this pressing problem, Augustenborg was a declining neighborhood with high tenant turnover and an unemployment rate of 30%, much higher than Malmö's average. The new open drainage system was constructed to handle as much rainwater as possible near the source via local infiltration on **green roofs, lawns, and permeable parking lots**. Heavy flows could be detained in ponds and temporary flooded areas and then transported slowly in 6 km of swales, ditches, and canals.	• 90% of **stormwater runoff** is now **directed** into the open stormwater system and can be handled locally • The **sewage system** now handles almost exclusively wastewater • No floods between 2002-2010, even during a 50-year rain event in 2007 • Green roofs absorb around 50% of annual rainfall and provide **cooling in summer** • **Biodiversity** increased by 50% • **Carbon emissions** decreased by 20% • 20% of residents participated in **dialogue** and/or design • **Election participation** increased from 54% to 79% • Tenancy turnover decreased • **Unemployment** fell from 30% to Malmö's average of 6% • Three local **"green" companies** were established
Related indicators: • *Co-benefits: biodiversity, resource efficiency, climate adaptation, social& economic benefits* • Total carbon removed or stored in vegetation and soil and carbon emissions reduction • Sustainable water management (reduction of carbon intensive water supply and drainage infrastructure) - embodied carbon in materials. Construction and operation.	

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Table 9: Case Study 3

Case Study: Community Composting – URBAN GreenUP Project (Valladolid, Spain)	
https://www.urbangreenup.eu/solutions/community-composting.kl	
Valladolid is a municipality in Spain and the primary seat of government of the autonomous community of Castile and León. It is also the **capital of the province** of the same name. It has a population around 300,000 people (2021 est.). From 1950 onwards Valladolid became an important industrial centre. This was the context in which companies such as ENDASA (1950), FASA RENAULT (1954), TECNAUTO (1956) and SAVA (1957) were created. During the 1960 and early 1970s the city attracted many immigrants, chiefly coming from the province of Valladolid and neighbouring provinces. The city started to expand across the western bank of the Pisuerga in the early 1960s. In 2010, the School of Agricultural Engineering, in order to generate well-being among the elderly population, together with the town council, started up urban vegetable gardens for retired people installed on the outskirts of the city. Years later, the city council set up allotments within the city for the unemployed. In order to renew itself and make itself more habitable, the city is committed to various projects, including urban renaturation URBAN GreenUP installing NBS. The orchards have become popular and have been improved with the installation of more efficient irrigation and composting within this project. Composting bins were located at urban orchards providing users with a source of fertiliser for their vegetable gardens as well as a way to manage the waste produced in the orchards. This solves a problem that has been going on for a long time, the users have nowhere to dispose of their waste and the cleaning services complain that they leave the surrounding area with horticultural waste as well as the urban bins. A total of 12 composters have been installed, that is, 3 composters of $1m^3$ in each of the 4 urban garden locations (each urban garden consists of 50 plots/gardens being operated one per unemployed person, each plot has environed $50m^2$). Compost production is approximately 0.70 m^3 per person per year. Almost completely eliminating the problems of waste generated in the orchard, in addition to the 90% of organic household waste that is also processed in them. This has translated in a reduction of fertiliser inputs by up to 90%.	**Impacts**: • 90% of **Chemical fertiliser input** is now replaced by **natural developed directed** into the urban gardens. • The **composting bins** now handles exclusively waste plants and food. • **Biodiversity** increased on the soil. • **Carbon emissions** decreased • Those responsible for the technical assistance and gardens beneficiaries participated in **dialogue** and/or design and also in training. • The organic waste generated in the city is reduced and transformed into a useful and quality product.
Related indicators: • *Co-benefits: inclusion, education, local and global connection, waste and food efficiency.* • Green areas sustainability. Total carbon removed or stored in vegetation and soil and carbon emissions reduction • Sustainable waste management (reduction of carbon intensive waste process) – embodied carbon in materials. Construction and operation.	

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Conclusions

Climate neutrality in cities means reducing the GHG emissions from all sectors and sources within the city's boundary. These sectors include the emissions from combustion of fossil fuels in all buildings and facilities (known as 'stationary energy'), from combustion of fossil fuels for all vehicles and transport, emissions arising from the consumption of electricity and district heating/cooling, arising from waste generated within the city boundary, emissions from changes in land use and from chemical process in industry. Since this is a huge challenge, there may be certain emission sources (e.g. specific industrial processes) that depending on their local circumstances cannot be fully mitigated (especially for the 2030 deadline) due to technological or financial constraints. So, compensating for any residual emissions is possible, to an extent, to account for those emissions sources which cannot be fully eliminated.

This is where **Nature-based Solutions (NBS)** come into play, which have a twofold potential in the achievement of climate neutrality in cities: (1) as key elements to compensate GHG emissions that cannot be reduced from some sources (up to 20% by 2030, as recommended by the EC Info Kit for Mission Cities), thus, acting as carbon sinks that collect and stores CO_2 directly from the atmosphere, resulting in "negative emissions"; and (2) because of their potential in the reduction of energy consumption and carbon emissions, mainly in the built environment, mobility and transport systems and circular economy (water and waste).

This report is therefore aimed at supporting cities in **assessing and planning the reduction of GHG emissions** through the use of urban Nature-based Solutions (NBS), which can be either by offsetting of residual emissions, carbon sequestration, capturing and storing, or through complementary solutions applicable mainly in buildings, stormwater management and transportation that help the savings in energy and carbon.

The report offered a comprehensive and critical analysis of the main **frameworks of NBS indicators**. Such frameworks include relevant publications, EU initiatives and EU projects on NBS.

It was shown that it is vital to connect climate neutrality contributions of NBS to the **co-benefits** that can be achieved with their deployment. They positively contribute to the better performance of cities across climate resilience, health, social, economy, resource efficiency and biodiversity. More details on the qualitative assessment of co-benefits are found under the activities and deliverables of WP10 (NBS Thematic Area, which is included in the Knowledge Repository in the NZC Portal) and the list and classification of co-benefits, developed also under WP10.

A **list of the NZC KPIs for the evaluation of NBS interventions** in cities has been provided. It is divided into **key indicators and additional indicators**, and further details of all of them can be consulted in the *Handbook Evaluating the impact of nature-based solutions: Appendix of methods*; the publication developed by representatives of 17 EU-funded NBS.projects and institutions as the EEA and JRC, as part of the European Taskforce for NBS Impact Assessment.

In conclusion, the list below outlines the **key findings** of this report, which can inform cities that work towards linking their Impact Metrics, Monitoring and Evaluation activities to NBS deployment:

- There are direct and indirect GHG net emission reductions resulting from NBS deployment

- Though often hard to characterise/monitor, a set of general and custom-made indicators can help capture the contribution in emission reductions.

- NBS can lower life-cycle emissions of infrastructure compared to Grey infrastructure

- Reducing emissions is a co-benefit delivered next to the primary/other benefits that drive the implementation of NBS (e.g. climate adaptation). These synergies need to be carefully planned.

- Case Studies – such as those presented in section 3.2 – show that it is possible for cities to design and implement NBS with intention, by capturing and quantifying social and climate co-benefits.

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