NATURELAB

Deliverable D1.1

Framework of key indicators to assess and categorize different types of nature spaces and their impact for therapeutic indications

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ABBREVIATIONS

Abbreviation	Definition
CO	Carbon monoxide
D	Deliverable
DF	Demonstrator Fellows
DSR	Daylight and Solar Radiation
ES	Experimental Sites
GIS	Geographical Information System
HWC	Health, Well-being and Comfort
IEQ	Indoor Environment Quality in buildings
NBS	Nature-Based solutions
NBT	Nature-Based Therapies
NO_2	Nitrogen dioxide
O_3	Ozone
OEQ	Outdoor Environment Quality
$PM_{\#.\#}$	Particulate Matter that is smaller than #.# microns
SO_2	Sulphur dioxide
T	Types of nature spaces (T1; T2; T3)
TESSA	Toolkit for Ecosystem Service Site-based Assessment
WHO	World Health Organisation
WP	Work Package

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Table of contents

DRAFT

DRAFT

Index of figures

Index of tables

Executive Summary

Executive Summary

Deliverable D1.1 provides a framework of key indicators of green space characteristics that have a high potential to be relevant regarding their impact on health and well-being. These indicators comprise the characteristics of a nature site, and its context, including the variables that can impact health and well-being, and also the requests that ensure people can have comfort and their basic needs attended to. Moreover, NATURELAB's holistic strategy seeks to offer also indicators that go beyond health and well-being, enhancing the resilience of the sites and the population therefore boosting communities' sustainability.

Since the topic of this document is wide, the work was done by a comprehensive team of experts. All authors used for this work their know-how and previous experience. This framework of scientific and practical background was supported with literature review, in order to ensure using state-of-the art knowledge and the integration of health, well-being, and sustainability and resilience of communities (Chapter 3).

There is evidence showing positive associations between green spaces and health and well-being outcomes. Despite this, there has been little research into which components of green spaces benefit people's well-being and health, and how they can be categorized. To address this gap, a proposal of key indicators of natural and infrastructural characteristics that have a high potential to be relevant for health and well-being is presented in Chapter 4. The following four categories of indicators are proposed: Spatial characteristics, design, and conditions; Infrastructural characteristics; Natural characteristics and Cultural Ecosystem Services.

The interconnectedness of health and well-being with sustainability best practices is explored by Chapter's 5 key indicators. Sustainable sites should promote cleaner air and water, reducing exposure to pollutants and to poor environmental conditions. Moreover, green and blue spaces and sustainable communities have been linked to improved mental health. Access to nature, greenery, biodiversity and well-maintained environments can reduce stress, anxiety, and depression while enhancing overall well-being. Reducing environmental hazards and ensuring water management strategies are pathways to increase biodiversity, greenness, mitigate and adapt to extreme precipitation and temperature that are connected to climate changes, thus contributing to sustainable, inclusive and resilient living spaces and communities. The indicators related to the sustainability and resilience of the sites and the population are divided in three categories: (i) climate and geophysical context which include the management of water cycle, solar radiation and climate region; (ii) air quality and (iii) noise.

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D1.1 is a thorough and comprehensive report. The indicators will be applied, tested and validated at all Experimental Sites (ES) through T1.2. During this implementation, a clearer awareness of the intrinsic value of each indicator, the easiness and effectiveness of measuring or establishing it, as well as the need of monitoring and updating each indicator will be recognised, allowing the development of future outcomes and deliverables under WP1.

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Chapter 1

Introduction

1. Introduction

1.1 Framework of Deliverable D1.1

This report is made in the framework of the work package 1 (WP1) of NATURELAB, related to the *assessment and selection of green spaces with potential for improving health and well-being*. This first deliverable of the WP1 derives from Task T1.1 that aims at developing a "*Framework of key indicators to assess and categorize different types of nature spaces and their impact for therapeutic indications*".

WP1 aims to establish and validate a portfolio of key indicators and guidelines to characterize, design, protect and manage different types of nature spaces, promoting environmental sustainability and setting the context where nature-based therapies (NBT) can take place. The main objectives of WP1 are:

- Establish a validated portfolio of key indicators of natural pre-conditions (e.g. topography, air quality, daylight, solar radiation, and noise levels) and infrastructure characteristics that significantly impact health and well-being;
- Evaluate cultural ecosystem services and integrate them into the portfolio of key indicators;
- Provide guidelines for the design, management and maintenance of blue and green spaces;
- Support the integration of NBT health cost benefits into the protection, rehabilitation, and enhancement of nature areas.

It is understood that there is a huge variety of nature spaces, some being undisturbed by man and human activities; others made or modified by man, which is common in urban contexts. Nowadays, cities are increasing their blue and green areas, much focused on climate change mitigation and adaptation, and nature-based solutions (NBS). However, the health care potential of nature areas and of NBS is not usually considered by landscape architects, urban designers, or city policymakers. To take out all the potential that nature has to offer in terms of human well-being is still a paramount challenge, demanded by research and by policy documents, e.g., by the European Commission and the United Nations (EC, 2021 and WWAP, 2019).

The indicators to be provided should represent the characteristics of a nature site, and its context, comprising not only the variables that can have an effect on health and well-being but also the requests that ensure people can have comfort and their basic needs attended to (e.g., toilet facilities, benches; accessibility to people with mobility restrictions), as well as dealing with the sustainability of the territory and the resilience to extreme events. Therefore, three types of dimensions will be addressed, namely:

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A. Physical characteristics and infrastructure, such as access to the location (by car, foot, bike, etc); parking places; size of the site; trails (existence and type); toilet facilities; seats; shelters, among others;

B. Natural features related to health and well-being, such as the biodiversity; the aesthetics of the site; the presence of water bodies, among others, including Cultural Services, such as recreation, leisure and tourism, educational use, mental and physical health, social relations and community benefits;

C. Factors that contribute to the sustainability and resilience of the sites and the population, such as the contribution to climate change resilience (by addressing temperature and rainfall); to sustainability (e.g. water use), and evaluating the presence of stressors that can impact health and well-being, such as air pollution and noise that are common nuisances for urban contexts.

Moreover, knowing that not all the population can access all types of nature spaces on a daily or weekly basis, NATURELAB will go beyond the state-of-the-art by characterising and comparing the health and well-being potential of three types (T for types) of nature spaces:

- Forests and protected areas (henceforth designated T1)
- Urban parks and healing gardens (henceforth designated T2)
- Horticulture and gardening spaces (henceforth designated T3)

This variety of spaces will be addressed at 15 experimental sites (ES) and 4 demonstrator fellows (DF) located in Portugal, Greece, The Netherlands, Germany and Peru, allowing the project to adjust the indicators in order to consistently represent factors such as cultural, geographical and climate pre-conditions.

The variety of the ES nature areas (*cf.* Table 1) raises the opportunity for a comprehensive test and validation of the best indicators to characterise the healing potential of the blue and green nature areas - forests, urban parks, and horticulture and gardening spaces. Urban healing gardens and horticulture and gardening spaces will be designed, implemented, and validated during the project, in Portugal and Peru, aiming at maximizing their potential to serve communities, providing enhanced environmental sustainability, as well as health and well-being services.

The project will analyse, through WP2 and WP3 activities, the impact of nature-based therapies (NBT) on the health and well-being of approximately 4000 participants, with distinct health needs, whom will be engaged in therapeutic programmes at all these locations. The results will allow the evaluation and validation of the indicators, based on the easiness and effectiveness of measuring/

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establishing the indicator, as well as on its value for contributing to the health and well-being. The latter will be assessed by WP3, through quantitative statistical analyses (structural equation models and linear regression models) that will lead to the identification of the mediators and moderators of the causal relationship between NBT and health and well-being improvements.

This report lays the foundation for NATURELAB to establish an innovative portfolio, ranking nature characteristics, for different types of spaces, and rating them in accordance with their potential to improve the health and well-being of people with distinct needs.

Table 1. Characteristics of the NATURELAB Experimental Sites

Site (Country)	Nature type	Coordinators & key stakeholders[1]
#1 National Park Sintra Cascais (PT)	Forest and protected area Area for nature conservation, Natura 2000 Main touristic area in the surroundings of Portugal's capital, Lisbon Area: 14,6 ha Water bodies: Yes/Lagoon	**CMS** **LNEC** Portuguese National Forestry Institute Local Public Health Center
#2 Ribafria farm, Sintra (PT)	*A NATURELAB Healing Garden will be designed and implemented in this area.* Green area with identified biodiversity Area: 13,3 ha Water bodies: Yes/Stream, cascade, lake	**CMS** **LNEC** Local Public Health Center
#3 Allotment in Algueirão parish, Sintra (PT)	*A NATURELAB horticulture & gardening space will be implemented.* Promotion of sustainable urban drainage and water use. Area: 0,8 ha Water bodies: Yes/Ground water	**CMS** **LNEC** Local public health center (ACES/Sintra)
#4 Rinchoa-Eco-Park Sintra (PT)	Urban Park Managed by the parish of Rio de Mouro (47,000 inhabitants). Area: 12 ha Water bodies: Yes/Stream	**CMS** **LNEC** Group of two elementary schools
#5 Foz do Neiva (PT)	Forest and protected areas Nature 2000 site, with biodiversity and providing geological artefacts. Area: 2797,80 ha Water bodies: Yes/River	**RN** **LNEC** Local population
#6 Esposende municipality (PT)	Horticulture and gardening Public and private gardens and backyards from local social charities, daycare centres, schools and houses located within the Northern Littoral Natural Park. Area: Various Water bodies: No	**RN** **LNEC**
#7 Garden of Brasa, Amsterdam (NL)	Urban Park The garden established on top of a tunnel covering a major highway with five sub-gardens, each with a different focus: flowers, vegetables, herbs, tea and agroforestry. Area: 0,2 ha Water bodies: No	**VU** GroenplatVorm Zuidoost (SO)
#8 Gelderland province (NL)	Forest, parks and protected areas (including the Veluwe; Natura 2000 site) Area: 514 ha Water bodies: Yes/Rivers, canals, lakes, ponds	**WU**
#9 Cologne city forest (DE)	Urban Park Located on the left bank of the Rhine river with an extensive network of paths and a game reserve.	**UHC**

Site (Country)	Nature type	Coordinators & key stakeholders[1]
	Area: 200 ha Water bodies: Yes/Ponds, water channels	
#10 & #11 Alkyonis & Calypso Houses Kapandriti, Attica (EL)	Farm Area: Each site has 400 – 500 m^2 with outdoor spaces & surrounding green parks Water bodies: No	**KMOP** Internal staff: psychiatrists, psychologists, social workers
#12 Prooptik House Xylokastro, Corinthia (EL)	Farm Area: 900m^2 with outdoor spaces & surrounding green parks Water bodies: No	**KMOP** Internal staff (24h supervision): psychiatrists, psychologists, social workers, nurses
#13 Puericultorio Perez Aranibar, Lima (PE)	*A NATURELAB Healing Garden will be designed and implemented in this area.* Area: 0,15 ha Water bodies: No	**APHTS** Puericultorio Perez Aranibar (SO)
#14 Lima (PE)	*A NATURELAB Healing Garden will be designed and implemented in this area.* Area: ± 1,00 ha Water bodies: No	**APHTS** Hospital Herminio Valdizan (committed to work with APHTS)
#15 Oxapampa Forest (PE)	Forest Protecting area of Yanachega Chemillen Area: Various Water bodies: No	**FICUS** **APHTS**

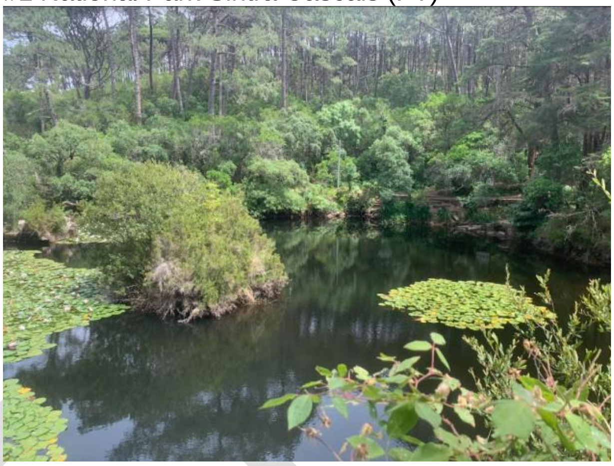
[1] Name of the partner responsible for the site is presented in bold

1.2 NATURELAB definition of the three nature spaces contexts

Green spaces are elements in urban contexts that provide some level of natural environment. An increasing body of literature shows that contact with the natural environment is related to health and well-being benefits (Hartig et al., 2014; Twohig-Bennett & Jones, 2018). However, contact with nature has many forms and can occur in many settings, from large-scale wilderness adventures or hiking activities in natural settings to small-scale activities, such as potting plants or watching the trees before the window (Frumkin et al., 2017). Positive effects of green space on mental and physical health could be found in various green space types (Beute et al., 2023; Gianfredi et al., 2021; Twohig-Bennett & Jones, 2018).

For the scope of the NATURELAB portfolio, we have chosen a scale of types, spanning three different kinds of nature spaces: forests and protected areas (T1), urban parks (T2) and additionally, we focus on horticulture and gardening spaces (T3), such as gardens and allotments (see Table 2).

Table 2. Categories of nature spaces in NATURELAB

Type	Category	Description	Examples	NATURELAB ES Examples
T1	Forests and protected areas	A land mainly covered with trees and undergrowth cover	Protected areas, forest in national parks, forest in nature reserves	#1 National Park Sintra Cascais (PT) 
T2	Urban parks and healing gardens	An area of vegetation used for recreation	Urban park, district park, neighbourhood park, grassed open spaces, healing gardens	#2 Ribafria farm, Sintra (PT) 
T3	Horticulture and gardening spaces	An area where plants, vegetables, fruits and flowers are cultivated.	Backyard garden (including private), botanical garden, edible garden, urban allotments	#3 Allotment in Algueirão parish, Sintra (PT) 

Note. Types of nature spaces in NATURELAB. Adapted from Beute et al. (2023).

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Chapter 2

Objectives

2. Objectives

As said in the previous chapter, this deliverable results from Task T1.1 of NATURELAB, and has the objective of presenting a first selection and a directory of key indicators to assess and categorize different types of natural spaces and their impact on therapeutic indications. It is based on the know-how and expertise of the partners, namely of LNEC, WU and UG, on literature review and on a baseline list of indicators for the assessment of healing forests provided by BCV during the proposal preparation.

The objective of D1.1 is **to provide an effective and objective framework of indicators that show a high potential of being relevant** – what will be shown on a next stage. Two issues are acknowledged as relevant and will be taken into account:

- The *level of complexity of the indicator* determination, calculation or measurement: Some indicators will be easily measured, such as the size/area. Others, such as the noise level, will require specific equipment and some level of technical knowledge.

- The *relevance of each indicator for each of the nature contexts* addressed by NATURELAB, namely forest and protected areas; urban parks and horticulture gardening spaces. Not all indicators will be relevant or have a similar value for the three types of nature contexts.

Therefore, it is part of the objectives that all the indicators presented herein are associated to a scale with three levels, assessing the following complexity of the determination, namely:

Level 3: Needs measurements with complex equipment and/or difficult to obtain (e.g. noise measurements with specific equipment)

Level 2: Needs gathering data and/or processing data (e.g. producing noise maps from discrete measurements available in public data sets)

Level 1: Very easy to obtain (e.g. data is available in public data sets)

The importance or requests for each of the three types of nature contexts will also be assessed. For instance, the size is obviously distinct when referring to a forest, an urban park or a space to carry on horticulture/gardening activities.

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Chapter 3

Concepts and key notes from the state of the art

3. Concepts and key notes from the state-of-the-art

Chapter Highlights

The topic of this document is wide, and the work was done by a comprehensive team of experts. All authors used their know-how and previous experience, including results from previous EU-funded projects, for this work.

It was understood as relevant to support this framework of scientific and practical background with information from a literature review, in order to ensure using state-of-the art knowledge and the integration of health, well-being, and sustainability and resilience of communities.

Therefore, the present chapter is focused on a literature overview, under the assumption that this is an efficient approach when the research question is broad, and a holistic understanding of a topic is needed.

3.1 Key notes regarding green space characteristics and Cultural Ecosystem Services related to health and well-being

Nature, which is often composed of areas of green space, has been linked to a wide range of health benefits (Hartig et al., 2014). Green spaces are associated with better general health (Frumkin et al., 2017; Hunter et al., 2023; Nguyen et al., 2021; Twohig-Bennett & Jones, 2018), well-being (Reyes-Riveros et al., 2021), stress resilience (Li & Lange, 2023) and mental health (Barnes et al., 2019; Beute et al., 2023; Chen et al., 2021).

Besides estimating the impact of green spaces on human health, much emphasis is on *the pathways that connect nature and health*. Three main pathways (Markevych et al., 2017) attempt to mediate the positive association between green spaces and health outcomes: Green spaces (I) *protect* users from harm (e.g., by reducing heat, noise, and pollution), (II) *improve* users' abilities (e.g., by building social or physical skills), and (III) *restore* users' capacities (e.g., by providing stress reduction or attention restoration). Moreover, it has been added that green spaces may have harmful consequences (e.g. threats from wildlife, allergens) as well (Marselle et al., 2021).

Until now, there is little emphasis on the "nature of the nature" (Barnes et al., 2019). However, it is crucial to investigate which *specific features of green spaces* contribute to people's health and well-being (Beute et al., 2023) and how to categorise them. Many studies on green spaces do not present sufficient details about the experimental site, its type, or characteristics. Besides this lack of information, systematic research has identified crucial characteristics at site level from literature (Felappi et al., 2020; Nguyen et al., 2021). The quality of green areas relies on certain objective factors like the number of amenities, trails, and lighting, as well as subjective characteristics such as safety perception and other perceptional experiences. Some features like litter, broken glass, and noise can discourage people from visiting and reduce the benefits for health and well-being. On the other hand, attractive features like good maintenance and access to toilets can enhance the number of visits. Features of green spaces help us understand the relationship between green spaces and health and well-being (Nguyen et al., 2021). This section summarises the green space features that previous research has shown to have a potentially positive impact on health and well-being.

- Spatial characteristics, design, and conditions
- Infrastructural characteristics
- Natural characteristics

We suggest the categories for NATURELAB based on publications searched by using relevant keywords (e.g., 'biodiversity' AND 'forest' OR 'park' AND 'health') in databases such as Web of Science, Google Scholar and PubMed. The search strategy included to focus on systematic literature reviews and use their bibliographies to hand search for other relevant studies. After summarising the main findings, we then propose measurable indicators for the NATURELAB sites, with at least one suggestion as to how the indicator can be obtained. As a result, Chapter 4 provides a broad overview of what is known about the characteristics of green spaces that are associated with health and well-being.

Moreover, in chapter 4, the contributions of the

- Cultural Ecosystem Services

to human well-being will also be described.

3.2 Key notes regarding sustainability and resilience of the sites and the population

3.2.1 Water cycle

Sustainable water management requires an integrated, adaptive, coordinated, and participatory approach (Brown et al., 2009). It gathers water supply, wastewater and stormwater management and integrates them with land use planning and economic development (GWP, 2013). It includes environmental, economic, social, technical, and political aspects of water management, integrating fresh water, wastewater and storm water, enhancing the management of water quantity and quality. The integrated urban water management principles are to i) consider alternative water sources; ii) consider the fit-for-purpose water quality; iii) integrate water storage, distribution, treatment, recycling, and disposal; iv) protect, conserve and exploit water resources at their source; v) account for non-urban users; vi) align formal and informal institutions and practices; vii) consider the relationships among water, land use, and energy, viii) account for efficiency, equity and sustainability; and ix) encourage participation by all stakeholders.

Fu and Butler (2021) state that "*While it is difficult to be specific about the characteristics of future urban water systems, several general trends have become clear through research and practice in*

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the last several decades: decentralisation, greening, circular economy, and digitalisation”. In order to know whether an urban water system is sustainable, it is fundamental that the objectives for these systems are known. The referred trends may constitute four pathways towards sustainable water systems achievement (decentralisation, greening, circular economy, and digitalisation). To ensure whether they are being addressed and evaluate the progress, assessment procedures are required, considering, performance metrics to assess the efficiency, effectiveness and resilience of water services provided, as well as definition of targets or other systems’ performance references.

Considering climate change with focus on water, relevant resilience assessment frameworks have been developed. Table 3 synthetizes the themes, urban sectors and metrics considered in each framework (Cardoso et al. 2020).

Table 3. Synthesis of resilience assessment frameworks for climate change (adapted from Cardoso et al. 2020)

Framework	Themes addressed						Sectors addressed							No. of metrics	Reference
	Governance	Social	Spatial	Built environment	Economy	Natural Environment	Water	Wastewater	Stormwater	Waste	Energy	Mobility	Other(s) *		
EPA conceptual framework	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	163	EPA (2017)
City Resilience Framework	✓	✓	✓										✓	156	ARUP (2015)
UNIDRR Disaster Resilience Scorecard for cities	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	47 preliminary 117 detailed	UNDRR (2017a, b)
City Resilience Index to Sea Level Rise	✓	✓		✓	✓	✓	✓						✓	13	Abdrabo et al. (2014)
Climate Disaster Resilience Index	✓	✓		✓	✓	✓						✓	✓	120	Joerin et al. (2011)
Climate Disaster Resilience Index	✓	✓		✓	✓	✓						✓	✓	82	Peacock et al. (2010)
Climate Resilience Screening Index	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	117	Summers et al. (2017)
Flood Resilience Index	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	91	Batica (2015)
Resilience Factor Index	✓	✓		✓	✓								✓	17	Ainuddin and Routray (2012)
Community disaster resilience	✓	✓		✓	✓	✓							✓	26	Yoon et al. (2016)
NIST (National Institute of Standards and Technology) Community Resilience Assess. Methodology	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓	-	Kwasinski et al. (2016)
UKWIR (UK Water Industry Research)						✓	✓	✓	✓					73	UKWIR (2017)
UN-Habitat City Resilience Profiling Tool (UN-Habitat CRPT)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	148	UNHabitat (2018)
RESCCUE RAF – Resilient Assessment Framework	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		719, essential 433	Cardoso et al. 2020
Resilient Assessment Framework for Nature-Based Solutions	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	71, aligned with the RAF framework	Beceiro et al. (2022)

*e.g., Telecommunications, Nature-Based Solutions (NBS), healthcare, education, population.

Cardoso et al. (2020) developed an urban Resilience Assessment Framework (RECCUE RAF) with scope on water focusing on the urban water cycle, considering interconnections and interdependencies with other closely related urban services. It is aligned with international frameworks for resilience assessment, particularly with UNDRR Disaster Resilience Scorecard (UNDRR 2017a and b).

Beceiro et al. (2022) proposed a resilience assessment framework for NBS, with a set of 71 metrics, aligned with the RESCCUE - Resilient Assessment Framework (RAF). A set of 10 resilience objectives is proposed in two dimensions. The first dimension addresses the city level, and the second dimension is focused on the assessment of resilience at the NBS level.

Water, green spaces and biodiversity are interconnected (e.g. Cook and Spray, 2012) and these characteristics are linked to health benefits (WHO, 2016, Annerstedt et al., 2012; White et al., 2013; White et al., 2014; Elliott et al., 2015). Nature space characteristics that have been considered in the literature include the following aspects:

- Size of green space (Giles-Corti et al., 2005; Nordh et al., 2009);
- Land cover type e.g. grass or woodland (Wheeler et al., 2015; Alcock et al., 2015; Votsi et al., 2013);
- Presence of water or coastline (blue space) (White et al., 2010; Völker and Kistemann, 2011);
- Recreational types e.g. open sports area, children's play areas, 'natural', formal gardens (Mitchell, 2013);
- Environmental qualities e.g. biodiversity, 'wilderness' (Annerstedt et al., 2012; Dallimer et al., 2012; Lovell et al., 2014).

These characteristics, connected to the presence of water, will be addressed in several chapters of the present report as they are significant for evaluating several dimensions. For instance, the presence of water bodies is a result from the water cycle (this section); water has also an aesthetic value (*cf.* 4.3.2) and provides support for cultural ecosystem services (*cf.* 4.4), such as biodiversity, among others. There is also evidence on the role of 'social qualities' of public green space such as amenities (e.g. the presence of benches, car parks, public lavatories) and environmental incivilities (e.g. the presence of litter, graffiti, dog waste), even if data on these characteristics are in general not readily available.

The moderation of extreme runoff events may be assessed by indicators such as the ones proposed by Beceiro et al. (2022):

- Estimated infiltration enhancement;

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- Estimated water retention enhancement;
- Estimated evapotranspiration improvement.

Gehrels at al. (2016) present the functions and benefits (including valuation options), as well as recommendations regarding design and maintenance of urban green infrastructure. In order to optimize water regulation, maximize water uptake, both by the canopy and by the root system, coniferous trees should be chosen over deciduous trees. It is also important to increase the vegetation density by allowing for multiple vegetation layers. Maximize infiltration rates by increasing the surface area of open soil, and the infiltration capacity of the soil (e.g., with coarse grained materials) and by temporarily storing water to allow it to infiltrate during a longer period are other actions the increase the contribution of NBS to sustainability.

Moreover, the regulation of the air temperature may be enhanced by the increase of the percentage of green areas in the city, especially during hot conditions. Regarding blue infrastructure, clear water is important for contributing to an attractive urban environment for physical exercise and mental health benefits resulting from the presence of surface water.

To improve blue infrastructure for leisure and use, it might be necessary, among others to implement some measures if citizens are directly exposed by surface water by swimming, playing, irrigation of gardens, etc., particularly to avoid pathogens, biological toxins, and chemicals. The latter is generally a minor issue in developed countries, but pathogens are often related to sewage overflows, and wastewater treatments plants. Reducing the effects of sewage is the most important measure.

In addition to design principles, a well-functioning green or blue infrastructure also requires maintenance. If maintenance is neglected, the quality will decline. For example, maintenance is required to remove the additional input of nutrients by leaves in the fall.

Rodl and Arlati (2022) present a summary of NBS assessment framework. They mention the overview of criteria and indicators by IUCN (2020), and refer to the EKLIPSE approach (Raymond et al. 2017) as one of the most cited frameworks that identifies how NBS provide ecosystem services and socio-economic benefits in urban areas.

Regarding water management, Raymond et al. (2017) describe the contributions of NBS to sustainable urban water management, as increasing infiltration, enhancing evapotranspiration, providing storage areas for rainwater, and removing pollutants. Additionally, creating artificial water bodies or ecosystems within urban areas, or conserving and enhancing natural ones, can retain and store rainwater and urban run-off. The aim is to prevent precipitation water from directly flowing into the sewerage system (overcharging the system), thus reducing and delaying flood peaks and allowing controlled discharge. NBS for water retention include creation of natural spaces for temporary water storage (green areas and urban wetlands); improving infiltration (green areas, plants improving infiltration); and enhancing evapotranspiration (trees, green areas, parks). Storing stormwater and grey water can also conserve water for reuse both on-site (e.g. for maintenance of green areas) and for distant water needs (Young et al., 2014), thus providing additional water resources and reducing pressure on existing freshwater, among others already mentioned.

EC (2021) presents an integrated framework assessment and indicators to evaluate and monitor NBS for climate resilience and water management, among others. Regarding climate resilience, the indicators include:

- Total carbon removed or stored in vegetation and soil per unit area per unit time;
- Avoided greenhouse gas emissions from reduced building energy consumption;
- Monthly mean value of daily maximum temperature;
- Monthly mean value of daily minimum temperature;
- Heatwave incidence: Days with temperature >90th percentile.

Concerning water management, these indicators include:

- Surface runoff in relation to precipitation quantity (mm/%);
- Total suspended solids (TSS) content;
- Nitrogen and phosphorus concentration or load;
- Metal concentration or load;
- Total faecal coliform bacteria content of NBS effluents.

3.2.2 Solar Radiation

Most of the present scientific knowledge regarding the daylight and solar radiation components of the Outdoor Environment Quality (OEQ) derive from previous studies and findings related with the Indoor Environment Quality (IEQ) in buildings.

There are still very few research studies that deal with the Daylight and Solar Radiation (DSR) components of the outdoor environment and in almost all of them the DSR is only included as a small part of the outdoor environment domains associated to other areas of the outdoor environment, such as acoustical, thermal and air quality components (Hong et al., 2013, Santos, 2023; Brandi, 2023, Hasegawa et al., 2022).

Many of the studies that address the main benefits arising from the use of daylight and solar radiation come from the area of building physics and, consequently, are "disconnected" from the reality of the

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external environment. However, it is possible to establish relationships and comparisons between the exterior and interior environments, allowing the incorporation of relevant information from the interior environment. Additionally, the main quantities used in the characterisation of the indoor and the outdoor DSR environment are the same, such as illuminances[1] and irradiances[2], despite inside buildings the solar radiation (irradiances) is not generally measured/evaluated. By opposition, the solar radiation is very useful in the characterisation of the outdoor environment, having connections to both the luminous and thermal environments.

Currently, a series of evidence have been demonstrating the beneficial effects of exposure to natural light and solar radiation on the health, comfort and well-being of individuals (Rebelo and Santos, 2023). In fact, exposure to daylight and sunlight helps individuals to: i) produce vitamin D, ii) improve the circadian rhythms and sleep patterns, iii) improve the concentration and focusing in mental tasks, among others. Ensuring that human beings “get enough” daylight and sunlight seems to be the key to physical and psychological comfort and well-being. However, since we now spend close to 90% of our lives indoors, it is increasingly harder to experience the benefits of daylight and sunlight, as we are not getting enough of it (Santos, 2023).

Within the scope of WP1 of NATURELAB Project, one of the objectives is to study the influence of daylight, sunlight, and views on the Health, Well-being and Comfort (HWC) of individuals. In Figure 1 the main components of the indoor/outdoor environment are presented. Naturally, the visual comfort plays a fundamental role in achieving an environment that contributes to the health and well-being of humans.

[1] Illuminance (lux) is defined as *the ratio of the total luminous flux incident on a surface, per unit area* (CIE, 2020). It is a measure of how much light illuminates a surface.

[2] Irradiance (W/m^2) is defined as the radiant flux received by a surface per unit area. It is the energetic equivalent of the term illuminance (CIE, 2020).

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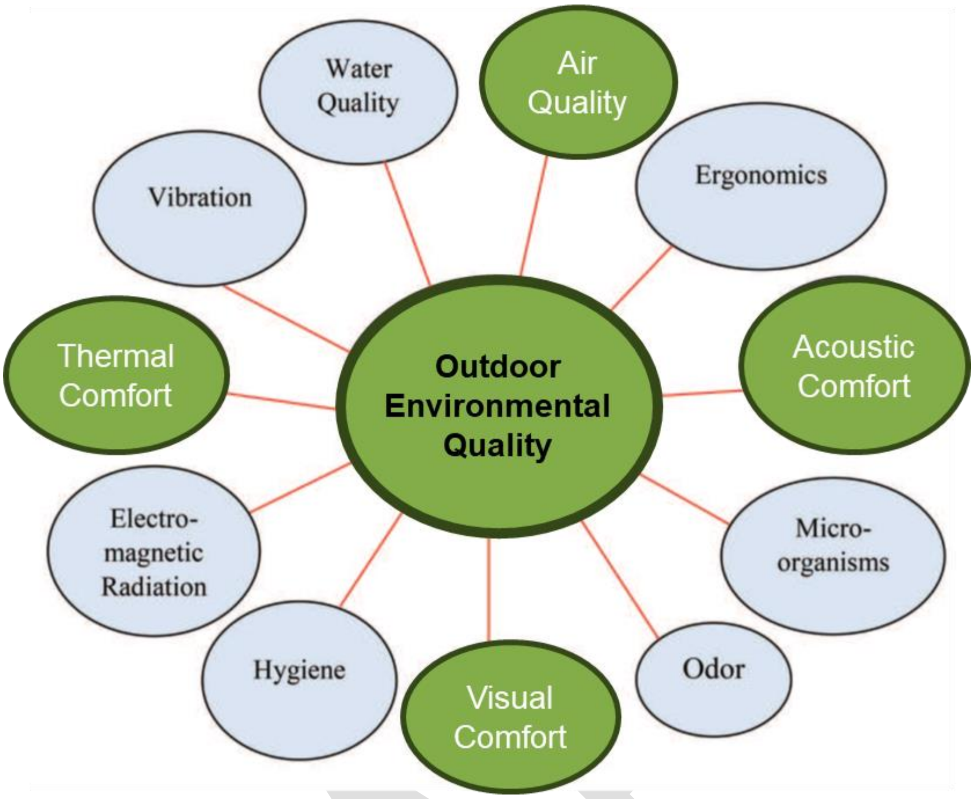


Figure 1. Main components of the indoor/outdoor environment

In Figure 2 the factors affecting the quality of the luminous environment (performance, ambience and comfort) and main properties of light(ing) are illustrated.

Figure 2. Factors affecting the quality of the luminous environment (performance, ambience and comfort) and main properties of light(ing) (Adapted from Dolnikova and Katunsky, 2019)

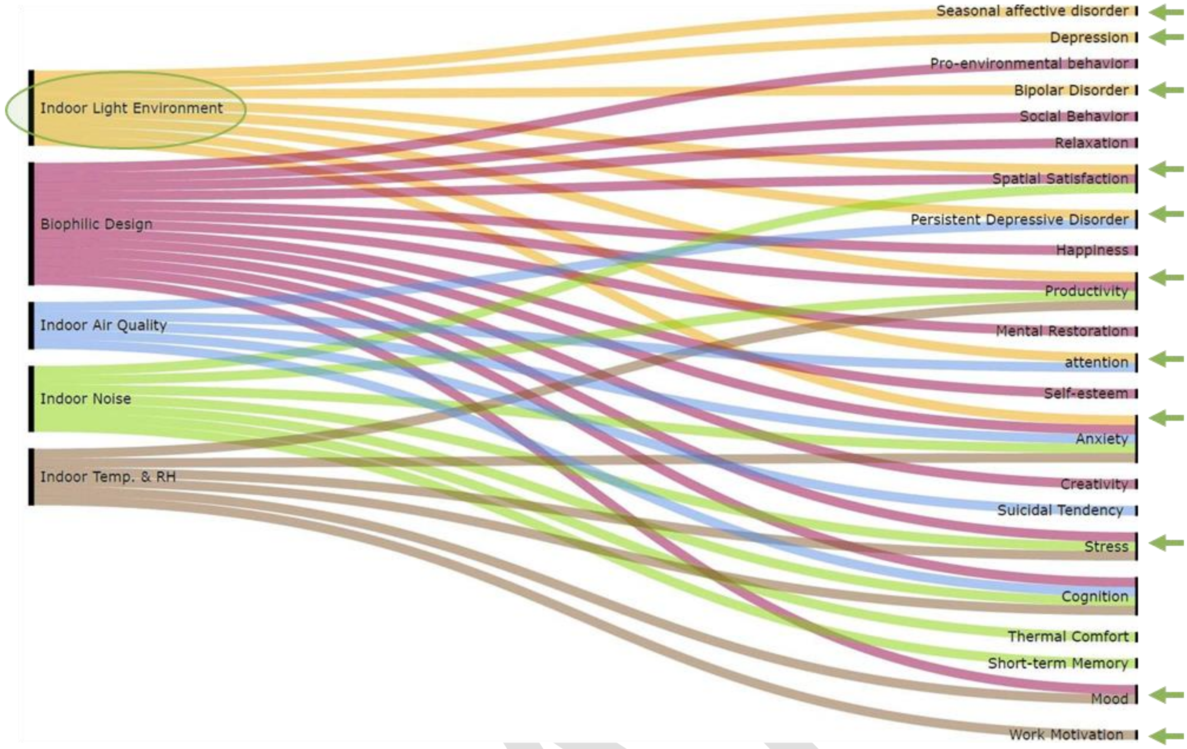


Figure 3. Indoor/Outdoor environmental factors influencing Human Health[3]

The diagram shown in Figure 3 shows some results of a study that aims to identify some health consequences due to several indoor/outdoor environmental factors, including the luminous environment. The figure refers to indoor environments, but in the case of the luminous environment it can also be applied to the outdoor environment (Delos, 2022).

Within the scope of the NATURELAB project, it is expected to be able to find/validate some aspects of the luminous environment with direct or indirect influence on the Health, Well-being and Comfort (HWC) of individuals. Factors such as the "amount" of sunlight, the quality of views, the directionality of daylight may be investigated to identify their possible influence on the referred HWC of individuals. It also the aim of the project to propose applicable indicators in daylight/solar radiation domains that correlate with the HWC of individuals so that "healing factors" can be identified.

3.2.3 Air temperature

Hot temperatures in cities are becoming more common alongside climate change and pose a threat to human health (IPPC, 2023). Urban heat islands (UHI) increase the rates of heat-related illnesses (van den Bosch & Ode Sang, 2017), can cause chronic stress (Berry et al., 2010) and contribute to approximately 4.3% of premature summer deaths in European cities (Iungman et al., 2023). Planting

[3] https://delos.com/resources/blog/how-your-indoor-environment-impacts-mental-health/
The green arrows indicate other health human aspects (Santos, 2023) also affected by indoor/outdoor luminous environment.

trees and increasing vegetation may help to cool urban areas (Piracha & Chaudhary, 2022). This is because vegetation reflects solar radiation, lowers heat absorption, removes pollutants from the atmosphere and creates a cooling microclimate through evaporation (Knight et al., 2021; Shanahan et al., 2016). A meta-analyses shows that grass surfaces are on average 0.55ºC cooler than comparison surfaces, parks and gardens are 0.79ºC cooler than the rest of the city and forest areas are 1.61ºC cooler than comparison areas (Knight et al., 2021). Green spaces often include water features, such as ponds or water fountains, that also contribute to thermal comfort (Beute et al., 2020). Green spaces can therefore help to reduce the harmful effects of heat and stress in an area and can promote the well-being and health of people (Jabbar et al., 2021; Javadi & Nasrollahi, 2021).

3.2.4 Air quality

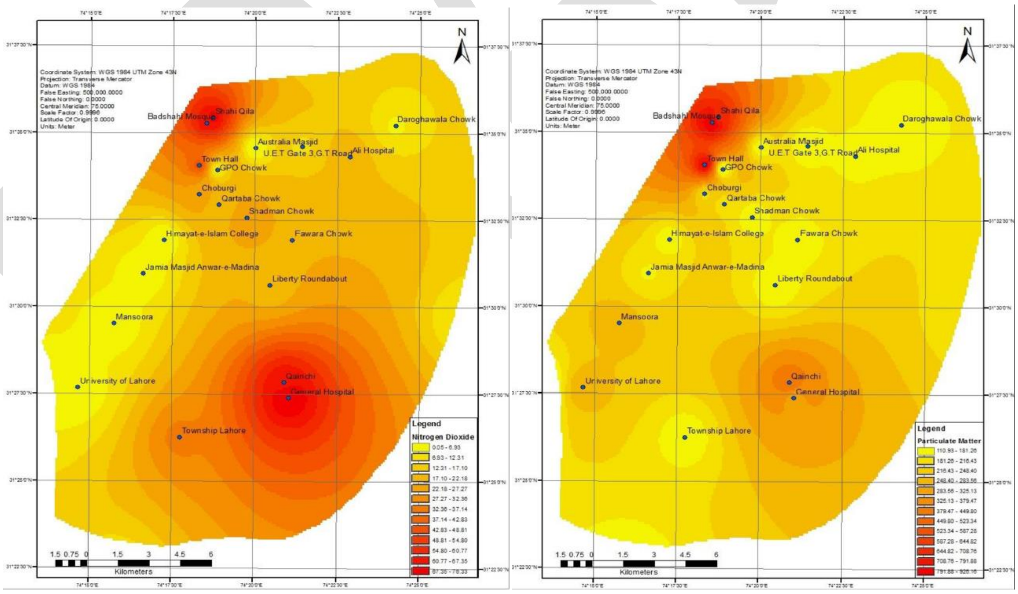
Air pollution can be defined as a mixture of unwanted material or any unwanted particles in the air causing risks to human health. The six major pollutants that are hazardous and are among the most studied ones are: carbon monoxide (CO), ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter that is smaller than 10 microns (PM_{10}) and particulate matter that is smaller than 2.5 microns ($PM_{2.5}$) (Anderson et al., 2011; Miao et al., 2023; Khan et al., 2022; Logothetis et al., 2023; WHO, 2021). Distinct characteristics of particles may be related to diverse health effects (WHO, 2021).

The Directive 2008/50/EC of the European Parliament and of the Council, on ambient air quality and cleaner air for Europe, refer that for the sake of protecting human health and the environment as a whole, the emissions of harmful air pollutants should be avoided, prevented or reduced. This Directive elaborates on the need for having appropriate objectives for ambient air quality, set in accordance with the World Health Organisation (WHO) standards and guidelines.

The distribution of air pollutants in urban settings results from complex interactions between factors such as street morphology (e.g., building volume, roof shape), green spaces (e.g., street trees, vegetation barriers, type of leaves), microclimatic factors (e.g., humidity, wind direction and intensity, temperature), traffic and other (e.g., fireplaces) emissions, background pollutant concentrations, pollution sources, physical processes, and photochemical reactions (Khan et al., 2022; Miao et al., 2023).

The specific urban and landscape setting, including the emission sources, are correlated with the presence of air pollutants. For instance, Khan et al. (2022) showed that the highest polluted areas in urban settings (in Pakistan) have the lowest vegetation levels, whereas areas with low pollution concentration have more vegetation cover. Douglas et al. (2023), among other authors, report that areas with parks and water bodies have consistently lower air pollution concentrations, which supports that nature-based solutions contribute to enhancing air quality. Logothetis et al. (2023) studied the air quality and the possible impact of wind patterns on the level of pollution of the Rhodes city (Greece), analysing different locations over. The results showed that the highest pollution level occurs in the city center, highlighting the impact of vehicle traffic and anthropogenic activities on the air quality.

In all cases, it is important to be aware that air quality measurements are related to temperature, humidity, and wind (direction and intensity), and to the land topography and use (Khan et al., 2022; Logothetis et al., 2023; Miao et al., 2023). Figure 4 depicts an example of the area distribution of concentrations of NO_2 and PM_{10} in the built-up space of Lahore; the air quality data used was collected at the EPA Punjab (Khan et al., 2022). This example, outside Europe, illustrates a location facing colossal air pollution problems, in Pakistan, where air quality parameters for several locations violate the national air quality standards. What is relevant, for the purposes of this deliverable, is to acknowledge (*c.f.*, Figure 4) that the concentration areas for different air quality parameters are not exactly the same, also because pollutants such as particles and gases have distinct physical and chemical behaviours. Moreover, there are variations along the 24h of a day, in accordance with the emissions, the weather variables and the physical phenomena controlling the transport and dispersion of pollutants.



(Extracted from Khan et al., 2022)

Figure 4. Maps with the 24-h mean observations of NO_2 and PM_{10} in the built-up area of Lahore (Pakistan). Concentrations are given in micrograms per cubic meter (µg/m^3).

Studies have shown that the deterioration of air quality and exposure to high-pollution levels are linked to various diseases. It has been documented that high levels of pollution trigger the onset of health disorders and the long-term exposure to unhealthy ambient-air conditions contributes to the onset of diseases related to the respiratory system, cardiovascular system, lung function and chronic obstructive pulmonary disease, cancers and cognitive decline, among others (e.g., Anderson et al., 2011; Rumana et al., 2014; Orellano et al., 2017; Juginović et al., 2021; Logothetis et al., 2023; WHO, 2021; Zhan et al., 2023).

Being known that air pollution impacts the health, in particular of sensitive population – children, the elderly, NATURELAB selected, at the proposal stage three representative air quality parameters to be assessed at the Experimental Sites, namely: NO_2; PM_{10} and $PM_{2.5}$. Exposure to fine particulate matter ($PM_{2.5}$), a dominant air pollutant, is associated with adverse health effects such as respiratory illness, cardiovascular disease, and premature mortality (Anderson et al., 2011; WHO, 2021).

3.2.5 Noise

Conventional research and legislative guidelines in the context of environmental acoustics have been dominated by noise as a physical measure (decibels expressed as Lden and Ln levels) and mainly focused on limit values and measures to reduce noise levels when these limits are exceeded. In the European Union, the assessment and management of environmental noise are legislated by the "Environmental Noise Directive" (Directive 2002/49/EC), which deals with the management of specific noise sources, in particular road, railway, aircraft, industrial, and equipment noise. In this context, environmental sounds are considered as psychophysical stressors, leading to adverse health effects, like annoyance, increased risk of ischaemic heart disease, sleep disturbance, or other impairments in health and well-being (WHO, 2018).

This approach focusses on reducing unwanted noise, ignoring the potential benefits of positive sounds. Recent studies in urban open spaces have shown that when the sound level is below the values of 65-70dBA, people's acoustic comfort evaluation is not only related to the sound level, but the sound type, the user characteristics, and other factors play an essential role (Yang & Kang, 2005). Consequently, the attention to the physical noise metrics is shifting towards a more holistic approach, where the process of how people perceive, experience, and/or understand an acoustic environment plays an important role. An example of this approach, called soundscape, highlights seven general concepts and their relationships: sound sources, context, acoustic environment, auditory sensation, interpretation of auditory sensation, responses, and outcomes (Figure 5). In this way, soundscape studies strive to understand the perception of a sound environment in context, including acoustic, environmental, contextual, and personal factors.

Soundscapes studies gained attention in recent years as a complementary approach to managing environmental noise and urban planning policies. Sound sources can be characterized into three major types: natural sounds that relate to non-biological sounds, such as wind, water, or thunder, and can cover the entire frequency spectrum (named as geophonies), the second type includes the sounds of non-human organisms, such as insects, bats or birds that have limited and predictable frequency ranges of between 2 and 8 kHz (named as biophonies), and the third type related with the all environmental sounds generated by human sources (anthrophony), such as human voices or human activity-related sounds (road, rail, air traffic noise, and industrial noise). These types of sounds are also incorporated into ISO (ISO 2018) and formalized into three main types of sound sources that are recommended for inclusion in soundscape surveys: sounds of nature, sounds of technology, and sounds of human beings.

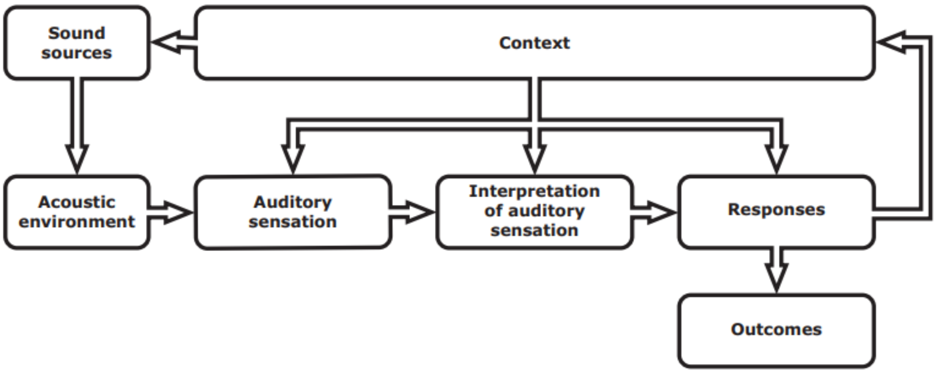


Figure 5. Conceptual model of soundscapes: relationship between the seven general concepts

Natural sound sources are generally assumed to have positive effects on health and well-being, while mechanized anthropogenic sounds are assumed to be negative. Technological sounds from transportation, industry, commerce, infrastructure, and construction have been related to adverse health consequences (EEA, 2020). Human sounds and music can be perceived as positive or negative, depending on the environment, circumstances, and individual factors (Alleta et al., 2018).

Regarding natural sounds, the work by Ratcliffe (2021) shows that there are variations even within a single category of nature sound (bird songs and calls): songbirds are qualitatively and quantitatively regarded as more pleasant, relaxing, and potentially restorative than birds which make rough, noisy, and simple calls, or those which have negative meanings or associations. Another example of natural sounds with positive perceptions is water sounds. Water is a typical passive sound. In the form of fountains, springs, or cascades, it is often used as a landscape element in open public spaces, with endless effects in coloring the soundscape. The importance of water sounds may relate to the critical role of water for survival, as well as the capacity of continuous water sounds to mask noise. These findings show the importance of considering the value of auditory aspects of nature for the study of restorative environments and the value of specific sounds.

In soundscapes research, studying how people perceive the acoustic environment starts by analyzing binaural sound recordings in terms of physical parameters to obtain quantitative information about the acoustic environment, using acoustic and psychoacoustics indicators. Moreover, traditional qualitative methods, such as questionnaires, soundwalks, interviews, and on-site observation accompanied by sound source classification are used to acquire subjective soundscape information (ISO, 2018). More complex approaches involve the combination of objective and subjective methods. The quantitative data obtained using questionnaires in soundscape investigations is analyzed and linked to the results of the acoustic data analyses in order to identify potential relationships. To achieve this goal, statistical analyses, such as correlation analyses, linear regression, or ANOVA (ISO, 2019), are used. The conceptual soundscape model depicted in Figure 6 represents the eight Perceptual Attributes Qualities (namely: Pleasant, Chaotic, Annoying, Monotonous, Calm, Vibrant, Uneventful Eventful) spread over a two-main dimensional model with Pleasantness on the horizontal axis and Eventfulness on the vertical axis. The first dimension relates to how Pleasant or Annoying soundscapes can be, while the second dimension represents the number of activities in the acoustic environment (Eventful or Uneventful scale).

Furthermore, two other axes are formed by a mixture of the two main dimensions when rotated at 45°. For instance, when rotating clockwise, the Eventful scale becomes the Vibrant and Monotonous dimension, while the pleasant scale turns to the Calm and Chaotic dimension (ISO, 2019). In this model, a Vibrant soundscape is both Pleasant and Eventful, a Calm soundscape will be both Pleasant and Uneventful, a Monotonous soundscape will be both Annoying and Uneventful, and lastly, a Chaotic soundscape will be both Annoying and Eventful.

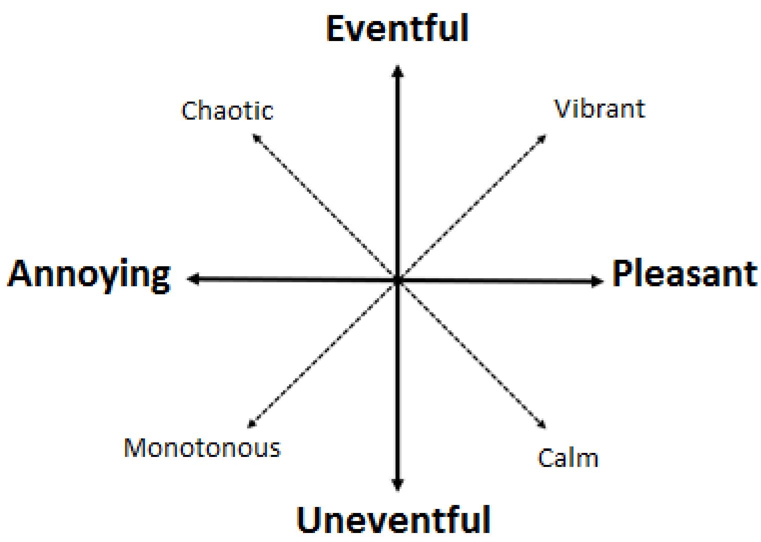


Figure 6. Circumplex model of soundscape perception (ISO, 2019)

Taking this 2D space as a reference, any perceptual outcome that is located in the Pleasant region of the model (e.g., Pleasant, Calm, Vibrant, or Similar) can be considered as a positive soundscape. In contrast, any perceptual outcome that is located in the Annoying region of the model can be considered as a negative soundscape (e.g., Annoying, Monotonous, Chaotic, or similar). Regarding the health effects of positive soundscapes, a systematic review made by Alleta et al. (2018) pointed out that positively assessed soundscapes (e.g., reduced noise annoyance) are statistically significantly associated with better self-reported health conditions. Figure 7 presents a schematic representation of the associations between positive soundscapes and positive health effect.

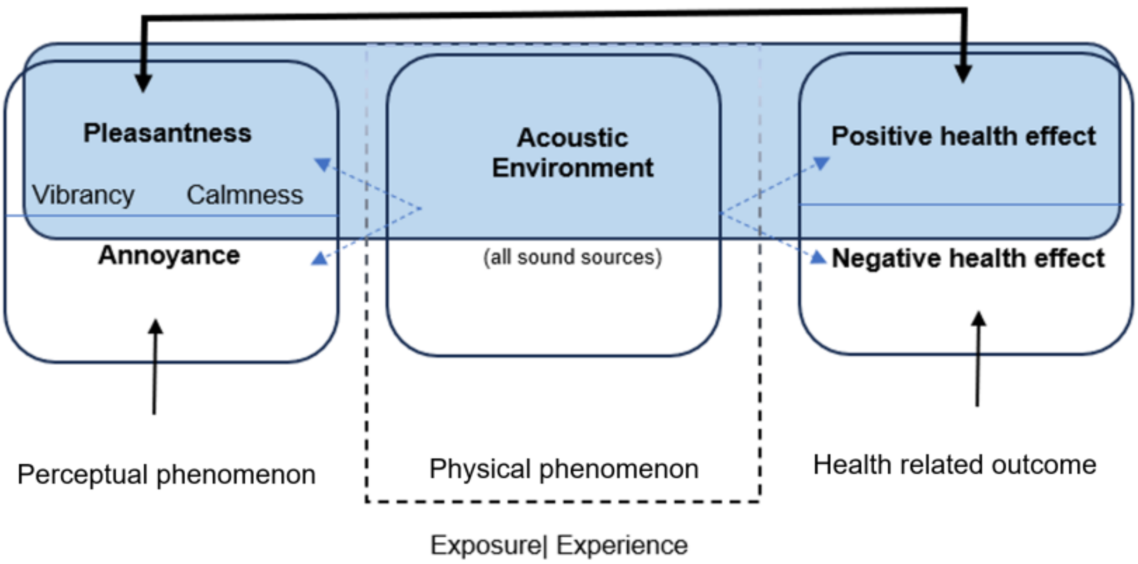


Figure 7. Schematic representation of the associations between positive soundscapes and positive health effects (area highlighted in blue, Alleta et al. 2018)

Chapter 4

Green Space characteristics that are related to health and well-being

4. Green Space characteristics and Cultural Ecosystem Services related to health and well-being

Chapter Highlights

This chapter provides a framework of key indicators of natural and infrastructural characteristics that have a high potential to be relevant for health and well-being. There is a growing body of evidence showing positive associations between green spaces and health and well-being outcomes. Despite this, there has been little research into which components of green spaces benefit people's well-being and health, and how they can be categorized.

To fill this gap, and as part of the D1.1 objective, relevant indicators are identified here based on current knowledge of green space characteristics and their influence on health and well-being. The definition of these and the practical recommendations for their characterisation are proposed for the different types of green spaces. The following four categories of indicators are proposed: Spatial characteristics, design, and conditions; Infrastructural characteristics; Natural characteristics and Cultural Ecosystem Services.

4.1 Spatial characteristics, design, and conditions

This section reviews the spatial characteristics, design and condition of green spaces that are associated with health and well-being benefits of individuals. Based on the existing evidence in the research literature, the chapter provides an overview on these indicators and summarises whether they primarily affect health and well-being.

4.1.1 Size

Research shows heterogeneity in whether the size of a green space influences its potential for health and well-being. Some authors of systematic reviews conclude that larger green spaces have a greater potential for restoration and health (Felappi et al., 2020; Nguyen et al., 2021). For instance, access to large parks was associated with lower Body Mass Index (Rundle et al., 2013) and positive mental health compared to small parks (Wood et al., 2017). In contrast, other authors note that green spaces of different sizes provide mental health benefits (Barnes et al., 2019). This is supported by findings that even small pocket parks and street trees are associated with the mental health of city dwellers (Nguyen et al., 2021). In most studies, the information on the exact size of green space site is missing; therefore, it remains to be seen whether a cut-off criterion (e.g., 0.25 ha - 1 ha) in terms of minimum size concerning health and well-being benefits exists (Ekkel & De Vries, 2017).

4.1.2 Accessibility

Accessibility is a crucial condition for benefiting from nature. Access can be understood in two ways: Firstly, in terms of the legal ability to visit a place (e.g. a public versus a private garden), and secondly, in terms of the barriers that people face when trying to enter a green space (Mery, 2010). For social, cultural or physical reasons, access to park areas can be challenging (Nguyen et al., 2021). Efforts should be made to reduce social (e.g., low income) and physical barriers (e.g., trails) to provide access to nature for all (Bratman et al., 2019). Opportunities to access green spaces (e.g. accessibility, use, visitation, presence, proportion of public urban green spaces per inhabitant) positively affect health (Reyes-Riveros et al., 2021). For older adults, accessibility is an important green space characteristic related to well-being (Xu et al., 2022).

4.1.2.1 Proximity to green space

People's access depends on the distance to the green space (Reyes-Riveros et al., 2021). This indicates that the proximity of green spaces can impact one's well-being and health (Ekkel & De Vries, 2017; Mery, 2010). Urban parks that are within walking distance have been found to enhance mental health (Wood et al., 2017), whereas the benefits of parks on well-being disappear when they are situated beyond walking distance (Ayala-Azcárraga et al., 2019; Barbosa et al., 2007). Daily access to close green landscapes is of greater significance than having access to distant nature parks (Li & Lange, 2023; Mery, 2010). This is particularly noteworthy for specific segments of the population such as older adults (Mery, 2010). If the green space is far from people's homes, it is necessary to ensure accessibility through public transportation to promote physical activity among individuals (Gianfredi et al., 2021).

4.1.2.2 Paths

Most green spaces, including small parks and large forests, have pathways or trails to guide people through them (Barnes et al., 2019). It's important to note that all types of green spaces benefit from having surfaces that are easy to walk on (Miralles-Guasch et al., 2019). Paths, and footpaths, vary in their qualities, such as being paved or not. The design of paths and trails is essential concerning the safety of green spaces and how inclusive they are, which depends on the specific population group (Chen et al., 2021). Paved paths have proven to be more successful in promoting physical activities (Kaczynski et al., 2008; Miralles-Guasch et al., 2019). Older adults like flat paths with seats (Jørgensen & Anthopoulou, 2007), younger adults prefer forested areas with unobstructed grounds for athletic, adventurous activities such as hiking, trail running, or mountain biking (Nguyen et al., 2021). Pathway infrastructure in parks is an important variable that predicts well-being (Ayala-Azcárraga et al., 2019), especially among older adults (Chen et al., 2021). Previous studies have reported mixed findings on how well paths affect people's quality of life (Nguyen et al., 2021).

4.1.3 Safety

Safety is the absence of abrupt threats to people's well-being, such as organised violence or natural disasters (Reyes-Riveros et al., 2021). Perceived safety serves as a potential moderator of park use for various activities, including physical activity or social events (Bratman et al., 2019). In the context of outdoor exercise among older adults, a sense of environmental safety is critical to their engagement, and safety concerns have also been identified among women (Chen et al., 2021).

Promoting safety in green spaces includes several infrastructure features, such as good maintenance - for example, no injury risk features - and the presence of lighting (Ayala-Azcárraga et al., 2019; McCormack et al., 2010; Xu et al., 2022). However, there is inconsistent evidence on the importance of perceptions of safety for health outcomes (Nguyen et al., 2021). Safety did not affect BMI (Bai et al., 2013), but was associated with better quality of life (Nguyen et al., 2021). In Georgetown, Guyana, researchers found that participants with safety concerns were unable to benefit from the restorative effects of green spaces (Fisher et al., 2021). Similarly, the well-being of park users in Mexico City was predicted by perceptions of safety (Ayala-Azcárraga et al., 2019).

4.1.4 Maintenance

One aspect of infrastructure is good maintenance, as exposure to well-maintained urban green spaces can improve health outcomes (Cowan et al., 2005; Gianfredi et al., 2021). Good maintenance is associated with cleanliness and the absence of nuisances (e.g. dog fouling, glass, overflowing bins, weeds, litter, dogs, litter or graffiti, nuisance people) (McCormack et al., 2010; Nguyen et al., 2021). To ensure good maintenance, maintenance procedures are needed (Selanon & Chuangchai, 2023). Managing institutions and green space users share responsibility for maintaining cleanliness (Stessens et al., 2020). Cleanliness of public green spaces was associated with lower rates of depression (Mears et al., 2020). For other outcomes, such as BMI or quality of life, the evidence was inconclusive (Nguyen et al., 2021). For example, lower levels of nuisance were not associated with better health or higher life satisfaction among older people in the UK (Sugiyama et al., 2009).

Table 4. List of spatial, design, and maintenance-related on-site characteristics that are related to health and well-being

Spatial, design, and management characteristics							
Indicator	Description	Metrics	*	Recommendation	Potential Relevance**		
					T1	T2	T3
Size	The size measured in hectares	GIS Analysis, GIS Database	1	Most studies used spatial analysis to measure green patch size (Nguyen et al., 2021)	x	x	x
Accessibility - Proximity - Paths	Measures of accessibility of the Site.	Entries, Fences, Walking paths, Bike lanes, Car parking space, Guiding signage, Public transport, Handicapped adaptions, Slope (Knobel et al., 2021)	2	Efforts should be made to reduce social (e.g., low income) and physical barriers (e.g., trails) to provide access to nature for all (Bratman et al., 2019).	x	x	x
Safety	Elements that create a condition of safety	Lighting, Safety adaptions from cars and bikes, Visibility from surroundings, CCTV (Knobel et al., 2021)	2	Perceived safety serves as a potential moderator of park use for various activities (Bratman et al., 2019).	x	x	x
Maintenance	Characteristics that make the Site enjoyable or less enjoyable	General litter, Alcohol use, Drug Use, Vandalism, Sex work, Noise, Smell (Knobel et al., 2021)	2	Exposure to well-maintained urban green spaces can improve health outcomes (Cowan et al., 2005; Gianfredi et al., 2021).	x	x	x

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

4.2 Infrastructural characteristics

This section reviews the *infrastructural features* of green spaces that have an impact on health and well-being of individuals. In addition to the spatial, design and condition aspects discussed above, the literature has identified facilities such as playgrounds, lawns, courts and amenities (*e,g*., seating or shelters as infrastructural features of green spaces to encourage visitation). As an illustration, Figure 8 shows a Google Earth image of the Naturelab Experimental Site #9 in Cologne with labels of the identified infrastructural features. The following section explains these indicators, summarises whether they primarily affect health and well-being, and provides recommendations for practical implementation.

Note. Google Earth image of the #ES 9 (here: Beethoven Park and Decksteiner Weiher, access date 08/11/2023) in Cologne, Germany. Labels identify park facilities and amenities.

Figure 8. Examples of facilities and amenities in urban parks

4.2.1 Facilities

Green spaces can include multiple *facilities, also known as grey infrastructure*, which should be balanced with the given green structure (Chen et al., 2021). Whether certain facilities are valued depends largely on the needs of specific user groups and the purpose of visiting the park (Lachowycz & Jones, 2013; Nguyen et al., 2021). Children may prefer to play in the playground, people with a dog may value the grassed areas, and a jogger may use the outdoor gym facilities. Therefore, facilities increase park use and its attractiveness (Grilli et al., 2020; McCormack et al., 2010), while they are not directly related to health and well-being (Nguyen et al., 2021). Here are a few examples of studies that support this finding: For instance, the quality of urban parks, measured by the presence of toilets, lighting and playgrounds in Tijuana (Mexico), was not a modifier of mental health outcomes in women (Bojorquez & Ojeda-Revah, 2018). While the number of facilities was positively associated with health outcomes in older adults in Tainan, the authors found no association for older adults in Hong Kong (Tan et al., 2019). In a study in the Netherlands park quality interventions had no short-term effect on the prevalence of physical activity or self-reported health among adults living in deprived neighbourhoods (Droomers et al., 2016). In an intervention study in Melbourne, where researchers refurbished several parks with items such as a picnic shelter, drinking fountains, garden beds and barbecues, this only had an impact on park use, but not on users' physical activity and emotional state (Dobbinson et al., 2020).

In this section we argue, based on the literature, why particular facilities might improve health and well-being.

Playgrounds encourage visits to green spaces (Grilli et al., 2020) and have a positive effect on physical activity (Smith et al., 2021). To reduce sedentary time, it is recommended to remove seating around playgrounds (Roemmich et al., 2014).

Grass patches are associated with mental recovery (Nordh et al., 2009) and not with self-reported health (Reid et al., 2017). This line of reasoning follows the idea that greenness promotes mental health (James et al., 2015; Kaplan, 1995).

Most green spaces that promote well-being include built or natural water features (or blue spaces), (Barnes et al., 2019), such as lakes, ponds, river or water fountains. There is evidence that the presence of water has a positive effect on physical health, mental health and well-being (Beute et al., 2020; Smith et al., 2021; Velarde et al., 2007). A meta-analysis calculated small effect sizes for urban blue space benefits on obesity, all-cause mortality, general health and self-reported mental health and well-being (Smith et al., 2021). Well-being effects depend on the quality of blue spaces, such as cleanliness, safety perception or water quality (Garrett et al., 2023). Access to water features, such as touching them, improves the restorative potential (Felappi et al., 2020; Zhao et al., 2018) and encourage many types of activities with positive health effects in terms of disease prevention by increasing physical activity (Zhao et al., 2018).

Sports facilities in urban green spaces, such as courts and outdoor gyms, provide opportunities for physical activity. Physical activity can for instance prevent diabetes and cardiovascular diseases (Ngom et al., 2016). The number of physical activity facilities (here: baseball fields, basketball courts, hoops, football pitches, etc.) was not associated with BMI after controlling for individual and neighbourhood socio-demographic characteristics (Rundle et al., 2013). The use of sports facilities is highly dependent on the cultural and geographical context of the community, which should be involved in the planning of parks and green spaces (Frumkin, 2003). A study comparing urban parks in Montreal found a correlation between neighbourhoods with poor health and parks that lacked facilities for physical activity. In contrast, facilities could increase the likelihood of physical activity (Coen & Ross, 2006).

4.2.2 Amenities

Seating infrastructure in green spaces includes a variety of amenities such as resting places, benches and designated picnic areas with tables. The amount of seating required depends on the size of the green space (Bullock, 2008) and the needs of the user population. Older adults desire more seating (Jorgensen & Anthopoulou, 2007), and also show more sedentary behaviour (Miralles-Guasch et al., 2019). However, the presence of seating infrastructure, such as tables, is also positively correlated with social interaction (Douglas et al., 2017; Peschardt et al., 2014), and social activities are associated with human health (Chen et al., 2021).

For some people, a toilet is optional; for others, it may be essential - the relative importance depends on the age of the visitor (Aspinall et al., 2010). For older adults, pleasantness, which includes the presence of facilities such as toilets and shelter in neighbouring open spaces, is associated with increased life satisfaction, but not with physical health (Sugiyama et al., 2008).

Some amenities protect against potential environmental risks. These risks can be heat, sun or storm. Some studies (e.g., Sugiyama et al., 2008; van Dillen et al., 2011) include these amenities as a factor of park quality. Whether these amenities alone increase the health potential of a green space remains to be determined.

Table 5. Indicators related to infrastructural on-site characteristics related to health and well-being

B Infrastructural characteristics							
Indicator	Description	Metrics	*	Recommendation	Potential Relevance**		
					T1	T2	T3
Facilities	Features that allow for the realization of specific activities	Supply of facilities (e.g. benches, fishing places, playgrounds, sports) (Van Herzele & Wiedemann, 2003) Playgrounds, Grass patches, Courts, Open space for multi-use, Water-related facilities, Outdoor gym (Knobel et al., 2021)	1	Therefore, facilities increase park use and attractiveness (Grilli et al., 2020; McCormack et al., 2010) but are not directly related to health and well-being (Nguyen et al., 2021),	x	x	x
Amenities	Features that make the Site more comfortable	Seating and benches, litter disposal, drinking fountains, public toilets, shelter, shade (Knobel et al., 2021)	1	Amenities, such as toilets, attract visitors and influence their welfare (Grilli et al., 2020).	x	x	x

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

4.3 Natural features

This section describes natural green space characteristics that impact human health and well-being. The most common natural features of green spaces, *biodiversity* (bird and plant species richness, habitat diversity), *attractiveness, naturalness* and *perceptional experience* have been identified from the literature. In the following, these indicators are defined, the main effects on health and well-being are summarized, and practice recommendations are derived.

4.3.1 Biodiversity

The Convention on Biological Diversity (UN, 1992) defines *biodiversity* as "[…] the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part […]" (United Nations, 1992). In the literature reviewed, the term refers to the variability of species, the diversity of genes within species, and the diversity of ecosystems in which species live (Aerts et al., 2018). Several reviews show that biodiversity can positively influence health and well-being (Aerts et al., 2018; Felappi et al., 2020; Gianfredi et al., 2021; Lai et al., 2019; Marselle et al., 2021). The systematic review by Gianfredi et al. (2021) suggests that increased exposure to natural habitats and microbial biodiversity protects against infections and immune disorders, describing a direct mechanism for the beneficial role of biodiversity.

Biodiversity can also affect human health indirectly by mitigating environmental stressors, such as buffering noise through dense and diverse planting, reducing air pollution through specific tree species, and decreasing air temperature through shading (Marselle et al., 2021). In the research field of green spaces and health, only a few studies have examined the influence of biodiversity in green spaces on mental health and well-being (Marselle et al., 2021). There is evidence that plant and animal species richness may have a positive effect on mental health and well-being, but this is not consistent across studies (Marselle et al., 2021).

In a review by Lai et al. (2019), 90% of the associations identified showed positive effects of biodiverse green spaces on health. In addition, 5% showed negative effects, and the remainder showed both positive and negative effects, particularly concerning allergies, obesity, and mortality (Lai et al., 2019). Possible explanations for the conflicting positive and negative health effects are different definitions and characteristics of green spaces in the studies, unmeasured factors, and different scales of the analysis (Lai et al., 2019).

Future studies should consistently measure actual and perceived biodiversity in different green spaces, both objectively and subjectively, and provide indicators to target green space planning and management (Felappi et al., 2020). Systematic reviews show that flora and fauna species richness can have positive effects on health and well-being (Gianfredi et al., 2021; Marselle et al., 2021;

Nguyen et al., 2021). *Bird species richness, plant species richness*, and *habitat diversity* showed the most positive effects, which is why these indicators are now explained in more detail (Marselle et al., 2021).

4.3.1.1 Bird species richness

In their systematic review, Aerts et al. (2018) observed that the most positive evidence for the effects of biodiversity on human well-being was found for measured and perceived bird species richness. Bird species richness can increase the use of urban green spaces, promote physical activity, and reduce the risk of health problems like obesity (Knobel et al., 2021). Several studies have shown that greater bird species richness is associated with higher levels of life satisfaction, positive affect, and psychological well-being (Marselle et al., 2021). The observed positive effects on mental well-being are due to the bird richness per se rather than the actual total species richness of birds (Cox et al., 2017). This means that it may not be the number of different species (species richness), but the total number of animals, plants, or birds (abundance) that appears to have an impact on health (Marselle et al., 2021). In addition, bird sounds contribute to restoration and stress recovery (Franco et al., 2017). These findings suggest that watching birds and listening to bird songs contribute to the positive effects of nature on mental health and well-being. However, the underlying mechanisms involved in the relationship between bird abundance and human health are not yet fully understood (Aerts et al., 2018).

4.3.1.2 Plant species richness

Positive associations exist between plant species richness and physical and mental health (Lindemann-Matthies & Matthies, 2018; Methorst et al., 2021). Plant species richness can increase soil bacterial diversity in urban green spaces, and exposure to a diverse environmental microbiome promotes the development and maintenance of a healthy immune system (Baruch et al., 2021). In terms of well-being, greater tree and plant species richness can improve mood and psychological well-being (Marselle et al., 2021). More than half of the results reported in the review by Marselle et al. (2019) showed a positive effect of perceived species richness on mental well-being. For example, greater perceived species richness of animals and plants was associated with psychological well-being, positive mood, arousal, and recreation (Dallimer et al., 2012). On the other hand, biodiversity loss may negatively affect health and well-being (Marselle et al., 2021). Overall, the evidence base is not yet sufficient to characterize the role of biodiversity concerning health and well-being (Marselle et al., 2021), but some factors may influence the perceived plant species richness and thus contribute to well-being benefits that should be considered in green space management (Heiland et al., 2019; Southon et al., 2018). Natural factors such as vegetation height, number of common species, and vegetation colour, as well as ecological knowledge and pro-environmental behavior, were significantly associated with a more accurate estimation of plant species richness (Southon et al., 2018). Therefore, green space management should promote high species richness and enable access to plants and wildlife to improve human well-being through positive experiences and restoration (Methorst et al., 2021).

4.3.1.3 Habitat diversity

There is evidence that not only exposure to nature but also exposure to diverse natural habitats leads to psychological and physical health benefits (Sandifer et al., 2015). More biodiverse ecosystems and habitats are positively associated with higher quality of life and health (Rantakokko et al., 2018; Wheeler et al., 2015). On the one hand, contact with diverse natural habitats is important for developing normal immune responses that protect against several diseases like allergic and autoimmune diseases as well as asthma, cardiovascular diseases, or depression (Sandifer et al., 2015). On the other hand, the diversity of habitat types may influence the perceptions of biodiversity and enhance mental well-being (Aerts et al., 2018; Marselle et al., 2021). There are mixed results regarding biodiversity at the ecosystem/ habitat level, as some studies have found no effects of different green spaces on well-being (Marselle et al., 2021). An investigation found that forest habitats with medium biodiversity had the strongest positive affect, followed by high biotopes and low biotopes (Johansson et al., 2014). Other studies did not find effects of biodiversity on health and well-being for different habitats, protected areas, or green space types (Marselle et al., 2021). Furthermore, green spaces with higher habitat diversity benefit wildlife, providing health benefits, as wildlife watching can improve the mood and happiness of green space users (Sandifer et al., 2015).

4.3.2 Aesthetics and Attractivity

Aesthetic and attractivity features are some of the most influential environmental parameters that affect the design of high-quality green spaces and should be considered in landscape planning (Javadi & Nasrollahi, 2021). Green spaces perceived as attractive, such as well-maintained and clean spaces with well-tended vegetation (low amount of deadwood and brushwood), can increase park use and physical activity (Felappi et al., 2020; Wolch et al., 2014).

Physical activity in green spaces is positively associated with mental and physical health benefits (e.g., lower stress levels and risk of cardio-metabolic diseases) (Akpinar, 2016). The presence of trees, shrubs, grass, and flowers can enhance the restorative potential of green spaces and have a positive effect on park use and physical activity (Felappi et al., 2020; McCormack et al., 2010).

Colourful planting, achieved through flower cover above a 27 % threshold, is seen by people as attractive and stimulating, while subtle greens are more psychologically restorative (Hoyle et al., 2017). In addition, using plants with different aesthetic characteristics for different seasons should be considered when managing green spaces (Chen et al., 2009). On the one hand, perceived biodiversity can increase aesthetic appreciation of green spaces and improve psychological well-being (Sandifer et al., 2015). On the other hand, the results of Akpinar's (2016) study suggest that landscape planning of urban green spaces should provide large, more open and visible areas for recreation. Well-maintained large and open green spaces can increase physical activity and improve people's physical and mental health by improving well-being and self-esteem (Akpinar et al., 2016).

4.3.3 Naturalness

According to a systematic review, green spaces that were perceived as natural, such as protected areas or bushland, provided greater benefits for mental restoration and physical health (Nguyen et al., 2021). Hoyle et al. (2017) found that moderately structured, natural planting can provide more restorative benefits than highly designed, least natural green spaces. One indicator of naturalness is the use of native plant species (Chen et al., 2009). Combined with public education about species and biodiversity, using native plant species can be an effective strategy for optimizing and managing green spaces with recreational benefits (Chen et al., 2009). Another characteristic that plays an important role in the perception of naturalness and can enhance the restorative potential of environments is water features (Zhao et al., 2018). A review by Barnes et al. (2019) found that most green spaces that promoted well-being had built or natural water features in common. The presence and accessibility of water improve the restorative potential of green spaces and supports species richness (Felappi et al., 2020). For landscape planning, establishing a waterscape in green spaces and increasing its accessibility can improve its restorative potential (Zhao et al., 2018).

4.3.4 Perceptional experience

Multi-sensory experiences (visual, auditory, and olfactory sensation) provided by different natural features contribute to the positive restorative effects of green spaces (Nguyen et al., 2021). The visual stimulation of green spaces is associated with feelings of comfort that reduce blood pressure, heart rate and psychological stress (Chen et al., 2021). The colour of vegetation is a sensitive feature to distinguish green spaces, as multi-coloured vegetation affects people's satisfaction with the environment and leads to more environmental comfort (Qin et al., 2013).

Another feature that can improve people's satisfaction with parks is the soundscape quality (Javadi & Nasrollahi, 2021). The presence of natural sounds can positively affect the quality of life (Ayala-Azcárraga et al., 2019), and the quietness of parks makes them more attractive and influences park use (McCormack et al., 2010). Biological sounds (e.g., birds) and geophysical sounds (e.g., water) can positively influence restoration, stress recovery, and tranquillity (Felappi et al., 2020). For example, birdsongs have been associated with stress reduction, improved mood and increased learning and concentration abilities as well as feelings of calm, relaxation and happiness (Ayala-Azcárraga et al., 2019). Bird singing is often associated with peoples' restorative experiences (Zhao et al., 2018). That is why landscape planners should filter out undesirable sounds and optimize the desirable ones, for example, by building habitats and nests to attract birds, building streams, or planting specific trees in high and windy topography (Zhao et al., 2018).

Another factor that determines environmental preference is olfactory sensation. Light natural scents from flowers, leaves, and rivers are highly valued by park users (Chen et al., 2009), and the sensation of smog or fumes makes park use unpleasant (McCormack et al., 2010).

Table 6. Indicators related to natural on-site characteristics related to health and well-being

C Natural characteristics							
Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
Bird species richness	Actual bird abundance and species richness	Bird surveys (point counts and distance sampling in defined landscape tiles) "Bird biodiversity" domain of the RETICAL tool (Knobel et al., 2021)	2	Encourage approaches for "optimal" bird population levels through supplementary food and nesting locations to increase local bird abundances (Cox et al., 2017)	x	x	x
	Perceived bird abundance and species richness	Single item "About how many different types of birds would you say are in this green space?" answered on a 4-point scale (1 = less than 5, 2 = 5-14, 3 = 15-30, 4 = more than 30 different types) (Fuller et al., 2007)	1				
Plant species richness	Actual plant abundance and species richness	Field surveys (species are sampled within randomly located quadrats in the defined landscape)	2	Managing green spaces for biodiversity (greater tree and plant species richness) Providing incentives to improve environmental and ecological knowledge for a more accurate species richness estimation (Southon et al., 2018)	x	x	x
	Perceived plant abundance and species richness	Single item "About how many different types of plants would you say are in this green space?" answered on a 4-point scale (1 = less than 10, 2 = 10-100, 3 = 100-300, 4 = more than 300 types) (Fuller et al., 2007)	1				

C Natural characteristics							
Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
Habitat diversity	Biodiversity at the ecosystem/ habitat level	Shannon diversity index of land cover and land use diversity (Rantakokko et al., 2018)	2	Consider different habitat types for biodiversity managing Forest habitats of intermediate biodiversity (Johansson et al., 2014)	x	x	x
Attractiveness	Objective measurable natural green space characteristics considered in terms of their aesthetic appeal and environmental quality (Nguyen et al., 2021)	Photograph-based or in-situ expert ratings of landscape characteristics (Zhao et al., 2018) →Percentage of land covered by vegetation: no vegetation=0; <35%=1; 36–70%=2; 71–100%=3 →Type of land vegetation: no vegetation=0; grasses/ shrubs=1; only trees/ tree with grass=2; mixed vegetation=3 →View scale: closed space=0; slightly open space=1; semi-open space=2; open space=3 Views, Primary surface, material of primary surface, seasonal and high maintenance vegetation, year-round vegetation, water fountain, public art, historic structure or buildings, public attractions (Knobel et al., 2021)	2	Large, more open and visible green spaces (Akpinar et al., 2016) Colourful planting (flower cover above 27 %) (Hoyle et al., 2017) Seasonal and high maintained vegetation (Chen et al., 2009) Public awareness strategies (brief introductions, notices, brochures) (Chen et al., 2009)	x	x	x
	Subjective natural green space characteristics considered in terms of their aesthetic appeal and	Single item “Evaluate the importance of the presence of a range of quality aspects (aesthetic, cleanliness, maintenance, largeness, shaded areas, lights, openness/visibility)”	1				

C Natural characteristics							
Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
	perception of the environmental quality (Nguyen et al., 2021)	on a 5-point Likert-scale ("not at all, little, neutral, fairly, very")					
Naturalness	More natural environments, such as protected areas or bushland with low degree of human-made surroundings and conditions (Nguyen et al., 2021)	Photograph-based or in-situ expert ratings of landscape characteristics (Zhao et al., 2018) →Visual naturalness of water: no water=0; orderly form=1;semi-natural form=2; natural form=3 →Accessibility of water: no water=0; difficult to access=1; neutral to access=2; easy to access=3 →Configuration of land vegetation: no vegetation=0; orderly configuration=1; semi-natural configuration=2; natural configuration=3	2	Setting up a waterscape in green space and enhancing its accessibility (Zhao et al., 2018) Moderately structured, natural planting (Hoyle et al., 2017) Use of native plant species combined with public education about species and biodiversity (Chen et al., 2009)	x	x	x
Perceptional experience	Visual stimulation	Photograph-based or in-situ expert ratings for visual quality evaluation (Zhao et al., 2018) →Number of colours: only one=0; two=1; three=2; four or more=3 →Colour contrast: no contrast=0; weak contrast=1; clear contrast=2; sharp contrast=3	2	Multi-coloured vegetation → satisfaction with the environment and comfort (Qin et al., 2013) Subtle greens →psychologically restorative (Hoyle et al., 2017)	x	x	x
	Auditory stimulation	Expert and perception-based semi-structured interviews with users "What sounds do you hear, or have you heard in this garden?"	1	Creating habitats and nests to attract birds, building streams, planting specific trees on high and windy topography (Zhao et al., 2018)	x	x	x
	Olfactory stimulation	Expert and perception-based semi-structured interviews with users "Is there any scent/smell/fragrance that catches your attention?" (Categorize good, bad or neutral)	1	Increase natural scents from flowers (seasonal vegetation) (Chen et al., 2009)	x	x	x

C Natural characteristics							
Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
				Reduce unpleasant smells like smog or fumes (McCormack et al., 2010)			

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

4.4 Cultural Ecosystem Services

Cultural Ecosystem Services, or simply "cultural services", are important contributors to human well-being (Millennium Ecosystem Assessment, 2005). They are the "experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits" (SEEA, 2021). Cultural services capture a diversity of benefits derived from human interactions with nature such as recreational services, visual amenity services, education and research services, spiritual and symbolic services, and others (SEEA, 2021). The benefits can be derived from being *active* in the ecosystem (such being able to undertake recreative activities) and from having a *connection* to the ecosystem (such as spiritual benefits) (SEEA, 2021). Cultural services can be expressed as either the actual or the perceived qualities of the ecosystem in which these benefits are generated; their quantification commonly requires the measurement of the type, number and/or quality of the interaction (SEEA, 2021). Where economic benefits are of interest (e.g. ecosystem accounting), the quantified benefits can often be translated into monetary terms.

The types of cultural services that will be considered in the assessment of features of green spaces in NATURELAB's experimental sites include (a) spiritual and religious importance, (b) cultural heritage, (c) aesthetic/beauty, (d) creative or artistic inspiration, (e) sense of place, (f) identity, (g) social relations/community benefits, (h) education and ecological knowledge, (i) mental and physical health, (j) recreation, leisure and tourism, (k) existence/bequest values, and (d) other nonmaterial values (see Toolkit for Ecosystem Service Site-based Assessment (TESSA; Peh et al., 2022). Here, NATURELAB combines the qualitative identification of a broad, encompassing range of cultural services with the assessment of specific indicators of key cultural services in green spaces.

Firstly, the broad identification of cultural services employs a 'free listing' exercise (TESSA method Cultural M1.A; Peh et al., 2022) with different stakeholder groups (e.g. experts and users), in which respondents will be asked to list all cultural ecosystem benefits that they associate with the green space. The advantage of this approach is its ease-of-use and its universal applicability to all sites and contexts. Possible examples of specific services thus identified may include 'being able to take walks' (recreational), 'enjoying the beauty of nature' (aesthetical), 'learning about nature during school trips' (educational), 'meeting other people' (social), 'feeling less stressed' (health), or 'getting ideas for arts' (artistic inspiration).

Secondly, the assessment of specific indicators of key cultural services involves a mixed methodological approach in which specific key benefits will be quantified, and subsequently translated into economic benefits, where possible (Table 7). Multiple cultural services can be assessed through (a) participatory mapping (based on TESSA method Cultural M1.C; Peh et al., 2022), where respondents identify places that they associate with specific services, and (b) through measuring visitation-related expenditures where cultural services are assessed through the total costs incurred by the visitors. Other specific benefits, including recreational, educational and therapeutic services, can be measured through visitor statistics related to the use of the green spaces for these purposes (Table 7). User surveys can reveal perception-based measures of benefits related to mental health and social relations (Table 7). Because a single interaction or visit may generate different benefits (e.g. enjoying beauty *and* connecting with people), respondents to user surveys should be asked for their main as well as associated purposes of the interaction or visit. Where possible, cultural services will be translated into economic benefits, through assigning relevant expenditures that allow access to a service (e.g. travel expenses by visitors, entrance or guiding fees), through costs for facilitating the generation of the services (e.g. salaries of guides or therapists), or through avoided health costs. However, potentially, not all benefits can be expressed in money terms and additional indicators may be required.

Table 7. Indicators related to Cultural Ecosystem Services

Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
Various cultural services	Free-listed inventory of ecosystem services in the site	User or expert survey using free listing "What cultural benefits are provided by this green space? Please list." *Cultural M1.A* approach in TESSA toolkit (Peh et al., 2022)	1	Map is used to define spatial boundaries; "cultural benefits" may need to be explained; photos of the site and prompts of service categories (see text) can be used to stimulate respondents; allow sufficient time to list all benefits	x	x	x
Various cultural services (relational importance)	Number of places identified as important to users, demonstrating their connection to the site	Participatory mapping as part of a user or expert survey "Where are the places in this green space that are of … (e.g. spiritual) importance to you?" Based on *Cultural M1.C* approach in TESSA toolkit (Peh et al., 2022)	2	Map is used to identify sites of perceived importance (spiritual, religious, cultural, aesthetic, inspirational, sense of place, identity, social, educational, health or bequest); follow-up questions to explain importance generate a deeper understanding. Valuation: visitation-related expenses (see below)	x	x	x
Various cultural services (visitation-	Objective measure of amount of money spent for the visit	User survey "How much do you spend to visit this green space?"	2	Main purpose of visit also needs to be identified	x	x	

related expenditures)		Metrics: Total expenditure for the visit, including admission fees, travel expenses, food and drinks, accommodation					
Recreation, leisure and tourism	Objective characterization of recreational visits and purpose	Visitor data, observations, or user survey Metrics: Number of recreational and leisure visitors to the site, the purpose of visit, and the length of visit	2	Valuation: visitation-related expenses (see above)	x	x	
	Length of walking paths and other types of paths	Metrics: Direct measure or GIS analysis	1-2	Valuation: none	x	x	
Educational	Objective characterization of educational use	Visitor data or observations Metrics: Number of educational visits and number of educational visitors	1-2	Valuation: entry fees or salary of guides for sessions in green space	x	x	x
Mental and physical health	Self-assessed effect on mental health state	User survey (before and after visit) “What is your current level of stress” on a 5-point Likert-scale (1-no to 5-severe stress) “How many working hours/days do you think you avoid missing out due to your visit?”	1	Length and main purpose of visit should be identified Valuation: through question on reduced loss of working days	x	x	x
	Objective characterization of therapeutic use	Visitor data, observations, or user survey Metrics: Number of therapeutic sessions and number of therapeutic participants	2	Valuation: fees or salary of therapists for sessions in green space	x	x	x
Social relations and community benefits	Perceived social interactions	User survey or observations “How many positive interactions did you have during your visit, and how long were they?” or recording number of observed interactions	1-2	Valuation: none	x	x	x

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

Chapter 5

Sustainability and resilience of sites and population

5. Sustainability and resilience of sites and population

Chapter Highlights

NATURELAB's holistic strategy seeks to offer indicators that go beyond health and well-being, enhancing the resilience of the sites and the population therefore boosting communities' sustainability. The interconnectedness of health and well-being with sustainability best practices is explored in this chapter's key indicators.

Sustainable sites should promote cleaner air and water, reducing exposure to pollutants of both humans and nature and health problems associated with poor environmental conditions. Moreover, green and blue spaces and sustainable communities have been linked to improved mental health. Access to nature, greenery, biodiversity and well-maintained environments can reduce stress, anxiety, and depression while enhancing overall well-being. Reducing environmental hazards and ensuring water management strategies are pathways to increase biodiversity, greenness, mitigate and adapt to extreme precipitation and temperature that are connected to climate changes, thus contributing to sustainable, inclusive and resilient living spaces and communities.

The indicators related to the sustainability and resilience of the sites and the population are divided in (i) climate and geophysical context which include the management of water cycle, solar radiation and climate region; (ii) air quality and (iii) noise.

5.1 Context

NATURELAB proposes an integrative and innovative approach to contribute to resilient communities with focus on health and care prevention. The project will enhance and expand the green and blue areas benefits - as the resilience to climate change, the promotion of biodiversity and urban water management – and link all of these to a Health Pillar and a Societal Pillar (*cf.* Figure 9). The consortium will work closely with stakeholders and communities, providing solutions to improve health and well-being and promoting the protection of biodiversity and sustainability.

The topography and natural features of the sites (e.g., ecosystems; fauna and flora biodiversity; soil and water) will be protected and enhanced through this design, ensuring their appropriate and sustainable long-term maintenance. Air pollution and noise levels will be managed as possible – e.g., by modelling the landscape and using vegetation – in order to create an area where people can benefit from reduced urban stressors. The expertise of the consortium allows bringing in the promotion of sustainable and safe management of water in cities (e.g., rainfall harvesting to irrigate the garden/horticulture; in situ disposal and treatment of stormwater; water reuse - irrigation with reclaimed water - and water quality monitoring), increasing resilience to climate change, and providing new sources of food, income, and well-being. The contribution of the NATURELAB nature areas to local urban resilience will be assessed.

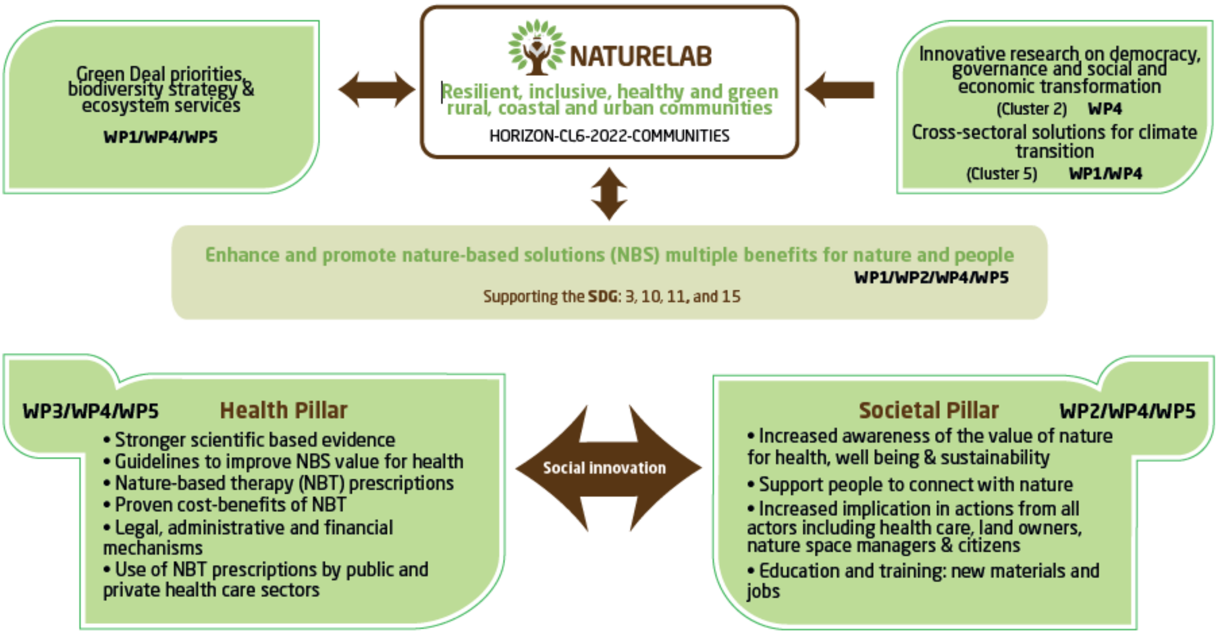


Figure 9. NATURELAB context and pillars to support global benefits of NBS for nature and human-being: relation to Work Packages (WPs) and to Sustainable Development Goals (SDG)

5.2 Climate and geophysical context

5.2.1 Water cycle

In the scope of NATURELAB there is the need to evaluate and manage the blue and green space characteristics in order to guarantee their contribution to sustainability and to cultural ecosystem services, namely to support the implementation of the therapeutic programmes. NBS in urban areas use water (e.g. for garden irrigation) and are part of the urban sanitation network. Therefore, solutions to ensure a sustainable water management must be guaranteed in order to keep in line with the current demands of EU legislation and policies, towards the best use of the potential of NBS, as presented in the previous sections. These solutions depend on the water availability in the nature space (e.g., grey water, rainwater, stormwater) and the demand needs for the distinct purposes, e.g. domestic or irrigation use. These aspects will also inform about the infrastructure need for water storage, maintenance needs and their costs, and the management responsibilities, including solutions that promote community involvement (e.g., maintenance of a community garden).

In order to ensure a sustainable and resilient water management for nature settings, it is important to consider the following steps:

1. Characterization of the ES context and activities to be carried out;
2. Characterization of the ES water availability and needs, for different scenarios, addressing uncertainty;
3. Definition of the system to assess water sustainability in the ES, based on indicators
4. Development of a diagnosis and sustainability targets definition;
5. Identification and characterisation of the measures to be implemented, including the resources needed (human, technological, financial);
6. Production of a plan or planning document integrating the results from steps 1-5;
7. Periodic monitoring and revision of the plan implementation.

A set of indicators was identified, related to sustainable and climate resilient water management, based on the state of the art, previous experiences, including developments from European projects. These indicators address mainly water-related aspects, and are complemented by others dedicated to assess other relevant aspects identified in the literature. The set of indicators is presented in Table 8, including information whether each indicator is mandatory or optional, depending on the type of nature space (i.e., the NATURELAB three classes), as well as which points of view are addressed.

Table 8. Indicators related to sustainable and climate resilient water management

Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
Water sources available	Water availability in the site	Which types of water supply sources exist? *Answer (identify):* *a) surface water, b) groundwater (wells), c) rainwater, d) stormwater, e) reclaimed water, f) sea water, e) other (specify)*	1	Explore lakes, rivers, abundant nature, serene water	x	x	x
Impervious area	Surface imperviousness	Percentage of impervious area (%)	2	Minimize concrete, prioritize green spaces; foster biodiversity, preserve natural drainage.	x	x	
Water needs	Water related facilities availability and needs and	Water supply needs (total, toilet equipment, water supply points, irrigation, washing) *Answer:* ▪ *major/moderate/low/do not exist* ▪ *l/day*	1	Assess water needs; enhance facilities for conservation and access	x	x	x
Physical access to water supply	Further information: B-WaterSmart Silva et al. (2023)	N.º of operational physical access points to water supply (public drinking water fountains, cooling fountains, etc.) in the area *Answer:* *(n.º/km²)*	1	Ensure easy access; promote safety around water bodies		x	x
Wastewater disposal	Further information: RESCCUE Cardoso et al. (2020)	Wastewater disposal exists and is adequately used? *Answer:* *yes/partially/no*	1	Monitor, maintain wastewater systems for environmental and public health	x	x	x

Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
Stormwater management	Further information: RESCCUE Cardoso et al. (2020)	Solutions for stormwater management are adequately used (promoting, interception, infiltration, storage, flow routing, avoiding flooding in routes, pathways, and facilities)? *Answer:* *yes/partially/no*	2	Invest in green infrastructure; mitigate floods, protect ecosystems.		x	x
Drinking water consumption	B-WaterSmart Silva et al. (2023)	Water supply consumption *Answer:* ▪ *major/moderate/low* *l/day*	2	Promote conservation; ensure safe, sustainable drinking water practices.	x	x	
Drinking water in non-potable uses	RESCCUE Cardoso et al. (2020) B-WaterSmart Silva et al. (2023)	Is drinking water being significantly used for non-potable uses? *Answer (identify):* *a) irrigation, b) street cleaning, c) fire fighting, d) other (specify)*	1	Implement greywater systems; optimize non-potable water usage wisely.	x	x	x
Water use from alternative sources	RESCCUE Cardoso et al. (2020) B-WaterSmart Silva et al. (2023)	Is being used for non-potable uses (e.g., a) irrigation, b) street cleaning, c) fire fighting, d) other (specify)? *Answer:* *major/moderate/low*	1	Explore diverse sources; reduce reliance, ensure sustainable water use.	x	x	x
Redundancy in Water supply sources	RESCCUE Cardoso et al. (2020)	Which types of water supply sources are being used? *Answer (identify):*	1	Establish backup sources; ensure resilience for water supply.		x	

Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
		a) surface water, b) groundwater (wells), c) rainwater, d) stormwater, e) reclaimed water, f) sea water, e) other (specify)					
Redundancy in Rainwater or stormwater storage capacity	Further information: RESCCUE Cardoso et al. (2020) B-WaterSmart Silva et al. (2023)	Is there a volume to store rainwater or stormwater? *Answer: major/moderate/minor/no*	1	Increase storage capacity; bolster resilience against fluctuating precipitation levels.		x	
Risk of Water supply interruption	Further information: RESCCUE Cardoso et al. (2020)	Water supply interruptions occurrence *Answer: major/moderate/minor*	2	Assess risks, diversify sources, ensure contingency plans for interruptions.		x	
Risk of Flooding	Further information: RESCCUE Cardoso et al. (2020)	Flooding incidents *Answer: major/moderate/minor*	1	Implement floodplain management; safeguard areas prone to inundation		x	
Risk of Wastewater discharges	Further information: RESCCUE Cardoso et al. (2020)	Wastewater discharges to ecosystem services *Answer: major/moderate/minor*	2	Monitor, regulate wastewater discharge; protect ecosystems from harmful contaminants effectively		x	x
Risk of Water quality compliance	Further information: RESCCUE Cardoso et al. (2020)	Is the water quality compliant with the legal requirements for its use? *Answer:* *yes/partially/no*	2	Ensure standards met; monitor, maintain water quality for environmental health.		x	x

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

Besides the aspects related to the sustainable and resilient water management of the ES, it is important to be aware that these areas potentially bring additional contributions to the urban resilience, as referred to before in the NBS description, as they contribute to the people's health and well-being, reduce Green House Gases Emissions, improve the air quality, regulate the noise, contribute to air cooling during heatwaves. Additionally, they may provide, e.g., a space for shelter, medical care, food production or storage, food supply, escape route, environmental education.

5.2.2 Solar radiation

The methodologies to be used in the characterisation of the Daylight and Solar Radiation (DSR) components of the outdoor environment, in the framework of the NATURELAB project, will be based on *in situ* characterisation and complementary analysis of the Experimental Sites. For an adequate *in situ* evaluation, a set of systematic measurement procedures (monitoring), adequate and feasible, is necessary, so that it can be possible to "extract" the relevant information from the measurements. To achieve this objective three different sets of measurements and evaluations will be proposed, constituting three different levels of monitoring: basic, standard and detailed. The monitoring protocols will allow the answer to thew following questions: i) what to measure (evaluate)? ii) when to measure? iii) how to measure? and iv) where to measure?

In general, the recommendations (SEEA, 2001) regarding the assessment of daylight and solar radiation are based on the measurement of the illuminance (in lux) and irradiance values (in W/m^2) at certain points of interest. However, the knowledge of these values alone may be insufficient for a complete characterization of the outdoor DSR analysis in the NATURELAB context. Thus, then it becomes evident that there is a need for a systematic set of measurements (which may be variable depending on the ES or objective to be achieved) that allow the most complete characterization possible of the outdoor DSR environment.

In the present section, a methodology for characterizing the outdoor daylight and solar radiation (DSR) conditions, based on in situ assessment and complementary analyses is presented. In Figure 9 an overview of the referred methodology is also illustrated.

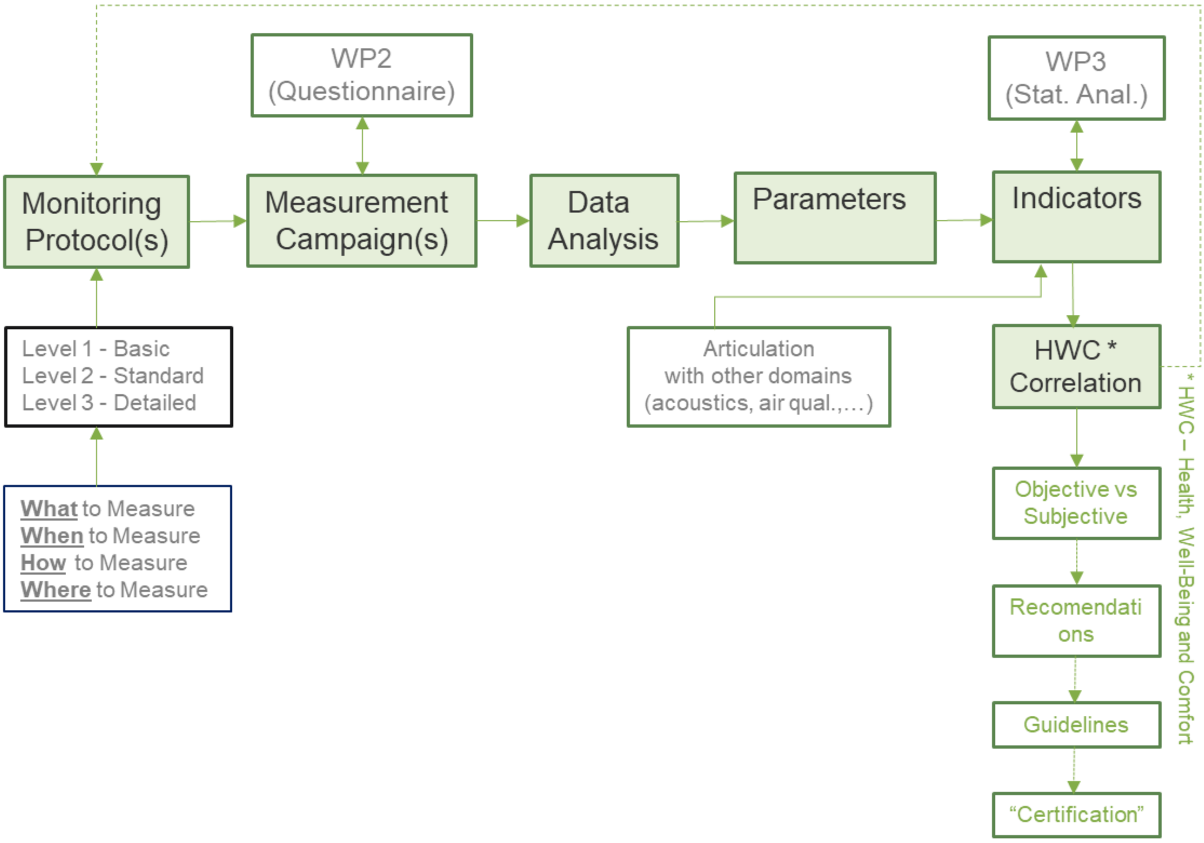


Figure 10. Methodology to be used in the characterisation of the Daylight and Solar Radiation (DSR) components of the outdoor environment in the context of the NATURELAB project

It is usual to define monitoring, in generic terms, as the set of observations, measurements and systematic collection of *in situ* data and their subsequent analysis (Santos, 2001). Figure 11. shows a diagram of a possible monitoring methodology for assessing outdoor daylight and solar radiation conditions.

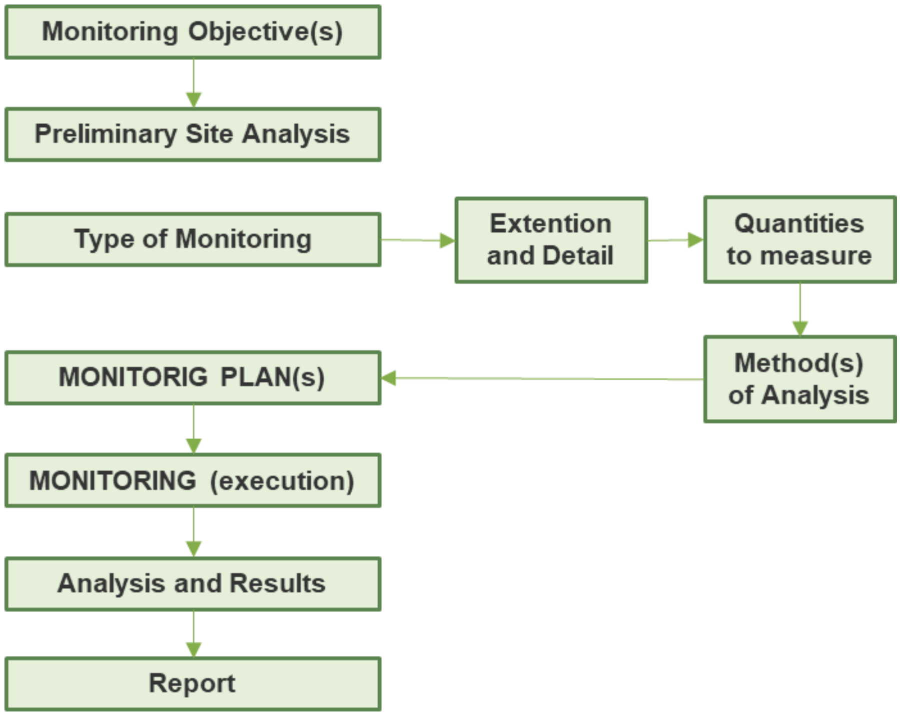


Figure 11. Schematic of a possible methodology for DSR outdoor monitoring

The pre-analysis phase is important in the collection of information necessary for the subsequent phases. The selection of the type of monitoring is essential for the effective success of the entire process, and should include the extent and detail, the parameters to be measured, and the methods of analysis. This information will then lead to the definition of the necessary equipment, allowing the establishment of a detailed and effective monitoring plan.

The type of outdoor DSR monitoring to be carried out will depend on the objectives to be achieved, the type and specific characteristics of the spaces being monitored, the type and characteristics of the visual tasks that are carried out and the resources available.

The first step in selecting the type of monitoring is to define its extent and detail. By extension and detail, it is intended to express the degree of "depth" (in space and time) of the monitoring. In general, it is not feasible to monitor all spaces of interest, so it is necessary to select samples of the spaces to be monitored. The samples should be representative of the whole area of interest for a particular site. Among the factors to be considered in its selection we can mention the following: (i) the different types of activities and corresponding visual tasks (reading, resting, exercising, etc.); the orientation and location of the areas to be monitored and the actual possibility of carrying out the measurements.

The methodology proposed in this document is based on the establishment of 3 levels of monitoring that aim to translate the "degree of depth" in terms of the spaces to be monitored, the monitoring periods and the quantities/parameters to be measured/evaluated, and in which the higher levels contain the procedures of the lower levels (Figure 12).

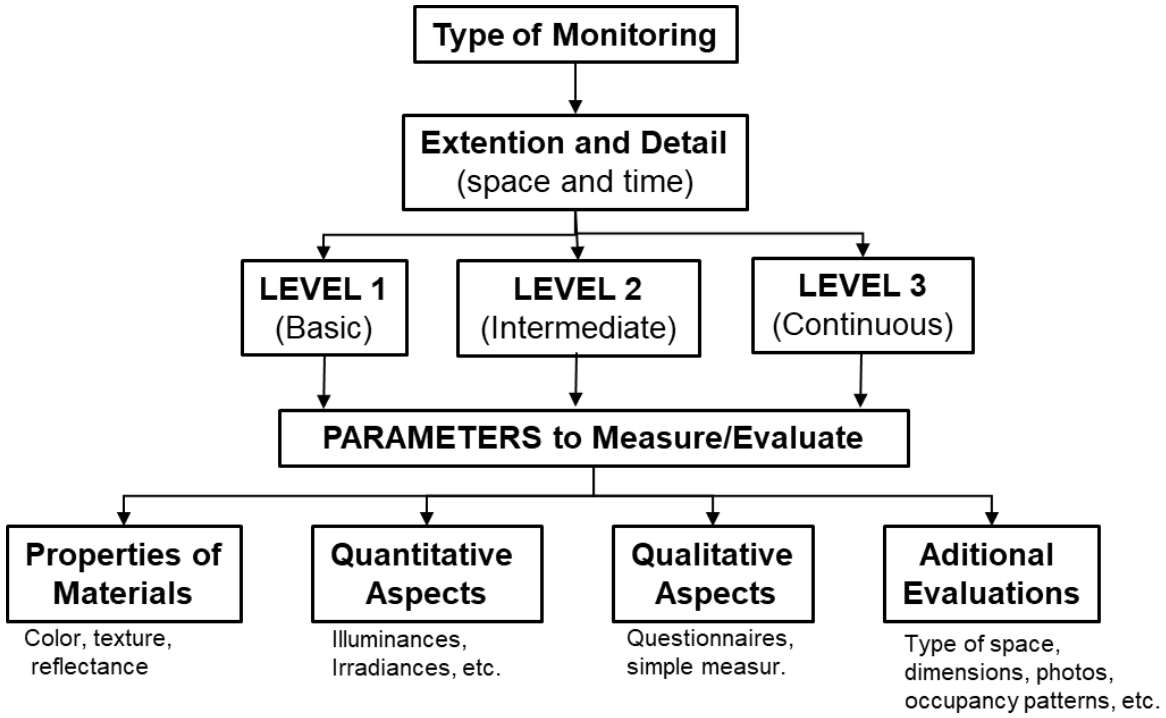


Figure 12. Schematic illustration of the monitoring type as a function of extent and detail (in space and time) and some of the parameters to be measured/evaluated

Level 1 is the basic level, and its purpose is to conduct a simple and expedite evaluation/assessment of the outdoor DSR conditions. Measurements should be made under clear sky conditions (ideal therapeutic conditions). The measurements/assessments should include: i) global Illuminances and irradiances at reference points and planes, ii) identifications of obstructions and views surrounding the measuring locations, iii) registration of individuals' opinions about the environmental conditions (DSR) available to them.

Level 2 is an intermediate level of monitoring and should allow the characterisation of the "average annual performance" of outdoor DSR. Level 2 shall include measurements under overcast conditions (worst case scenario) and under clear sky conditions (ideal therapeutic conditions). The monitoring should include the assessment of quantitative aspects (global and diffuse illuminances and irradiances, on vertical and horizontal planes, sunshine duration and qualitative aspects (general visual comfort assessment, existence of glaring situations, etc.). Level 2 monitoring should also include the identifications of obstructions and views surrounding the measuring locations, and the opinion of the individuals regarding the environmental conditions (DSR) available to them. The last line of the diagram of Figure 12 includes several other measurements/observations of interest for a Level 2 monitoring.

Level 3 is the most comprehensive level of monitoring and includes, in addition to the procedures of Level 1 and 2, the continuous monitoring of several parameters. However, monitoring the long-term outdoor DSR conditions can be time consuming and complex and, in most cases, impractical, due the difficulty of allocating the necessary equipment and human resources. Level 3 aims for a rigorous characterization over a long period of time (usually never less than 9 months) of the outdoor DSR conditions. In practice, however, it is usually replaced by intermediate-level monitoring complemented with additional measurements/assessments.

The indicators to be proposed will be divided into two groups: i) quantitative indicators and ii) qualitative indicators. The former will be particularly useful in the development of forecasting statistical models in the domains of DSR and the latter will be a set of more simple indicators useful for direct application.

Possible quantitative key indicators: i) preferred levels of illuminance; ii) preferred levels of irradiances; iii) threshold of "healing" illuminance and irradiance, among other still to be developed.

Possible qualitative key indicators: i) preferred outdoor luminous conditions, ii) level of satisfaction with the outdoor conditions, iii) improvement in perceived health conditions, iv) improvement in perceived comfort and well-being conditions, among others.

Naturally, most of the key indicators will be derived from the measurements, assessments and observations at the experimental sites and, therefore, the previously referred indicators are provisional.

Table 9 presents the indicators related to daylight and solar radiation.

Table 9. Indicators related to the assessment of exterior Daylight and Solar Radiation (DSR)

Indicator	Description	Metrics	*	Recommendation	Potential Relevance **		
					T1	T2	T3
QUANTITATIVE							
- preferred levels of illuminance - preferred levels of irradiances - threshold of "healing" illuminance and irradiance	Fundamental quantities in the domains of DSR that are central for the characterization of the outdoor luminous environment	Measured illuminances and irradiances at reference points and planes (Santos, 2011) Measured illuminances and irradiances at reference points and planes (Santos, 2001) Range of "useful" illuminances and irradiances (Santos, 2012)	1 2 2	Contribution of DSR for health, comfort and well-being will be assessed and resulting recommendations and best-practice will include these findings.	x	x	x
QUALITATIVE							
- preferred outdoor luminous conditions - level of satisfaction with the outdoor conditions - improvement in perceived health conditions - improvement in perceived comfort and well-being conditions	Simple quantities derived from questionnaires and validated by measurements in the domains of DSR	(To be defined)	2 2 2 2	Contribution of DSR for health, comfort and well-being will be assessed by using a combination of measurements and statistical analysis. The information obtained will be scaled-down in order to obtain simple quantitative indicators and metrics.	x	x	x

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.

** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

5.2.3 Climate region

Climate regions are a typical reference to large geographic areas with relatively consistent patterns of temperature, precipitation, and atmospheric conditions for a certain period. These climate regions may influence local ecosystems, weather, and human activities. For the classification of climate regions, the Köppen classification is one of the most widely used systems for categorizing climate regions. The most relevant climate regions are (e.g. Peel et al. 2007):

Tropical climate Characterized by high temperatures throughout the year, with low temperature range between seasons and abundant rainfall.

Arid climate Characterized by low precipitation and rather dry conditions with extreme temperature variations during the day.

Temperate Characterized by moderate temperatures with distinct seasons. Winters are cool to cold, and summers are warm to hot. There is a balanced distribution of rainfall.

Continental Characterized by large temperature variations between seasons, with cold winters and hot summers. Precipitation is relatively evenly distributed.

Polar Characterized by extremely cold temperatures, especially in winter. Precipitation is generally low, and the polar regions experience long periods of darkness in winter and continuous daylight in summer.

Highland Characterized by varied climate depending on elevation. As you go higher in altitude, temperatures decrease, and precipitation may increase.

These climate classifications provide a broad overview, and variations and subcategories exist within each. The specific geography and topography of an area, as well as its proximity to oceans or other water bodies, play a significant role in determining the local climate.

Concerning the characterization of the Experimental Sites of NATURELAB, the most relevant features related to climate are temperature and precipitation patterns.

Climate regions are often defined by their temperature characteristics, including the average temperature range, seasonal variations, and extremes. The distance from the equator and the influence of ocean currents can significantly impact temperature patterns.

The amount and distribution of precipitation and other forms of precipitation play a crucial role in climate classification. Areas with consistent and high precipitation may fall into tropical or temperate climates, while regions with limited rainfall might be classified as arid.

For context characterization related to climate context Cardoso, et al. (2020) proposed in the RESCCUE project a large set of indicators such as:

1. Altitude (range)
2. Climate type
3. Temperature: Annual average; Average of the wettest month; Average in the driest month*
4. Rainfall: Annual average; Average of the wettest month; Average in the driest month*
5. Relative air humidity: Annual average; Average of the wettest month; Average in the driest month*
6. Snowfall: Annual average; Average of the month with highest snowfall; Average duration of snow cover; Average snowmelt water equivalent*
7. Wind: Average yearly velocity; Average velocity of the month with the strongest wind; Average for the calmest month*
8. Sea level*: Annual average maximum tidal amplitude; Annual average local mean sea level*
9. Frequency and average duration of heat waves*
10. Frequency and average duration of cold waves*
11. Water exploitation index) of the area

*The period considered for the average must be specified e.g. [1971 to year 2001]

This large set of indicators is rather complete but for the NATURELAB objective and to comply with an easy classification a new set of indicators was identified, related to the climate region, based on the state of the art, previous experiences, including developments from European projects. The set of indicators is presented in Table 10, including information whether each indicator is mandatory or optional, depending on the type of nature space (i.e., the NATURELAB three classes), as well as which points of view are addressed.

It is known that in distinct regions and cultures the population is adapted to the local climate and there are distinct perspectives on what is the “good” climate for being outside. Therefore, if there are no health or well-being specific needs, most of the population should be able to deal with the local climate. Other situations may take place, for example, for the purposes of implementing therapeutic programmes (to be addressed under WP2) it is necessary that the responsible/facilitator ensures that the temperature, rainfall and wind do not conflict with participants’ comfort and well-being.

Along the execution of NATURELAB, data analysis will allow understanding the value and need of recommendation regarding these indicators.

Table 10. Indicators related to the climate context

Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance		
					T1	T2	T3
Temperature	The temperature characterization must contain the annual average, the average of the hottest and coldest month	Must be obtained with historical time data series available from the meteorological services	1	Temperature, rainfall and wind should not conflict with people's comfort, well-being and health while being outside.	x	x	x
Rainfall	Must contain annual average; average of the wettest month; average in the driest month	Must be obtained with historical time data series available from the meteorological services	1		x	x	x
Wind	Must contain annual average velocity and monthly averages for the calmest and strongest wind	Must be obtained with historical time data series available from the meteorological services	1		x	x	x

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

5.3 Air quality

The Directive 2008/50/EC sets air quality assessment and air quality management, with the purpose of ensuring that all Member States assess ambient air pollution, at all zones and agglomerations, and also considering transboundary issues. All the framework is based on the need of managing sources of pollution, and ensuring that exposure, even in the long term (yearly basis) is below acceptable guidelines and thresholds.

The World Health Organisation (WHO), since 1987, has been responsible for proposing health-based air quality guidelines, meant to support governments and civil society to reduce human exposure to air pollution and its adverse effects. The WHO air quality guidelines prior to the most recent (from 2021) were published in 2006 (WHO, 2021). Noteworthy, the Directive 2008/50/EC took into account the WHO air quality guidelines that were available at the time of publication of the Directive.

As mentioned in section 3.2.4, NATURELAB selected already three representative air quality parameters to be assessed at the locations where the therapeutic programmes will take place, namely: NO_2; PM_{10} and $PM_{2.5}$. For the purposes of NATURELAB it is chosen to use the WHO's air quality standards. These guidelines are not only updated, as are more aligned with the motivation and purposes of the indicators to be established under the present deliverable than the referred Directive.

Table 11 reports the WHO most recent standards for these parameters, and also the previous one, dated from 2005. It is observed from the comparison of the 2005 and the 2021 guidelines that the updates in research and practice have pushed the concentration levels to reduced values.

Table 11. Ambient air quality standards based on WHO (2021)

Pollutant	Averaging time	WHO 2005 air quality standards	WHO 2021 air quality guidelines (AQG)
Nitrogen Dioxide (NO_2)	24h[a)] Annual	[b)] 40 µg/m^3	25 µg/m^3 10 µg/m^3
Particulate Matter: PM_{10}	24h[a)] Annual	50 µg/m^3 20 µg/m^3	45 µg/m^3 15 µg/m^3
Particulate Matter: $PM_{2.5}$	24h[a)] Annual	25 µg/m^3 10 µg/m^3	15 µg/m^3 15 µg/m^3

a) 99th percentile, i.e., 3-4 exceedance days per year.

b) NO_2 standard for 24h was not established. A 1h-average of 200 µg/m^3 was proposed.

In terms of proposed methodology, it is suggested to use a portable equipment that fits the purpose of a wide use by stakeholders in the future. This approach also supports:

- Guaranteeing having a common methodology across the experimental sites, so that the data analysis (under WP3) will be comparable;

- Establishing, for each ES, a benchmark based on local measures with sensors. This characterization will support the implementation of the therapeutic programmes (under WP2), namely regarding the selection of participants, the time of the day, and the paths/ locations within the ES most suited for the activities, taking into account air quality. For instance, if an ES has air quality issues, participants with respiratory concerns should not be taken to this location.

Local air quality monitoring using low-cost sensors have been successfully used by Connolly et al. (2022) to evaluate outdoor and indoor $PM_{2.5}$ levels in a community in California (USA). As referred by the authors, technological advancements have been able to provide air quality sensors that support expanded air monitoring in a more affordable and portable direction.

The AEROQUAL equipment was selected due to its suitability for the purposes of NATURELAB. According to Delgado-Saborit (2012), who used this exact equipment in his research: "*The main strength of the wearable sensor technology is the increased resolution of these instruments, which allows for the identification of short-term or peak exposures. These readings coupled with additional spatially referenced information, e.g. GPS data or diary information (this case) reveal the location and activities most relevant to exposure. This is important as contaminant sources, strengths and exposures vary throughout the day as individuals move through different environments. Accurate assessment of instantaneous peak personal exposure allows researchers to investigate associations between acute exposures and health effects*."

Below there is a first proposal of a simple methodological approach steps for measuring local air quality data by no experts, at the experimental sites (ES) of NATURELAB. This information is to be used as a site-specific characteristic, and not intended to describe the local air quality. Moreover, the methods below are to be tested in the practice, at the eight NATURELAB ES that are committed to these measurements[4].

1. Selection of 2 to 4 different locations at each site where the air quality parameters will be measured. These locations should represent places with equally expected influence of

[4] Although in the scope of another WP1 task, namely T1.2, it is worth mentioning that the six experimental sites in Portugal already started using the AEROQUAL sensors to measure the air quality, and the methodology and equipment revealed to be appropriated.

pollution sources (e.g., near streets or roads) and sites expected to be "cleaner", based on an overview of pollution sources and dominant wind. The GPS coordinates of these locations must be included in the data collection. The measurement height should be approximately 1.50 m above ground level to guarantee equivalent measurements.

2. Measurements: A plan for the measurements at each chosen location must be established, based on the management of the existing equipment. Information on the wind direction and intensity, temperature and humidity during the monitoring days (e.g., using available and reliable weather websites) should be ensured. At each location/site, each parameter should be measured for 30 minutes, aiming at getting the following set of data:
    a. Each location from each ES should be characterised by at least 5 measurements taken in 4 different days (i.e., 2 of the 5 measurements can be obtained in the same day if two distinct timeslots are selected, one in the morning and the second in the afternoon);
    b. Observation and record of the variability of the parameter during the 30 min of measurement (e.g.: value raised when the wind got more intense; when cars passed by, etc.).

All data obtained must be summarized, in order to characterize each ES in terms of average concentrations and extreme (minimum and maximum) of NO_2, PM_{10}, and $PM_{2.5}$.

Besides this overall characterisation, and with the purpose of evaluation the impact on health and well-being of exposure to these air pollutant indicators, for a couple of hours, these variables must be measured during the implementation of the programmes. NATURELAB specific spreadsheets will be established to harmonise data collection (within WP1) and data treatment (within WP3).

Table 12. Indicators of environmental sustainability and risks

Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
Air quality	Nitrogen Dioxide: NO_2	10 µg/m³ (24h average [a]) (WHO, 2021)	1/2	For level 1: Use public or private air quality data sets provided by reliable organisations. For level 2: Use a portable sensor that is properly calibrated. Measurements should be georeferenciated, and associated to wind (direction and speed), humidity and temperature records.	x	x	x
	Particulate Matter: PM_{10} $PM_{2.5}$	15 µg/m³ (24h average [a]) 15 µg/m³ (24h average [a]) (WHO, 2021)	1/2				

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces
[a] *99th percentile, i.e., 3-4 exceedance days per year.

5.4 Noise

To evaluate the environment sound in nature settings to be used for therapeutic activities, which is the target of NATURELAB, in addition to measuring sound levels, data about how people perceive this environment should be collected, since this provides information on the context in which the sounds are heard. Consequently, a set of qualitative and quantitative indicators is proposed hereafter.

Qualitative Indicators:

For each sound source perceived during a therapeutic activity in nature, a subjective assessment should be made, preferably using standardized questions and scales (five-point Likert scale). Sound sources should be categorized into natural sounds, sounds from humans, and technological noise. Figure 13 to Figure 15 list the questions to be asked and the associated scale following ISO/TS 12913-2 standard (ISO, 2018).

To what extent do you presently hear the following four types of sounds?

Please tick off one response alternative per type of sound

	Not at all	A little	Moderate	A lot	Dominates completely
Traffic noise (e.g., cars, buses, trains, air planes)	☐	☐	☐	☐	☐
Other noise (e.g., sirens, construction, industry, loading of goods)	☐	☐	☐	☐	☐
Sounds from human beings (e.g., conversation, laughter, children at play, footsteps)	☐	☐	☐	☐	☐
Natural sounds (e.g., singing birds, flowing water, wind in vegetation)	☐	☐	☐	☐	☐

Figure 13. Qualitative assessment of sound source identification (source ISO/TS 12913-2)

Overall, how would you describe the present surrounding sound environment?

Very good	Good	Neither good, nor bad	Bad	Very bad
☐	☐	☐	☐	☐

Figure 14. Qualitative assessment of the surrounding sound environment (source ISO/TS 12913-2)

Overall, to what extent is the present surrounding sound environment appropriate to the present place?

Not at all	Slightly	Moderately	Very	Perfectly
☐	☐	☐	☐	☐

Figure 15. Qualitative assessment of the appropriateness of the surrounding sound environment (source ISO/TS 12913-2)

The last qualitative indicator is related to the perception of the sound environment, considering the eight affective perceptive qualities indicated in the soundscapes standard (ISO/TS 12913-2).

Quantitative indicators:

The acoustic environment is commonly characterized through the established acoustic metrics, such as the equivalent energy level (e.g., L_{eq}) and the related statistical levels (i.e., levels exceeded for a given percentage of time, concerning the acquisition period, Lx), the level variability over time (e.g., Lx–L100−x), and the proportion of low-frequency sounds (e.g., LC–LA). These classical indicators shall be measured according to ISO 1996-2 (ISO, 2017).

For the intermediary and higher-level monitoring, psychoacoustic indicators like loudness, sharpness, roughness, and fluctuation strength (and time-variant indicators) will be used. Loudness is considered to be the most important psychoacoustic quantity describing the perception of volume in detail. Measurements of loudness should be made according to ISO 532-3 (ISO, 2023). The psychoacoustic parameter sharpness described the timbre of sounds with special emphasis on high-frequency noise components. While fluctuation strength and roughness model the perception of modulations, a maximum of fluctuation strength is obtained at a modulation frequency of 4Hz instead of 70Hz modulation frequency for a maximum of roughness. Also, the spectral content of the acoustical environment should be registered through the measurement of third-octave levels or spectrograms. The main indicators proposed for the characterization of the acoustic environment are present in Table 13.

The basic level for the assessment of the acoustical environment comprises:

- Collection of existing data about the sound environment, such as noise maps and action plan published for the location;
- A qualitative analysis of the acoustical environment which should be made in each location, considering sound source identification, surrounding sound environment, and assessment of the appropriateness of the surrounding sound environment. For this analysis the questions and scales presented in Figure 13 to Figure 15 should be used.

Table 13. Main quantitative indicators for the characterization of acoustic environment

Parameter	Metrics	Reference	Monitoring type
Sound pressure level	L_{Aeq}, L_{Ceq}, $L_{AF10,T}$; $L_{AF90,T}$; $L_{AF50,T}$;	ISO 1996-1	Intermediary and high level
Sound pressure level	Third octave analysis or spectrograms	ISO 1996-1	Intermediary and high level
Loudness (time variant loudness)	N, N_{10}, N_{90}, N_{50}	ISO 532-1	High level
Sharpness (time variant sharpness)	S, S_5, S_{95}, $S_{average}$	DIN 45692	High level
Roughness	R	–	High level
Fluctuation strength	F	–	High level

The intermediate level for the assessment of the acoustical environment comprises:

- Completing the steps for the basic level;
- Collection of acoustical data (sound levels) and audio recordings at the selected locations in the nature setting where the therapeutic activity is planned to take place. The measurements must comply with the ISO 1996 standards series (ISO 2017), and values of temperature, relative humidity, wind speed, and direction must also be recorded. The duration of each measurement will be related to the percentage of technological sources present. For natural sound sources, measurements should be made for the different seasons of the year, in order to characterize variations that usually take place.

The high level for the assessment of the acoustical environment comprises:

- Completing the steps for the basic and intermediate level;
- For each measuring location, binaural audio recordings (30s length) should be taken simultaneously with the perceptual questionnaires about the eight perceptive affective qualities by a qualified person.

Table 14 shows a selection of the indicators related to the sound perception.

Table 14. Indicators related sound perception

Indicator	Description	Metrics	*	Recommendation	Potential Relevance**		
					T1	T2	T3
QUANTITATIVE							
- noise maps and action plans information	Fundamental quantities in the acoustical domain for environmental sounds characterization	L_{den} (day-evening-night noise indicator) and L_n (night noise indicator)	1	Contribution of the acoustical environment for health, comfort and well-being will be assessed and resulting recommendations and best-practice will include these findings.	x	x	x
- sound pressure level		L_{Aeq}, L_{Ceq}, $L_{AF10,T}$;$L_{AF90,T}$; $L_{AF50,T}$; third octave analysis or spectrograms	3		x	x	x
- psychoacoustical indicators	Quantities related with the auditory system perception	Loudness, Sharpness, Roughness, and Fluctuation Strength (and time variant indicators)	3		x	x	x
QUALITATIVE							
- sound source identification	Simple quantities derived from questionnaires and validated by measurements in the domain of sound perception	(To be defined)	2	Contribution of the acoustical environment for health, comfort and well-being will be assessed by combination of measurements and statistical analysis.	x	x	x
- surrounding sound environment			2				
- appropriateness of the surrounding sound environment			2				
- perceptual attributes questionnaires			3				

Notes: * Scale for the metrics: Level 1: Very easy to obtain; Level 2: Needs gathering data and/or processing data and Level 3: Needs measurements with complex equipment or difficult to obtain.
** T1 - Forests and protected areas; T2 - Urban parks and T3 - Horticulture and gardening spaces

Chapter 6

Final remarks

6. Final remarks

This Deliverable provides a framework of key indicators of green space characteristics that have a high potential to be relevant regarding their impact on health and well-being.

The key indicators comprise the characteristics of a nature site, and its context, including not only the variables that can have an effect on health and well-being but also the requests that ensure people can have comfort and their basic needs attended to. This holistic strategy supported the establishment of a framework of indicators that go beyond health and well-being, encompassing the sustainability and the resilience of the sites and the population.

To promote a systematic analysis, the present work established an approach based on three domains each one including distinct dimensions. The indicators for each dimension were selected and proposed after an analysis based on the know-how, state-of-the-art, law and international guidelines. This approach is illustrated in Figure 16.

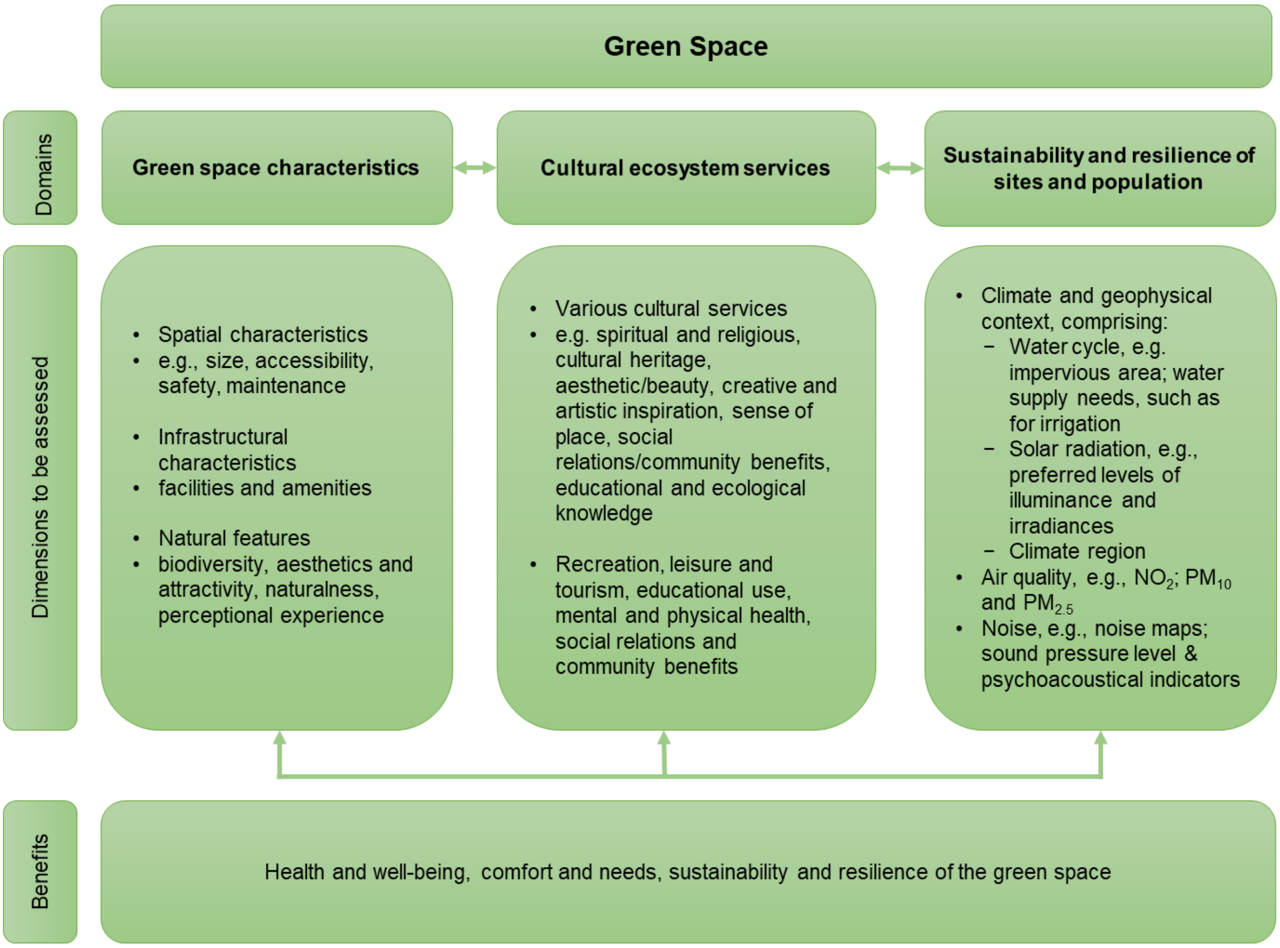


Figure 16. NATURELAB framework of proposed domains and dimensions to be assessed in the scope of the characterization of different types of nature spaces

Taking into account the broad scope of the research topic, within Chapter 3, a summary of relevant information was presented. This allowed to combine the scientific and practical background of the authors with state-of-the art knowledge from the literature as well as gaining new insights into the interconnections of different scientific fields with health, well-being, and the sustainability and resilience of communities. Research on the indicators will be conducted under NATURELAB, in order to identify characteristics of nature that have an impact on human health and well-being, and to derive recommendations for green space planning and management.

Despite studies showing positive associations between health and well-being and exposure to green spaces, there is a need for more robust scientific evidence identifying mediators of these relationships. To address this gap, relevant indicators regarding green space characteristics with a potential to influence health and well-being were identified in Chapter 4. Additionally, this chapter addresses the cultural ecosystem services that capture a diversity of benefits derived from human interactions with nature.

Sustainable environments where communities live should promote cleaner air and water, reducing exposure of humans and nature to pollutants. Reducing environmental hazards and ensuring water management strategies in nature settings are pathways to increase biodiversity, greenness, mitigate and adapt to climate changes, thus contributing to sustainable, inclusive and resilient living spaces and communities. For this reason, Chapter 5 establishes a set of indicators related to the sustainability and resilience of the sites and the population.

This deliverable will be applied, tested and validated through T1.2 that will support all ES to characterize the domains and dimensions presented in Table 2. In WP3, namely in the activities from T3.2 and T3.3, qualitative and quantitative assessment of causal relationship between the exposure of green sites, with specific features, and the impact on health and well-being of populations and of the participants at the NATURELAB programmes.

It is understood that D1.1 is a thorough and comprehensive report, aiming at providing a wide scope of indicators. During its application, test and validation, a clearer awareness of the intrinsic value of each indicator, the easiness and effectiveness of measuring or establishing it, as well as the need of monitoring and updating each indicator will be recognised.

Noteworthy that although having established three levels of easiness of measuring or founding the indicators, it is acknowledged that some methodologies proposed for level 3 (Needs measurements with complex equipment and/or difficult to obtain) demand specific expertise and equipment, and may not be a tool for general use by stakeholders. Nevertheless, they will sustain the research on the impact of the indicator and NATURELAB will also study if simpler indicators can provide similar information. For example, solar radiation will be quantitatively measured by specific equipment, and will also be assessed through qualitative tools (e.g. questionnaires).

The indicators proposed in this D1.1 represent a sound portfolio of characteristics of nature settings that play a role in all the three dimensions. They will be tested and validated in T1.2 and the results from these activities will support the selection of the final set of indicators, feeding in the development and content of the following project deliverables:

- D1.3 – Portfolio for the classification of the therapeutic potential of nature spaces (due M42);
- D1.5 – Recommendations for the selection of nature spaces for therapeutic uses (due M50);
- D1.6 – Guidelines for analysing the health benefits of green areas conform the requirements of natural capital accounting (due M54);
- D1.9 – Guidelines for the creation and management of private and public healing gardens and horticulture and gardening spaces (due M54).

Chapter 7

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