LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL

NATURELAB

Study of indicators to assess nature spaces potential to support communities' resilience and sustainability

REPORT 97/**2025 – DHA/NRE**

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NATURELAB – Nature-based interventions for improving health and well-being

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Title

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Study of indicators to assess nature spaces potential to support communities' resilience and sustainability

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NATURELAB – STUDY OF INDICATORS TO ASSESS NATURE SPACES POTENTIAL TO SUPPORT COMMUNITIES' RESILIENCE AND SUSTAINABILITY

Abstract

NATURELAB – Nature-Based Interventions for Improving Health and Well-Being is an European funded project coordinated by LNEC, aiming to enhance the benefits of nature spaces for health and well-being. It is structured around six working packages, with activities implemented at 15 Experimental Sites (ES) across Portugal, Greece, the Netherlands, Germany, and Peru. Besides the coordination, LNEC co-leads WP1, which focuses on assessing nature spaces potential to contribute to healthy and resilient communities. Indicators being developed to assess this potential include environmental, infrastructure, and cultural ecosystem services. Specifically, the indicators related to the sustainability and resilience of sites and their populations are divided into four main areas: (i) Exterior daylight and solar radiation; (ii) Environmental sound; (iii) Air quality and (iv) Sustainable and climate resilient water management.

The project focuses on assessing and comparing three distinct types of nature spaces, (i) Forests and protected areas; (ii) Urban parks and healing gardens and (iii) Horticulture and gardening spaces. The six experimental sites located in Portuguese encompass all three types.

This document provides a comprehensive overview of the progress and challenges in monitoring key environmental variables. The report is organised into sections dealing with the four themes that under WP1 have direct contributions from LNEC, namely: i) Assessment of Exterior daylight and solar radiation; ii) Characterisation of the environmental sound; iii) Air quality characterisation and iv) Sustainable and climate resilient water management. A preliminary review of the state-of-the-art is included, alongside with initial results from field monitoring.

The report content responds to its objectives, allowing a clearer perception of the status and challenges of the work at the NATURELAB experimental sites in Portugal, particularly in monitoring more complex variables such as daylight and solar radiation, environmental sound and air quality. Air quality monitoring results confirm that no significant pollution issues hinder the potential of the six experimental sites to promote health and well-being. NATURELAB's indicators for sustainable and climate-resilient water management are expected to be effectively applied across the Portuguese sites and beyond.

On the other hand, it is clear that the evaluation of daylight and solar radiation, as well as the assessment of environmental sound are challenging and require fine tuning monitoring methodologies and approaches, which will be done in the ongoing and future steps.

Keywords: Sustainability / Natural spaces / Well-being / Indicators / Resilience

NATURELAB – ESTUDO DE INDICADORES PARA AVALIAR O POTENCIAL DE ESPAÇOS NATURAIS PARA APOIAR A RESILIÊNCIA E SUSTENTABILIDADE DE COMUNIDADES

Resumo

O NATURELAB – *Nature-Based Interventions for Improving Health and Well-Being* é um projeto europeu coordenado pelo LNEC, com o objetivo de potenciar os benefícios dos espaços naturais para a saúde e o bem-estar. O projeto está estruturado em seis *Work Packages* (WP), com atividades implementadas em 15 locais experimentais em Portugal, Grécia, Países Baixos, Alemanha e Perú. Para além da coordenação, o LNEC co-lidera o WP1, que se centra na avaliação do potencial dos espaços naturais para contribuir para comunidades saudáveis e resilientes. Os indicadores que estão a ser desenvolvidos para avaliar este potencial incluem aspetos ambientais, infraestruturais e de serviços de ecossistemas. Especificamente, os indicadores relacionados com a sustentabilidade e a resiliência de territórios e das suas populações estão divididos em quatro áreas principais: (i) Iluminação exterior e radiação solar; (ii) Contexto sónico; (iii) Qualidade do ar e (iv) Gestão sustentável da água e resiliência climática.

O projeto centra-se na avaliação e comparação de três tipos distintos de espaços naturais, (i) Florestas e áreas protegidas; (ii) Parques urbanos e jardins terapêuticos e (iii) Espaços de horticultura e jardinagem. Os seis locais experimentais localizados em Portugal abrangem os três tipos.

Este documento fornece uma visão abrangente dos progressos e desafios na monitorização de variáveis ambientais chave. O relatório está organizado em secções que abordam os quatro temas que, no âmbito do WP1, têm contribuições diretas do LNEC, nomeadamente: i) Avaliação das condições de iluminação natural e da Radiação Solar; ii) Caraterização do ambiente sonoro; iii) Caracterização da qualidade do ar e iv) Gestão sustentável e resiliente da água. Inclui-se uma revisão preliminar do estado da arte, a par dos resultados iniciais da monitorização no terreno.

O conteúdo do relatório permite uma perceção mais clara do estado e dos desafios do trabalho nos locais experimentais do NATURELAB em Portugal, particularmente na monitorização de variáveis mais complexas como a luz do dia e a radiação solar, o ambiente sonoro e a qualidade do ar. Os resultados da monitorização da qualidade do ar confirmam que não haverá problemas significativos de poluição que afetem o potencial dos seis sítios experimentais para promover a saúde e o bem-estar. Espera-se que os indicadores do NATURELAB para a gestão sustentável e resiliente da água sejam efetivamente aplicados nos sítios portugueses e não só. Por outro lado, ficou patente que a avaliação da luz do dia e da radiação solar, bem como a avaliação do ambiente sonoro são desafiantes e requerem um ajuste fino das metodologias e abordagens de monitorização, o que será feito nas etapas em curso e futuras.

Palavras-chave: Sustentabilidade / Espaços naturais / Bem-estar / Indicadores / Resiliência

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1 | Introduction

NATURELAB – *Nature-Based Interventions for Improving Health and Well-Being* is a research and innovation project, coordinated by LNEC and funded by EU under the Horizon Europe Programme. It has an integrative and innovative approach to contribute to resilient communities with a focus on health and care prevention. The project aims at enhancing and expanding 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. NATURELAB implementation is based on an inter- and transdisciplinary approach, and the partnership brings multiple and relevant scientific expertise, regarding sustainable cities and communities, Nature-based Solutions (NBS), climate resilience, ecosystems services, health, and health care, as well as social and behavioural sciences. Research activities were established to increase the recognition of green and blue spaces as care providers, by investigating the benefits of nature-based therapies (NBT) in well-being promotion, and to support health prevention and rehabilitation.

The project workplan is organised around six Working Packages (WP) and all activities will be implemented at 15 Experimental Sites (ES) across Portugal, Greece, the Netherlands, Germany, and Peru.

LNEC takes a key role by *leading WP6 – Coordination and management*, and also in co-leading *WP1 – Assessment and selection of green spaces with potential for improving health and well-being*.

WP1 runs during the entire duration of the project (from June 2023 until November 2027) and has four tasks. This WP aims to establish and validate a portfolio of key indicators and guidelines to characterise, design, protect and manage different types of nature spaces, promoting both environmental sustainability and NBT. The main objectives are as follows:

- Establish a validated portfolio of key indicators of natural conditions (*e.g.*, topography, biodiversity, water systems, air quality, solar radiation, noise/sound levels) and infrastructure characteristics (*e.g.*, pathways, benches) 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 therapeutic blue and green spaces;
- Support the integration of Nature-based therapies health cost benefits into the protection, rehabilitation, and enhancement of nature areas.

LNEC is responsible for specific research under WP1, regarding the characterisation of i) Exterior daylight and solar radiation environment; ii) Environmental sound and iii) Soundscape characterisation, which takes place at the six experimental sites located in Portugal, namely in the region of Sintra (four sites) and of Esposende (two sites). Site-specific assessment methodologies were established and are being tested for this purpose, and equipment purchased by the project is being used. In the future, the sites' physical/psychoacoustic, and soundscape indicators, as well as the classification of the daylight and solar radiation, will contribute to evaluate the role and significance of these data.

LNEC also provided directions for air quality monitoring at these six ES locations in Portugal and to others in Peru (three sites) and the Netherlands (one site). All these sites have different contexts, characteristics, and levels of exposure to traffic, an urban relevant source of pollution. Ensuring the sustainability and resilience of the sites and the population comprise climate and geophysical dimensions, including the management of the water cycle, which is likewise under the responsibility of LNEC.

NATURELAB has seven committed deliverables under WP1, and the first one was submitted by January 2024: *Framework of key indicators to assess and categorize different types of nature spaces and their impact for therapeutic indications* (deliverable D1.1). This document presented a framework of indicators designed to evaluate the inherent characteristics of natural spaces and their contextual variables, focusing on aspects that influence health and well-being and promote environmental sustainability. Since the project focuses on assessing and comparing three distinct types of nature spaces, (i) Forests and protected areas; (ii) Urban parks and healing gardens and (iii) Horticulture and gardening spaces, the framework of indicators differentiates these three categories, whenever appropriate.

The proposed indicators comprise attributes of natural spaces and their settings, including variables that directly impact health and well-being (including daylight, sound levels, and air quality) and elements ensuring comfort and accessibility. Additionally, the framework integrates considerations of territorial sustainability and resilience to extreme climate events, such as intense precipitation and heatwaves.

Two critical aspects were recognized and addressed in the D1.1 framework:

- <u>Complexity of indicator determination, calculation, or measurement:</u> Some indicators, such as size or area, are straightforward to measure. Others, like noise levels, may require specialized equipment and technical expertise.
- <u>Relevance of each indicator to the specific natural contexts addressed by NATURELAB</u>: The project ES include forests, protected areas, urban parks, and horticultural or gardening spaces. However, not all indicators carry the same level of significance or applicability across these contexts. The framework assesses the importance and relevance of each indicator based on the specific nature context. For instance, the relevance of size varies significantly depending on whether it refers to a forest, an urban park, or a horticultural/gardening space, reflecting the distinct characteristics and needs of each site.

To account for these factors, the proposed indicators were categorized on a three-level scale based on the complexity of their determination (Level 1: Very easy to obtain; Level 2: Needs some calculation/data collection; and, Level 3: Needs measurements with specific equipment), as well as the importance or requests for each of the three types of nature contexts.

D1.1 was due at an early stage of the project (month 8) and included a framework based on literature review, previous research and expertise of the team. A coming deliverable advancing results of monitoring and validation of applications of D1.1 to the experimental sites, is due in M42. Therefore, it was considered most advantageous to elaborate this report, focused on monitoring outcomes from the work under LNEC's responsibility at the six experimental sites in Portugal, allowing to organise and present the information already gathered. Moreover, a preliminary review of the state-of-the-art is included, allowing to set the scene and support directions to improve methodologies and effectively achieve the expected outcomes.

The contributions to this report come from the Department of Hydraulics and Environment (DHA) and the Buildings Department (DED), and although issued in February 2025, the preparation of the document, in terms of structure, content, and initial writing started back in 2024.

2 | Objective

The primary goal of this report was already established in the Introduction. This document is focused on compiling information, including state-of-the art overview, establishment of the indicators (presented under D1.1), monitoring methodologies and first results and outcomes from the work under LNEC's responsibility in WP1. The monitoring results herein presented are the ones obtained at the six experimental sites in Portugal. This document allows organising, presenting and making a first assessment of the data gathered so far.

This report is organised into sections dealing with the four themes that under WP1 have direct contributions from LNEC, namely:

- Assessment of exterior daylight and solar radiation;
- Characterisation of the environmental sound;
- Air quality characterisation;
- Sustainable and climate resilient water management.

An initial section was needed, to give an overview of the characteristics of the six experimental sites (ES). It was also considered interesting to include information gathered by the ES coordinators, namely Rio Neiva (RN) and Câmara Municipal de Sintra (CMS), during the period from August to November 2024, and inputted through the NATURELAB App.

The data included in the section concerning *Air quality characterisation* at the ES was provided by the ES coordinators (Rn and CMS) to LNEC, as an Microsoft Excel spreadsheet, in April and May 2024. The data was collected from July to October 2023, launched the use the AEROQUAL equipment and provided a first evaluation of air quality.

3 | The six experimental sites in Portugal

3.1 Global characterisation and location

As mentioned in the Introduction, the scope of the NATURELAB approach (see D1.1 for further details), is based on three different types of spaces: T1 – Forests and protected areas; T2 – Urban parks and T3 – Gardening spaces. The indicators to assess the potential of nature spaces to support communities' resilience and sustainability, defined in NATURELAB D1.1, depend on the type of natural site (T1, T2 or T3). In this section, as featured in Table 3.1, characteristics of the Experimental Sites located in Portugal are presented.

Table 3.1 – Types of nature spaces in NATURELAB (adapted from Beute *et al.* 2020)

T1	Forests and protected areas	A land mainly covered with trees and undergrowth cover	Protected areas, forest in national parks, forest in nature reserves	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	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	Allotment in Mira Sintra, Sintra[1] (PT) 

[1] The picture depicts the urban context where the projected allotment will be implemented.

The six Experimental Sites in Portugal are in the municipalities of Sintra and Esposende (*cf.* Figure 3.1). They were chosen as to provide differentiated geographical locations, allowing for evaluations of climate, temperature, precipitation, and sunlight, among others, roles in the promotion of biodiversity, health and well-being.

Esposende Municipality

Experimental site		Type (Table 3.1)	NATURELAB partner
ES5	Foz do Neiva	T1	RN Rio Neiva
ES6	Esposende	T3	RN Rio Neiva

Sintra Municipality

Experimental site		Type (Table 3.1)	NATURELAB partner
ES1	Sintra Cascais Natural park	T1	Sintra Municipality
ES2	Quinta da Ribafria	T2	Sintra Municipality
ES3	Allotment in Mira Sintra	T3	Sintra Municipality
ES4	Parque Urbano Rinchoa "Eco Park"	T2	Sintra Municipality

Figure 3.1 – Experimental Sites in Portugal

3.2 ES1 – National Park Sintra-Cascais

National Park Sintra-Cascais has 14580 ha and is located in the district of Lisbon, extending through the territories of the municipalities of Sintra and Cascais. It is inserted in the Network Natura 2000 and it is explored and protected by the Portuguese Institute for Nature Conservation and Forests.

It extends from the mouth of the river Falcão, northern limit of the municipality of Sintra, to the Guia area, in Cascais. It is located in the western region of Terra Saloia and in the north-western quadrant of the Lisbon Metropolitan Area. The Sintra-Cascais Natural Park supports a diverse range of wildlife which includes a variety of bird species. Additionally, the park has well-marked hiking trails, providing an opportunity for outdoor enthusiasts to explore its natural features (*cf.* Figure 3.2).

Figure 3.2 – Photographs from the ES1 – National Park Sintra-Cascais (Forest)

This Experimental Site includes a considerable diversity of habitats, nine of which are considered a priority for nature conservation. It is an important place for mammals and birds, which include the *Falco peregrinus* and *Aquila fasciata*[2]. It has the incredible Lagoa Azul (Blue Lagoon), a place surrounded by both lake and trees.

The Sintra-Cascais Natural Park is a place where nature, culture, and history pleasantly coexist. Besides the natural features, Sintra-Cascais Natural Park has also important cultural heritage such as the iconic Pena Palace.

Table A1.1 in Annex I presents the indicators regarding the spatial characteristics, design, and conditions for this Experimental Site.

3.3 ES2 – Ribafria Farm

Ribafria Farm is an important nature space in the municipality of Sintra, at the gates of the city of Lisbon, with various species of trees and shrubs. This site includes hiking trails, classified national monuments and an old manor house. It has different water bodies including the Colares river. This property from the

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2 https://www.parquesdesintra.pt/pt/sobre-nos/blog/que-aves-podemos-encontrar-na-serra-de-sintra/.

16th century is located in Várzea de Sintra. It is a magnificent Renaissance-style manor house, where the impressive medieval-inspired tower stands out. The surroundings of the manor house comprise an original staircase and a vast and meticulously shaped gardens, adorned with ornate fountains, tranquil ponds, and meandering pathways. The property includes 13 ha of gardens and woodlands, with centuries-old sequoias and other remarkable specimens of trees and shrubs can be observed (*cf.* Figure 3.3).

Figure 3.3 – Photographs from the ES2 – Ribafria Farm

Table A1.2 in Annex I presents the indicators regarding the spatial characteristics, design, and conditions for this Experimental Site.

3.4 ES3 – Horticulture allotment in Mira-Sintra

Horticulture Allotment in Mira-Sintra is placed in the homonymous parish, in Sintra, with 41.323 inhabitants, and is expected to become a nature-based horticulture and gardening space. Additionally, it will also encompass adapted gardens for disabled citizens. It has approximately 0.25 ha and is located in the urban area of Mira Sintra near the Experimental Site 4 (*cf.* Figure 3.4). It will serve as a refuge for local residents to connect with nature, escape the hustle and bustle of daily life, and cultivate their own fresh produce. The influence of the activities related to horticulture and gardening on the improvement of mental and physical health will be evaluated in this allotment.

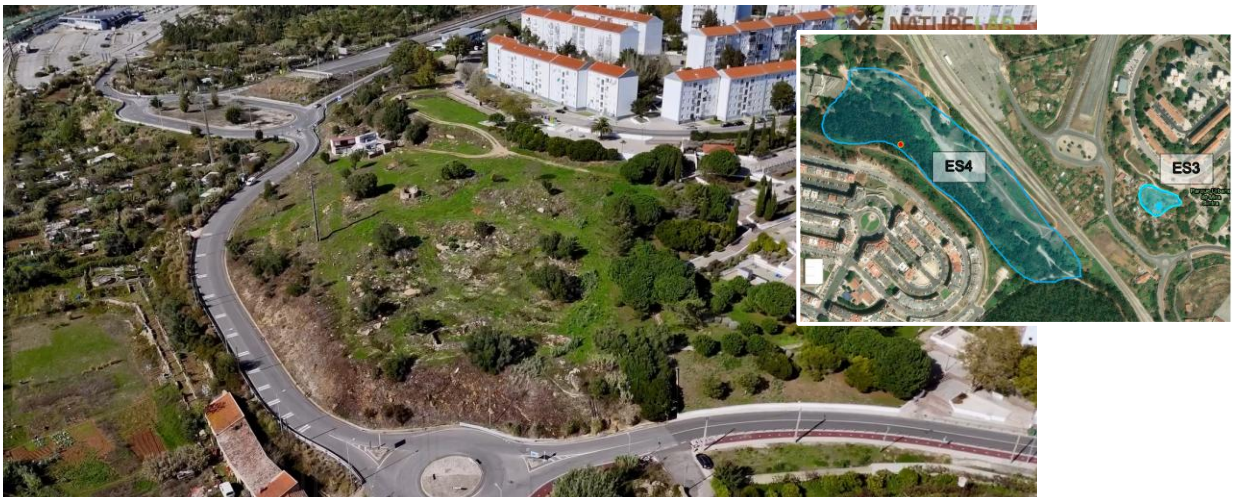

Figure 3.4 – Location of the ES3 allotment in Mira Sintra (under construction)

Table A1.3 in Annex I presents the indicators regarding the spatial characteristics, design, and conditions for this Experimental Site.

3.5 ES4 – Rinchoa Eco-Park Sintra

Rinchoa Eco-Park Sintra is a nature space in an urban environment, managed by the parish council of Rio de Mouro (population of around 47.000 inhabitants). It was rehabilitated and transformed into a park with an area of approximately 12 ha, dedicated to leisure, sport and culture. The park was restored with arrangements on the water stream and the installation of urban furniture such as picnic tables with benches, litter bins, bench with backrest, recycling bins, bicycle rack, and informative posters. The park provides extensive walking and cycling paths, as well as areas for outdoor gatherings.

The park is known as "Eco Park" and represents a vibrant and environmentally conscious urban park in Rinchoa[3]. It stands out as a shining example of green and sustainable urban planning, designed to offer a multifaceted experience for visitors of all ages.

One of the prominent features of the Urban Park of Rinchoa is its dedication to environmental conservation and education. The park encompasses various eco-friendly elements, including lush green spaces and wetlands. This focus on sustainability extends to energy-efficient lighting, waste recycling initiatives, and water conservation measures throughout the park.

Figure 3.5 presents some photographs of the park.

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[3] Further information in: https://ambiente.sintra.pt/parques-e-jardins/parques-urbanos/parque-urbano-de-rinchoa-fitares.

Figure 3.5 – Photographs of the ES4 – Rinchoa Eco-Park Sintra

Table A1.4 in Annex I presents the indicators regarding the spatial characteristics, design, and conditions for this Experimental Site.

3.6 ES5 – Foz do Neiva

The Experimental Site 5 is the Foz do Neiva. This ES and the ES6 are coordinated by Rio Neiva Association[4], an environmental conservation association based in Antas in the municipality of Esposende since 1989. Its essential objectives include defending and enhancing the environment and natural and cultural heritage, promoting balanced regional development in the Neiva River Valley, optimizing the role of environmental defence in its several perspectives (*e.g.*, protection, awareness, appreciation, and nature sports).

Foz do Neiva stands for the mouth of the Neiva River, in the immediate vicinity of the association's headquarters. Among the various activities, one that stands out is the enhancement of spaces and interpretative trails, specifically two trails (named PR1 and PR4 as presented in Figure 3.6). This initiative aimed to yield three main outcomes: the creation of a guide to local biodiversity, the installation of outdoor signage, and the development of a manual to document the implementation process. Field trips were organised, involving the local school community, expert collaborations, and species surveys.

[4] Further information in: https://rioneiva.com/

As presented in Figure 3.6, the Experimental Site is located in the Northern Litoral Natural Park on the south side in the Municipality of Esposende and in the Litoral GeoPark on the north side, in the Municipality of Viana do Castelo. It is a Natura 2000 area with rather diverse biodiversity. The total area is about 2800 ha including riverine and estuarine zones.

For the activities within NATURELAB, the closest proximities to the Neiva River Association headquarters will be considered namely a 4 km radius, considering the headquarters as the centre (approximately 50 km^2).

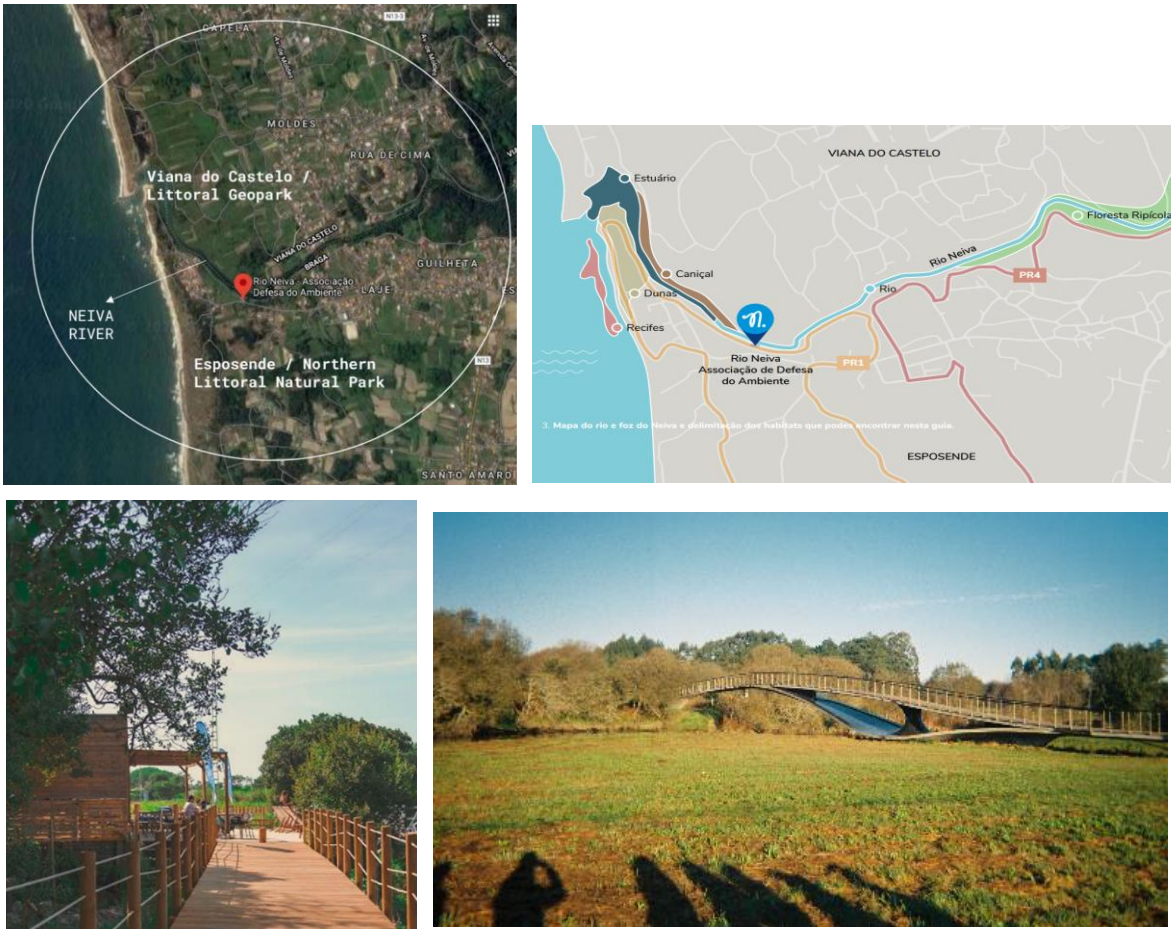


Figure 3.6 – Maps and photographs from the ES5 – Foz do Neiva

Table A1.5 in Annex I presents the indicators regarding the spatial characteristics, design, and conditions for this Experimental Site.

3.7 ES6 – Esposende Municipality

Experimental Site 6 is located on the southern side of the river Neiva within the Esposende Municipality (*cf.* Figure 3.7). Within this Experimental Site, three distinct sub-categories will be considered, namely: (i) gardens / backyards of local social charities and day care centres for elderly; (ii) gardens / small horticulture areas with local schools; and (iii) backyards of private homes in the local area. Rio Neiva Association will proactively foster connections and interactions with key stakeholders, encompassing schools, social charities, and the residents of local homes with backyards. The association will also meticulously identify the specific sites for on-site interventions, delineating details such as which trails to prioritize and the precise locations along the river where these interventions should be executed. Following this, the association will put the established protocol into action and evaluate its effectiveness within this area.

It is important to note that these gardens and backyards are situated within the Northern Littoral Natural Park, which places a significant emphasis on biodiversity and conservation. This is particularly pertinent given that the area within this municipality overlaps with Natura 2000.

Figure 3.7 – Maps and photographs from the ES6 – Esposende

Table A1.6 in Annex I presents the indicators regarding the spatial characteristics, design, and conditions for this Experimental Site.

4 | Assessment of exterior daylight and solar radiation

4.1 Introduction

In the domains of daylight (natural light) and solar radiation, the main objectives of NATURELAB are the assessment of how both Daylight and Solar Radiation (DSR) can contribute to the health, comfort, and well-being of individuals in outdoor spaces. Additionally, the potential positive effects of those factors will be evaluated as part of therapeutic programmes. For this purpose, a set of indices and indicators are proposed based on "on site" evaluation" of the luminous environment and on the statistical analysis of groups of individuals regarding the before mentioned outdoor luminous environment (NATURELAB D1.1).

This section describes the main procedures for the characterisation of the daylight and solar radiation component of the outdoor environment at two experimental sites until December of 2024.

4.2 State-of-art

Most of the present scientific knowledge regarding the DSR 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 DSR components of the outdoor environment and in almost all of them it is only included as a small part of the outdoor environment domains associated to other areas of the outdoor environment (NATURELAB D1.1).

Many of the studies that address the main benefits arising from the use of DSR come from the area of building physics and, consequently, are "disconnected" from the reality of the 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[5] and irradiances[6], 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 evidences 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, 2024). 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

[5] 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.

[6] 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).

others. Ensuring that human beings "get enough" daylight and sunlight[7] 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.

Figure 4.1 presents the factors affecting the quality of the luminous environment (performance, ambience and comfort) and main properties of light(ing).

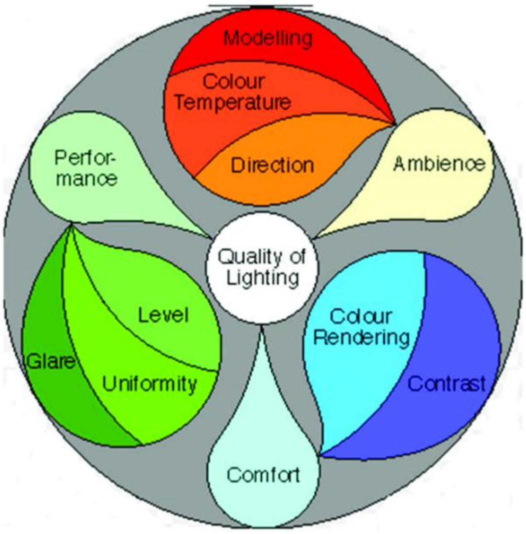


Figure 4.1 – Factors affecting the quality of the luminous environment (performance, ambience and comfort) and main properties of light(ing)

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 is 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.

4.3 The monitoring methodologies

4.3.1 General considerations

As referred in NATURELAB D1.1, the methodologies used in the characterisation of the daylight and solar radiation (DSR) components of the outdoor environment will be based on *in situ* characterisations and complementary analysis of the ES selected as case studies.

In general, the recommendations 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) (Santos, 2001).

7 Usually, daylight refers to the visible diffuse part of the solar radiation (from the sky) and sunlight refers to the direct radiation received from the sun.

An outline of the methodology used for characterising the outdoor daylight and solar radiation (DSR) conditions, based on *in situ* assessment and complementary analyses is, presented in Figure 4.2.

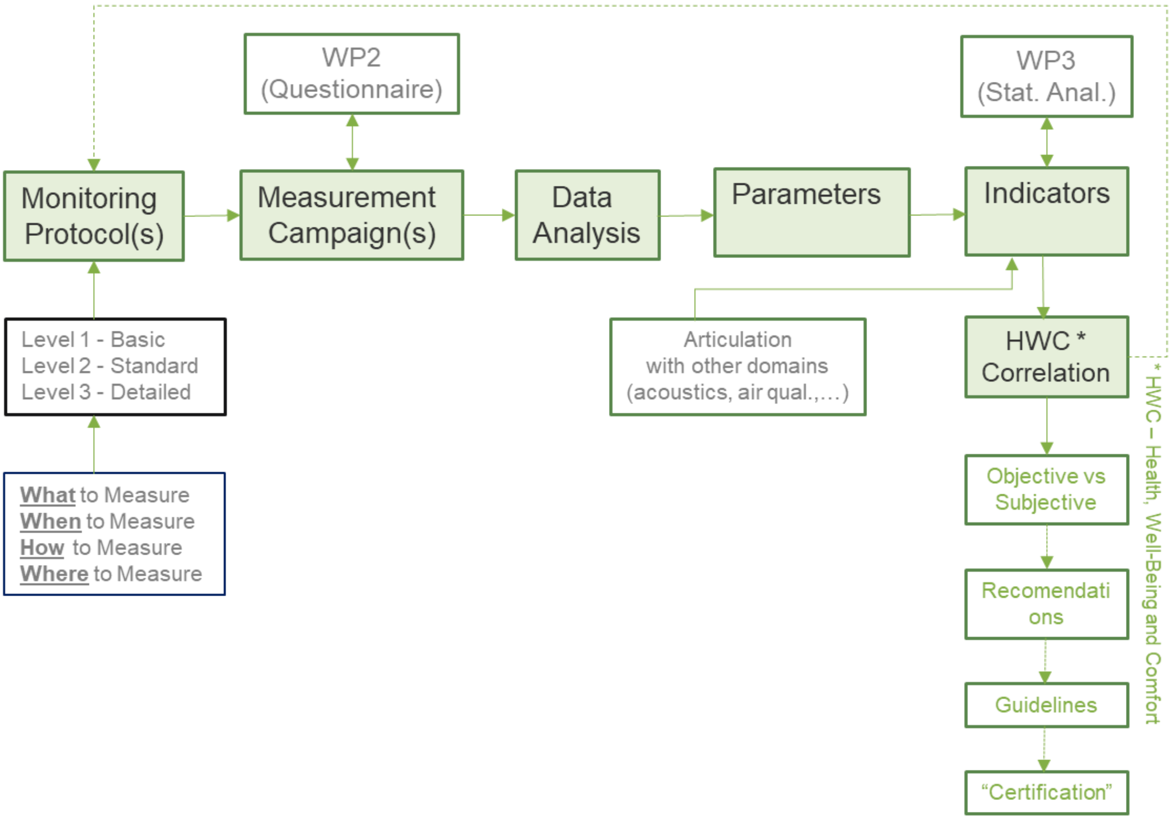


Figure 4.2 – Illustration of the methodology used in the in the characterisation of the daylight and solar radiation (DSR) components of the outdoor environment

During the period in analysis (year 2024), a set of systematic measurement procedures (monitoring protocols) were defined, applied, analysed, modified and validated in two of the selected Portuguese ES. The results obtained are briefly described in the "Monitoring" section and they are the initial basis for the development of "key proposed indicators" in the domains of DSR.

4.3.2 Monitoring Protocols

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 4.3 shows a diagram of a possible monitoring methodology for assessing outdoor daylight and solar radiation conditions.

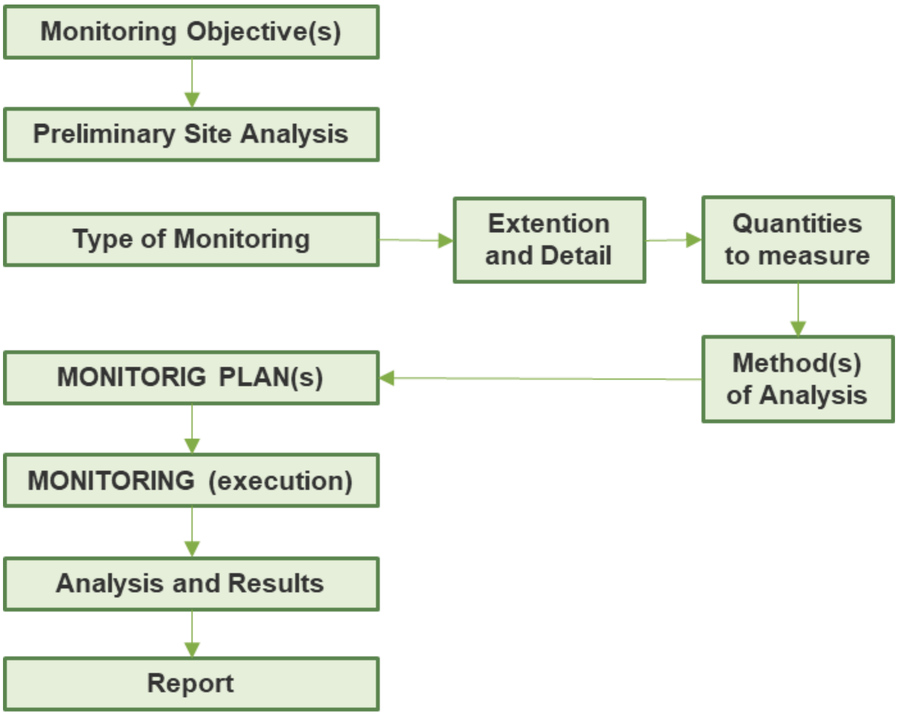


Figure 4.3 – Schematic diagram of a possible methodology for DSR outdoor monitoring

With the information obtained during the pre-analysis phase and depending on the specific scope of monitoring and the resources available, it is necessary to select the type of monitoring to be carried out. The pre-analysis phase is important in the collection of necessary information 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 equipment needed, 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 the following can be mentioned: (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 monitoring levels contain the procedures included in the lower monitoring levels (*cf.* Figure 4.4).

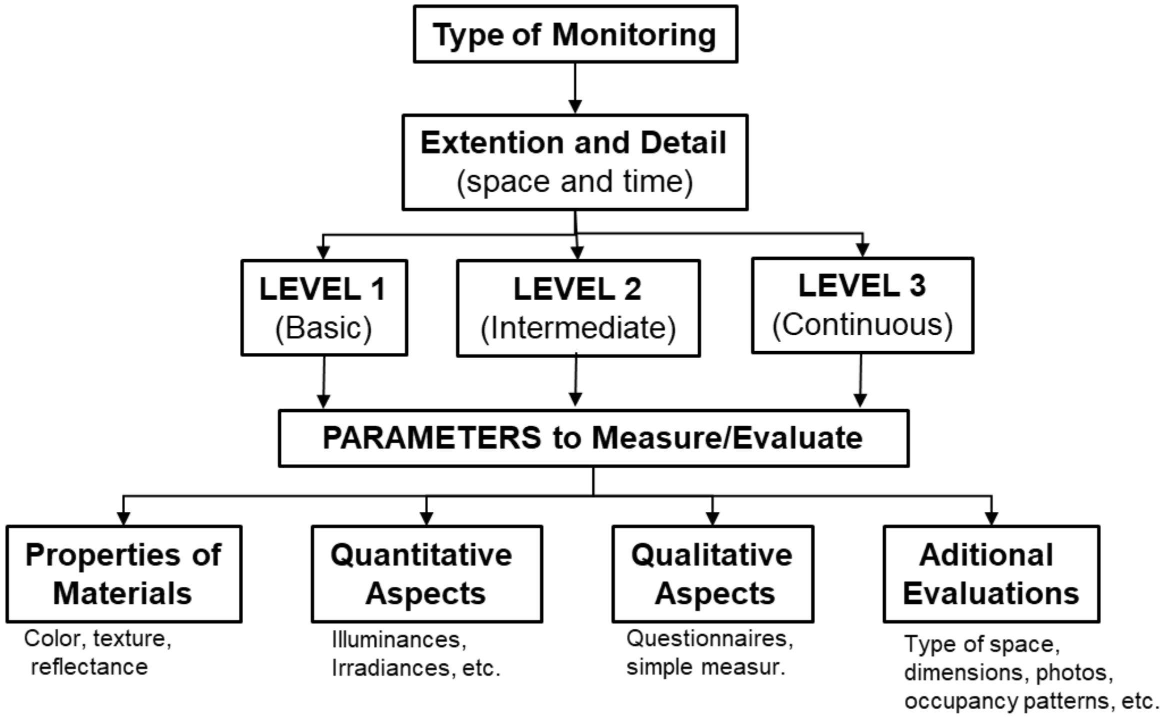


Figure 4.4 – Schematic illustration of the monitoring type as a function of extent and detail (in space and time) and some of the parameters to be measured/evaluated

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.

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 daylight and solar radiation (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 characterisation 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.

4.4 *In situ* monitoring

4.4.1 Equipment used

The equipment used for exterior daylight and solar radiation was acquired by LNEC. It was selected due to its suitability for the purposes of NATURELAB. Table 4.1 presents the measured variables and the used equipment.

Table 4.1 – Measured luminous and radiative properties and equipment

ID	Measurement/Quantity	Equipment
$E_{g,h}$	Global horizontal illuminance (lux)	LI-COR LI 210 SA Illuminance sensor plus LI COR LI 250 A
$E_{diff,h}$	Diffuse illuminance (lux)	BF 5 – sunshine sensor 1
$I_{g,h}$	Global horizontal irradiance (W/m^2)	LI-COR LI 2OO SA Irradiance sensor plus LI COR LI 250 A
$I_{diff,h}$	Diffuse irradiance (W/m^2)	BF 5 – sunshine sensor 3

Figure 4.5 presents photos of the used equipment.

(a) (b)

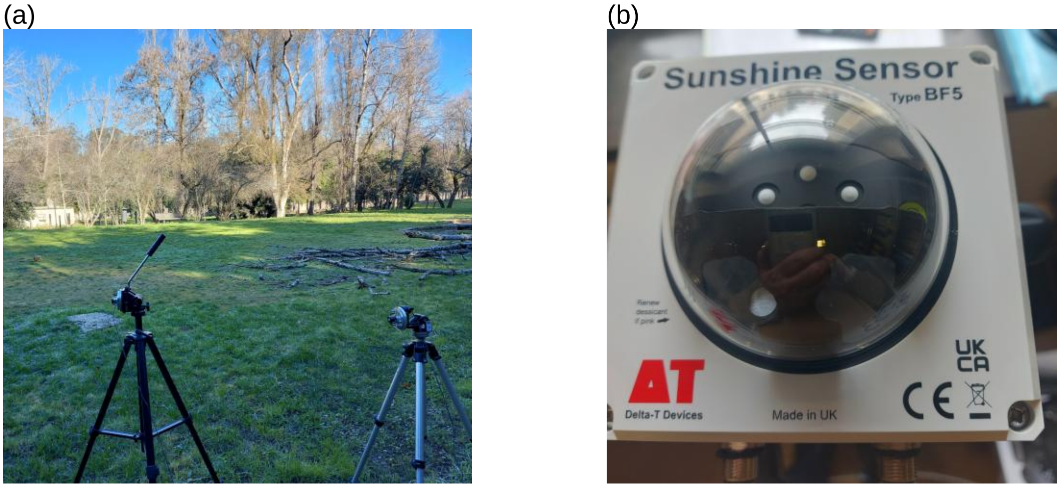


Figure 4.5 – (a) LI-COR illuminance (right) and irradiance (left) sensors on tripods measuring vertical illuminances and irradiances at Ribafria Farm under clear sky conditions and (b) BF5 Sunshine sensor for light and radiation measurements

4.4.2 Monitoring campaigns

During 2024 different monitoring campaigns were performed to assess the exterior daylight and solar radiation conditions in two of the Portuguese Experimental Sites: ES2 – Ribafria Farm (QRF) and ES4 – Parque Urbano Rinchoa "Eco Park". Table 4.2 summarizes the present state of the referred DSR evaluations.

Table 4.2 – Status of the DSR assessment at the Portuguese ES (December 2024)

Experimental Site	Valid.	2024 Winter		2024 Autumn		2025 Winter		2025 Spring	
	C/O	Clr.	Ovc.	Clr.	Ovc.	Clr.	Ovc.	Clr.	Ovc.
ES1 – Sintra Cascais Natural Park (Forest)	Yes	-	No	-	-	-	-	-	-
ES2 – Ribafria Farm (Healing Garden)	Yes	-	Yes	-	-	-	-	-	-
ES3 – Allotment in in Mira Sintra	NRY	-	NRY	-	-	-	-	-	-
ES4 – Parque Urbano Rinchoa (Eco Park)	Yes	-	Yes	-	-	-	-	-	-
ES5 – Foz do Neiva	NRY	-	NRY	-	-	-	-	-	-
ES6 – Esposende	NRY	-	NRY	-	-	-	-	-	-

Legend:
Valid: Reconnaissance of ES and validation of the methodology under clear and/or overcast sky conditions
Clr.: Assessment under Clear Sky conditions
Ovc.: Assessment under Overcast Sky conditions
NRY: No Visit/Reconnaissance Yet

The referred evaluations included:

- The definition of a preliminary monitoring protocols (for each ES) in permanent adjustment;
- The definition of the exact locations of the measurements;
- The previous calibration of the equipment used in the measurements (illuminance and irradiance meters, basically);
- The measurement of the luminous and radiative properties of the exterior environment with the equipment presented in section 4.4.1.

The observations included: photographic reports of the different ES, including vegetation characteristics, relevant obstructions and type of cloud cover during the measurements, identification of the most relevant locations for fixed measurements ("points of measurement"), identification of the type of usage by users (when, where and how different people use the space).

The referred measurements were (and will be, in the future) performed under clear and overcast skies and will be completed during 2025.

The measurements of the quantities previously referred were measured in certain periods (roughly coinciding with the Solstices and the Equinoxes and, at least, during three periods of the day – 9:00 True Solar Time – TST; 12.00 TST; 15:00 TST) (Santos, 2001).

Each monitored site was thoroughly analysed in terms of the exterior luminous and solar environment and if it is found that additional measurements are needed (of the same quantities previously referred) the measurement protocols, to be further defined, will naturally be adjusted. These protocols must allow for a complete characterisation of the exterior daylight and solar radiation environment and its potential effects (beneficial, harmful, or neutral) on the health of the users of these outdoor spaces.

The main difficulties/limitations observed, so far, during the monitoring campaigns were:

- Weather conditions in the ES locations: It was/is not possible to perform measurements under rainy conditions and whenever the ground is wet and/or muddy;

- Strong random fluctuations of the nebulosity, especially during overcast and intermediate skies;. Also medium/strong windy conditions will also have a strong influence on the quality and reliability of the measurements;
- Schedule compatibility with the "owners" of the experimental sites;
- Availability of helping crews to transport, placing and setting the experimental apparatus;
- Opening hours to the public in some ES.

Table 4.2 depicts the *in situ* evaluations already performed and the ones to be performed during the next seasons.

4.5 Preliminary findings, conclusions and further work

Regarding the daylight and solar radiation components of the outdoor environment and their influence on the health and well-being of individuals there are still no definitive findings since the measurement campaigns just started a few months ago. Nevertheless, the preference of individuals regarding the natural environments is well known, so, it is not surprising that some of the key findings, so far, highlight the influence of natural light and solar radiation in improving the health, well-being, and comfort of individuals in leisure contexts. More concrete findings are expected in the next months with further findings expected as more measurements are carried out and new indicators proposed.

The next steps in the DSR assessment will be the completion of monitoring campaigns in all ES with the application of adjusted DSR monitoring protocols to the selected case studies.

5 | Environmental sound characterisation

5.1 Introduction

Quantitative and qualitative sound environment characterisation (in terms of human perception) aims to help assess how the sound environment of natural spaces can improve the health and well-being of participants involved in therapeutic programs. This section describes the main guidelines for the acoustic characterisation of the ES.

5.2 Preliminary state-of-art

Conventional research and legislative requirements in environmental acoustics have been dominated by noise as a physical measure (decibels expressed as L_{den}, day-evening-night noise indicator, and Ln, night-time noise indicator) 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 regulated by the "Environmental Noise Directive, END" (EU, 2002), which deals with the management of specific noise sources, particularly road, railway, aircraft, industrial, and equipment noise. In this context, environmental sounds are considered 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 focuses on reducing unwanted noise, ignoring the potential benefits of positive sounds. Studies in urban open spaces have shown that when the sound level is below the values of 65-70 dBA, people's acoustic comfort evaluation is not only related to the sound level, but also to the sound type, the user characteristics, and to other factors which 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 scientifically as Soundscape, highlights seven general concepts and their relationships: sound sources, context, acoustic environment, auditory sensation, interpretation of auditory sensation, responses, and outcomes (*cf.* Figure 5.1). In this way, soundscape studies strive to understand the perception of a sound environment in a specific context, which includes acoustic, environment, global context, and personal factors.

In recent years, soundscape studies have gained attention as a complementary approach to managing environmental noise and urban planning policies. Sound sources can be characterised 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 between 2 and 8 kHz (named as biophonies). 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). All these types of sounds are also incorporated into

ISO/TS 12913-2 (ISO, 2018) and formalized into three main types of sound sources recommended for inclusion in soundscape surveys: sounds of nature, sounds of technology, and sounds of human beings.

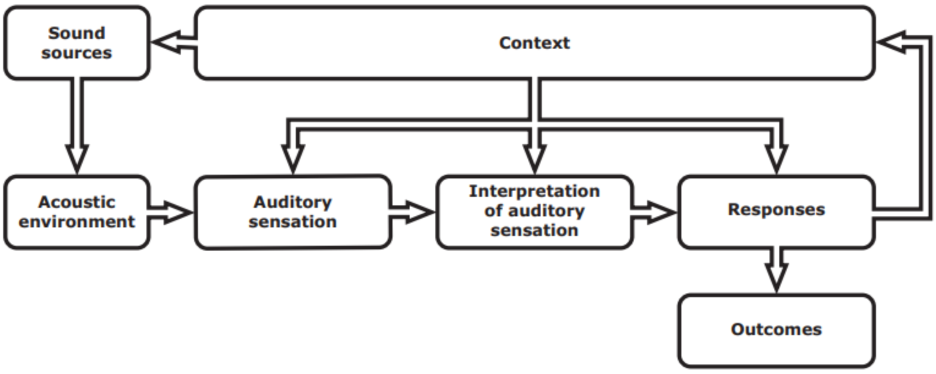


Figure 5.1 – Conceptual model of soundscapes: relationship between the seven general concepts (ISO 2019)

Natural sound sources are generally assumed to have positive effects on health and well-being, while mechanized anthropogenic sounds are often associated with negative impacts. Technological sounds due to transportation, industry, commerce, infrastructure, and construction have been correlated 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 the 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 colouring 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 sounds for the study of restorative environments and the value of specific sounds. In soundscape research studies, addressing on how people perceive the acoustic environment, they start by analysing 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 analysed and linked to the results of the acoustic data analysis 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 5.2 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.

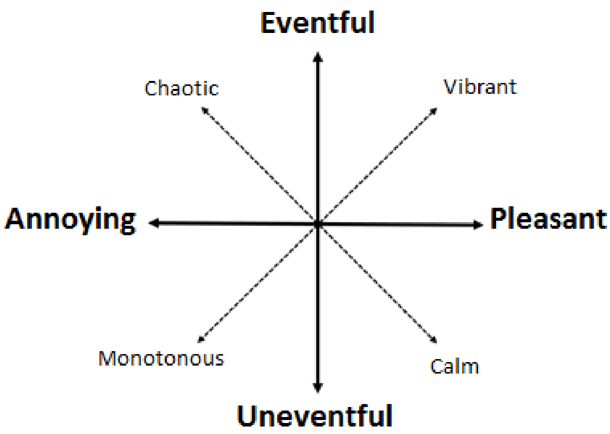


Figure 5.2 – Circumplex model of soundscape perception

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 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 5.3 illustrates a schematic representation of the associations between positive soundscapes and positive health effects.

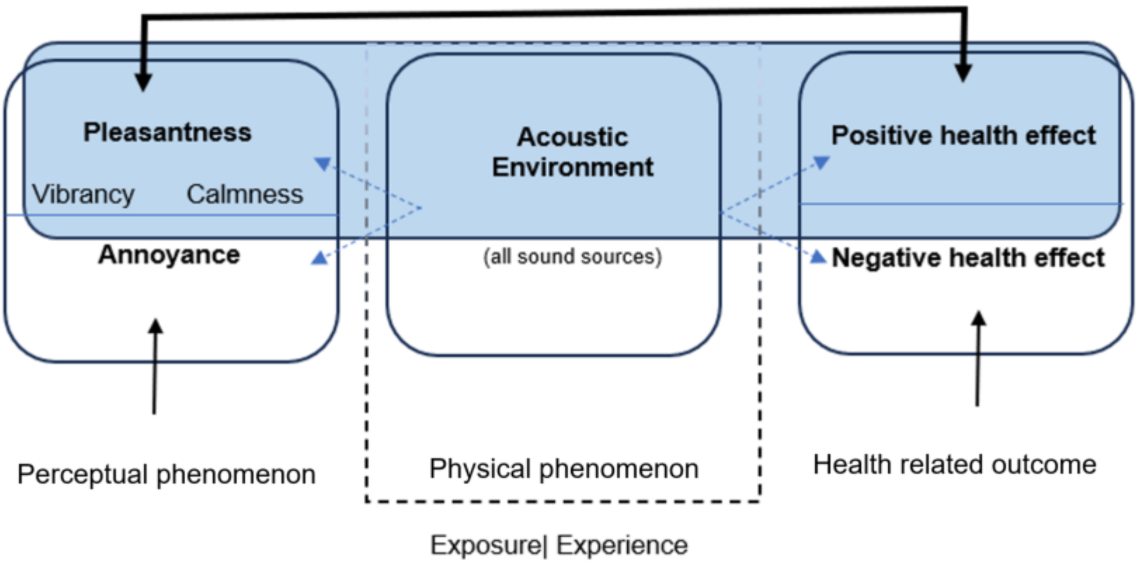


Figure 5.3 – Schematic representation of the associations between positive soundscapes and positive health effects (area highlighted in blue, Alleta *et al.* 2018)

5.3 Legislation and health related recommendations

Environmental noise is a significant public health issue, featured among the top environmental risks to health. Its negative impacts on human health and well-being are a growing concern among the public and European policymakers. The European Union issued the Directive 2002/49/EC (EU, 2002) to establish a framework for environmental noise planning. This Directive (END) requires all member states to develop strategic noise maps of major roads, railways, airports, and cities. Once the maps have been developed, member states must also develop noise action plans to manage noise issues and effects.

Standardized assessment methods of urban sound typically focus on objective noise quantification defined through equivalent sound level parameters based on the A-weighted long-term average sound level, determined over all the day/ evening /night (L_{day} / $L_{evening}$, L_{night}) periods of a year as defined in ISO 1996-2 (ISO, 2017). Each member state established noise limits in its national legislation for the noise indicators L_{den} (day-evening-night noise indicator) and L_n (night noise indicator).

Moreover, the END demands that all Member States protect so-called 'quiet areas'. Regrettably, the END did not define 'quiet areas', causing a need for a good practice guide (EEA, 2014). This document defined a 'quiet area' as a place where noise is absent, or at least not dominant. Moreover, these guidelines indicate that a definition linked only to the sound level is inappropriate since most people look for a quiet (calm) place and not a place where silence is dominant. In fact, sounds are meaningful and provide information about our surroundings. A model of the relationship between sound-pressure levels and perceived acoustic quality for green areas is presented in Figure 5.4, according to EEA (2014).

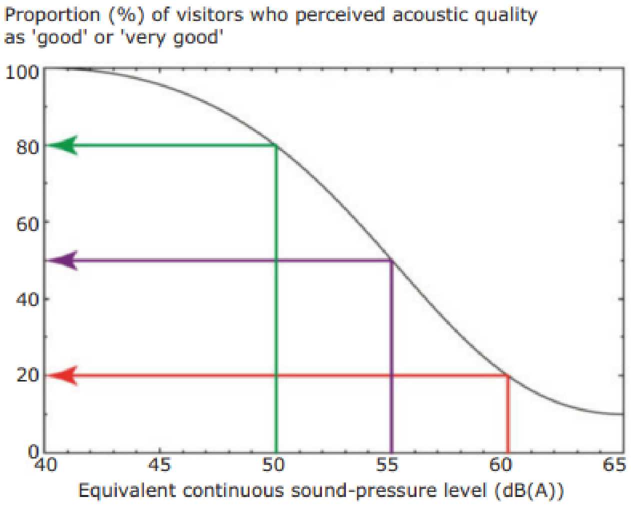


Figure 5.4 – Model of relationship between sound-pressure levels and perceived acoustic quality of green areas (source: EEA, 2014)

The good practice guide (EEA, 2014) also includes guidelines for sound pressure levels (*cf.* Table 5.1), highlighting that besides sound pressure levels, other area qualities, like visual and air quality, perceived types of sounds, visitors' activities, and expectations, can act as moderators in the perceived acoustic quality.

Table 5.1 – Sound pressure levels related to perceived acoustic quality/appreciation (EEA, 2014)

Sound pressure levels (L_{Aeq}, L_{day})	Perceived acoustic quality/ appreciation
< 45 dB	~100% of visitors perceive acoustic quality as good
45-55 dB	~50 % of visitors perceive acoustic quality as good

Regarding environmental noise, the WHO Regional Office for Europe published recommendations for protecting human health from exposure to environmental noise emitted from various sources (WHO, 2018). The document also describes the effects of noise on health, such as noise-induced hearing impairments, sleep disturbance effects, cardiovascular and psycho-physiological effects, and effects on performance, speech intelligibility, and social behaviours. These recommendations comprise guideline values for sound levels (L_{den} and L_n) for road (53 dB), rail (54 dB), aircraft (45 dB), and wind turbine noise (45 dB). Above these levels there is a clear evidence of adverse health effects related to noise. Table 5.2 presents the guidelines and values of the WHO (2018).

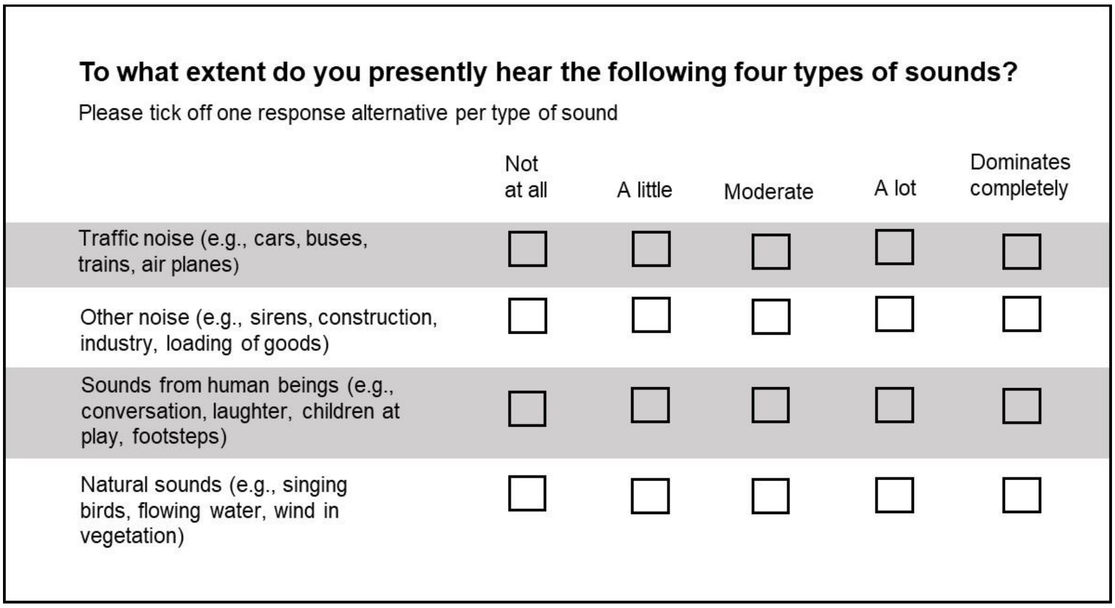
Table 5.2 – Sound pressure levels related to perceived acoustic quality/ appreciation (WHO, 2018)

L_{den}	Road traffic noise	Railway noise	Aircraft noise	Wind turbine noise
Day	53 dB	54 dB	45 dB	45 dB
Night	45 dB	44 dB	40 dB	–

5.4 Proposed key indicators

To evaluate the environment sound in nature settings to be used for therapeutic activities, 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 are 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 5.5 to Figure 5.7 list the questions to be asked and the associated scale following ISO/TS 12913-2 standard (ISO, 2018).

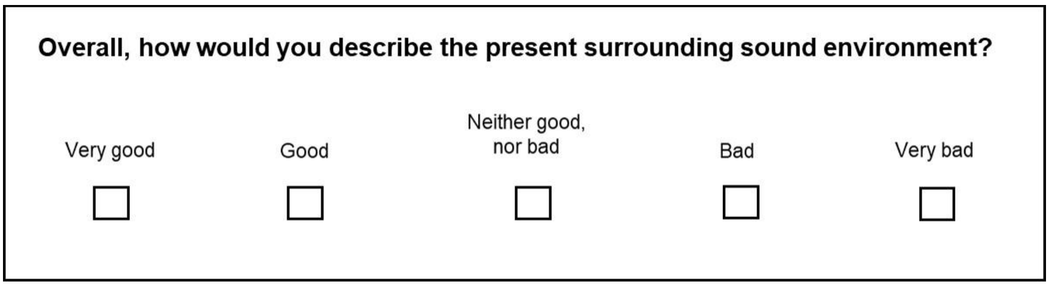


To what extent do you presently hear the following four types of sounds?

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 5.5 – Qualitative assessment of sound source identification (source: ISO, 2018)



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

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

Figure 5.6 – 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 5.7 – Qualitative assessment of the appropriateness of the surrounding sound environment (source: ISO, 2018)

The last qualitative indicator is related to the perception of the sound environment, considering the eight affective perceptive qualities indicated in the soundscape's standard (ISO, 2018).

<u>Quantitative indicators</u>:

The acoustic environment is commonly characterised through the established acoustic metrics, such as the equivalent energy level (*e.g.*, $L_{eq,T}$) and the related statistical levels (*i.e.*, levels exceeded for a given percentage of time, concerning the acquisition period, L_x), the level variability over time (*e.g.*, L_x–L_{100-x}), and the proportion of low-frequency sounds (*e.g.*, L_C–L_A). These classical indicators shall be measured according to ISO 1996-2 (ISO, 2017).

Psychoacoustic indicators like Loudness, Sharpness, Roughness, and Fluctuation Strength (and time-variant indicators) will be used for intermediary and higher-level monitoring. Loudness is considered the most important psychoacoustic quantity, as it describes the perception of volume in detail for a sound stimulus. Measurements of loudness should be made according to ISO 532-3 (ISO, 2023). The psychoacoustic parameter sharpness describes 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 4 Hz instead of 70 Hz 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 leading indicators proposed for the characterisation of the acoustic environment are present in Table 5.3.

Table 5.3 – Main quantitative indicators for the characterisation 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

5.5 The monitoring methodologies

Environmental sound assessment can be done differently, depending on the measurement goals, sampling techniques (spatial and temporal) used, and the effort directly associated with obtaining representative results. The purpose of the measurement can be related to the sound level's characterisation of all the sounds present at a given time without discriminating between their origin or connotation (pleasant or unpleasant sound). On the contrary, it can be related to characterising the sound levels associated with human activities (specific sounds), including noise emitted from road traffic, rail traffic, air traffic, and industrial activity. In the former case, the assessment is more related to the adverse effects of noise on human health, and the noise descriptor generally used, *i. e*. the A-weighted equivalent continuous sound level, should be representative of the annual average equivalent noise levels. Long-term noise measurements are an expensive and complex process. However, the application of the European Directive (EEA, 2020) implies the production of noise maps for agglomerations with more than 100,000 inhabitants, major roads (more than 3 million vehicles a year), and major railways (more than 30.000 trains a year), in a cycle of every 5 years. These noise maps result from applying duly validated emission and propagation models for previously referenced sound sources. In this context, the information already available and the knowledge of sound source characteristics can be used in short-term strategy techniques to optimize the selection of measurement locations in ES.

Within this project's scope and to characterise the environmental sound (quantitative and qualitative aspects), three strategies will be used: basic, intermediate, and high (as presented in Table 5.4). Each strategy is associated with the different objectives and indicators. The basic level monitoring methodology strategy involves collecting all the information about the characteristics of the sound sources related to human activities present at each ES. It is more closely associated with characterising the adverse effects of noise (or its absence). The information gathered will optimize the higher-level monitoring after preliminary measurements. Intermediate-level monitoring will be carried out over one year to consider sound propagation and emission characteristics. The high-level monitoring strategy, which is more related to the assessment of sound perception, complements the previous strategies and involves the measurement of more complex indicators (*cf.* Table 5.4). This characterisation will be carried out in specific locations, along the therapeutic pathways with simultaneous assessment of sound perception.

Table 5.4 – Basic, Intermediate and High levels to characterise the sound environment

Basic Level
• Collection of existing data about the sound environment, such as noise maps and action plans published for the location. • A qualitative analysis of the acoustic environment 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 5.5 to Figure 5.7 can be used.
Intermediate Level
• Completing the steps for the Basic level. • Collection of acoustic 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 to characterise variations that usually take place.
High Level
• 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.

5.6 Characterisation of Sintra Experimental Sites

5.6.1 Basic level monitoring

This section presents the analysis of the noise map of Sintra municipality (in case of Sintra-Cascais Natural Park and Ribafria Farm), and the noise map from major railway (Rinchoa Eco-Park Sintra). For each ES, the sound levels from the noise maps are compared with the guideline values published by the WHO Regional Office for Europe when noise from rail, road, airplane traffic, or industry is present.

Sintra-Cascais Natural Park (Forest)

In the case of Sintra-Cascais National Park, it is possible to verify that noise levels (L_{den}) are below 50 dB(A) since no significant sources such as road, rail, and aircraft noise are present in the surroundings. According to the European Environment Agency, this ES complies with the sound level values related to good acoustic quality for the totality of visitors concerning technological sound sources. In this ES, natural sound sources are dominant.

Ribafria Farm (Healing Garden)

Figure 5.8 presents an extract from the noise map of the municipality of Sintra (July 2020) where Ribafria Farm area is marked with black dashed lines. Information from the noise maps indicated that long term noise indicator (L_{den}) is between 50 and 55 dB(A). The major noise source is road traffic from Estrada da Várzea (two-lane municipal road). Considering the recommendations of the WHO Regional Office for Europe, the L_{den} value should be below 53 dB(A) for road traffic noise. In this ES, more detail is needed about sound levels, with measurements throughout one year carried out in each season.

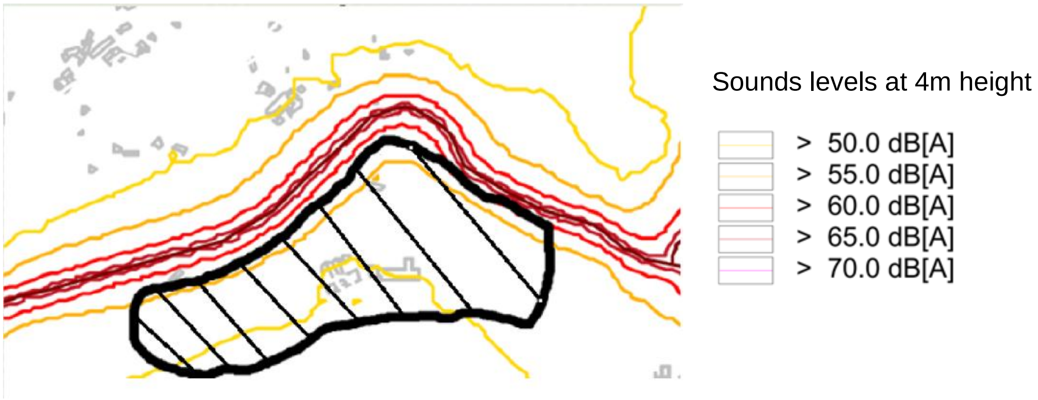


Figure 5.8 – Extract form Sintra noise map for L_{den} noise levels

Rinchoa Eco-Park Sintra.

In the Rinchoa Eco-Park Sintra., the most crucial anthropogenic sound source is railway traffic derived from trains of *Linha do Oeste*, which accompanies the development of the park to the east, and from trains at *Linha de Sintra*/Lisboa in the southern part of the park. Acoustic information was collected from the Linha do Oeste noise map (Bifurcation of Meleças and Mira Sintra), published in 2017. Analysing Figure 5.9, sound levels vary between 50 and 65 dB(A) throughout the park depending on the location, which makes it possible to identify some zones where rail traffic noise is above 54 dB(A).

At the moment, Linha do Oeste is being renovated, and there are some restrictions to rail traffic. According to the concessionaire, there is still no date for the service to return under normal conditions (https://servicos.infraestruturasdeportugal.pt/pt-pt/alertas/ferrovia/modernizacao-da-linha-do-oeste).
So, during this period it is expected that the noise levels in the Rinchoa Eco-Park Sintra will be lower than those shown on the noise map (*cf.* Figure 5.9). Table 5.5 presents the train timetable information for *Linha do Oeste* and *Linha de Sintra* related to 2024 (information collected from the same website). Analysing the values in Table 5.5, it shows fewer trains between 10 am and 4 pm, which will be associated with lower noise levels due to rail traffic.

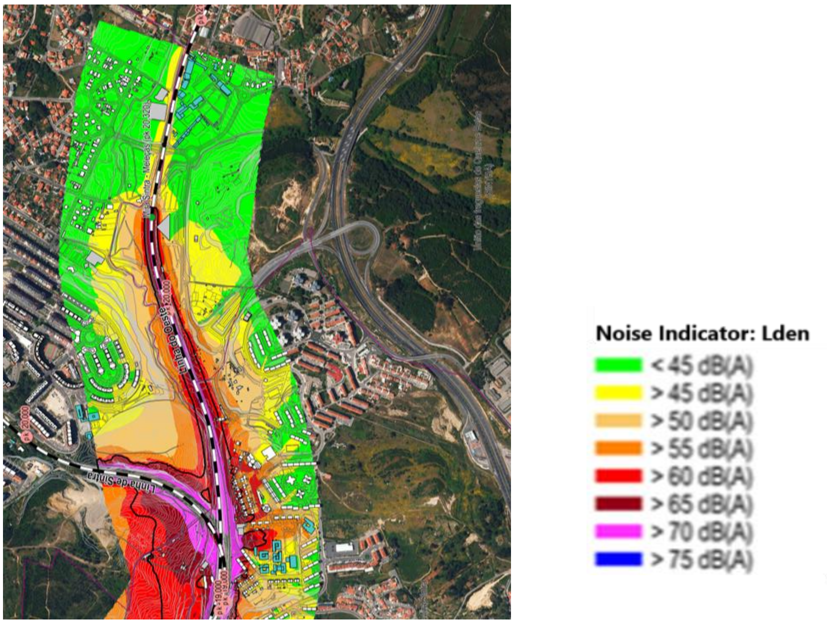


Figure 5.9 – Extract form Linha do Oeste noise map for L_{den} noise levels

Table 5.5 – Train timetable for Mira Sintra-Meleças Station (left) and Rio de Mouro station (right) during weekdays

Hours	Total trains
08h-10h	8
10h-12h	5
12h-14h	4
14h-16h	5
16h-18h	8
18h-20h	6

Hours	Total trains
08h-10h	31
10h-12h	22
12h-14h	19
14h-16h	20
16h-18h	27
18h-20h	30

Regarding other sound sources, sometimes it can be distinguished road traffic noise from local traffic, but with very low intensity.

5.6.2 Equipment used

Preliminary measurements were conducted with a Bruel & Kajer sound analyser, model 2260, SN: 2180663 (*cf.* Figure 5.10). This portable, battery-powered analyser is designed for various types of real-time acoustic analysis. With Sound Analysis Software BZ 7210 becomes a Type 1 sound level meter (IEC 61672) capable of performing 1/3-octave wideband real-time frequency analyses, spectral analyses, and statistical distributions calculations. Also included is Charge Injection Calibration (CIC) to check the condition of the microphone.

Figure 5.10 – Equipment for measuring sound levels (Bruel & Kjaer 2260 sound analyser)

A summary of the technical specifications of this equipment is presented in Annex II.

5.6.3 Preliminary site analysis

Very short-term measurements (5 minutes each) were carried out in the two Sintra ES, where anthropogenic sources are more prevalent, namely in Ribafria Farm and Rinchoa Eco-Park Sintra. Figure 5.11 presents the four measuring points (P1, P2, P3, and P4) at Ribafria Farm, and Table 5.6 presents the associated sound levels (continuous equivalent sound level, L_{Aeq}) and average sound level (L_{A50}). Table 5.6 also presents the sound source identification during the measurements, namely: a) light traffic on Estrada da Várzea; b) lawnmower at a distance; c) natural sounds (birds); d) aircraft (jet) flying overhead at a distance.

Figure 5.11 – Location of measuring points at Ribafria Farm (very short measurements)

Table 5.6 – Measurement results at Ribafria Farm and sound sources identification

	$L_{Aeq,T}$ [dB[(A)]	L_{A50} [dB(A)]	Sound Sources
P1	46	45	a), b), c), d)
P2	46	45	a), b), c)
P3	47	46	a), b), c), d)
P4	44	43	a), c), f)

Figure 5.12 presents the four measuring points (P1_R, P2_R, P3_R, and P4_R) at Rinchoa Eco-Park Sintra, and Table 5.7 presents the associated sound levels (continuous equivalent sound level, L_{Aeq}) and average sound level (L_{A50}). Table 5.7 also presents the identification of the sound sources, namely: a) human activities (physical exercise-running); b) natural sounds (birds); c) natural sounds (water); d) light traffic at a distance e) train passing by (Linha de Sintra); f) electric circular saw at a distance.

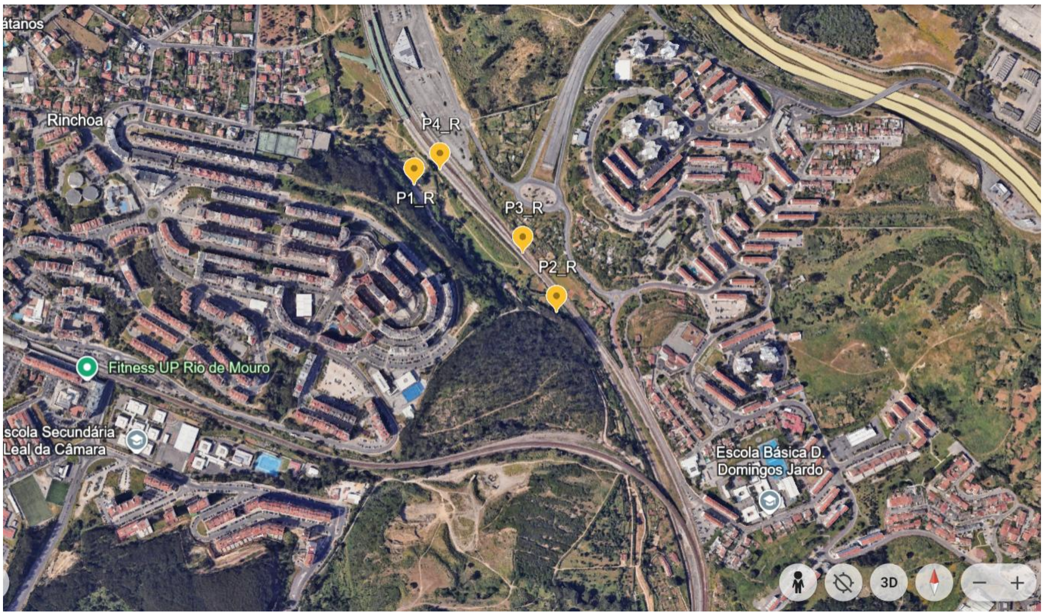


Figure 5.12 – Location of measuring points at Ribafria Farm (very short measurements)

Table 5.7 – Measurement results at Rinchoa Eco-Park Sintra and sound sources identification

	$L_{Aeq,T}$ [dB[(A)]	L_{A50} [dB(A)]	Sound Sources
P1	43	41	a); b); c)
P2	47	44	a); b); c); d); e)
P3	40	39	b); d);f)
P4	40	37	a); c)

5.7 Discussion of the results

About Ribafria Farm and Rinchoa Eco-Park Sintra, both sites are influenced by sound sources of anthropogenic origin, such as road traffic (Ribafria Farm) and railway traffic (Rinchoa Eco-Park Sintra); however, both sites are also influenced by nature sounds. The results of preliminary measurements made (very short samples) showed a variation between 44-47 dB(A) at Ribafria Farm and 40-47 dB(A) at the Rinchoa Eco-Park Sintra. However, they should be used as indicative values to optimize the choice of measurement location in the following monitoring campaigns.

In the case of environmental sound, there must always be a dual approach, as we have both noise sources (and therefore with the potential to cause discomfort) and sources of natural origin, potentially producing beneficial effects for human health.

As far as noise sources are concerned, the option was to choose three measurement locations in Ribafria Farm and take measurements for approximately 90 minutes at each point in each season of the year. Five locations for the Rinchoa Eco-Park Sintra were chosen, with measurements lasting approximately one hour for each season. However, the assessment of the sound environment of these sites and their potential does not depend solely on sound levels; there are other factors, such as the qualitative assessment of the sound environment and proximity to the place of residence (in the case of Rinchoa Eco-Park Sintra this could be a pertinent aspect). In this context, the characterisation of these three sites will also be done using soundscape methodology. Also, audio recordings of the three sites will be analysed to differentiate the natural sounds present in each one using physical descriptors.

6 | Air quality characterisation

6.1 An overview of the state-of-the-art

The increase in air pollution levels in urban areas affects the quality of city residents' everyday life, endangers human health, and harms the environment. Air quality is a major concern worldwide, particularly in urban areas, due to its direct consequences not only for life (humans, fauna and flora) but also on infrastructure and buildings, including historic ones. In the political agenda, air quality issues are related with climate change mitigation, since many actions towards air quality improvement contribute to the reduction of greenhouse gas emissions.

Traffic emissions, an increased number of vehicles, road-traffic density, industrial areas, as well as anthropogenic activities, are some of the dominant factors that contribute to the increase in the concentration of pollutants in ambient air, leading to the deterioration of air quality (Antonopoulou *et al*., 2023).

Around 90% of city dwellers in Europe are exposed to pollutants at higher concentrations than the air quality levels deemed harmful to health. For example, fine particulate matter (PM2.5) in air has been estimated to reduce life expectancy in the EU by more than eight months (Dumitru and Wendling, 2021).

Air pollution also harms the ecosystems and the environment. According to Dumitru and Wendling (2021) between 1990 and 2010, acidification problems in Europe's sensitive ecosystem areas were significantly reduced due to acid deposition of excess sulphur and nitrogen compounds. Vulnerable ecosystems exposed to high atmospheric nitrogen decreased slightly between 1990 and 2010.

In this work the focus is air quality in relation to human health. 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 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 ($PM_{2.5}$).

Particulate matter, nitrogen dioxide and ground-level ozone, are currently recognised as the three pollutants that most significantly affect human health. Long-term and peak exposures to these pollutants range in severity of impact, from impairing the respiratory system to premature death. The long-term exposure to unhealthy ambient-air conditions contributes to the onset of diseases, which are related to the respiratory system, cardiovascular system, lung function, cancers and cognitive decline (Antonopoulou *et al*., 2023).

The scientific community has developed an array of air quality indices, that describe the potential impact of pollution levels on human health, to research the air quality and its related effects. In general, these indices are a metric for a population health risk assessment (Antonopoulou *et al*., 2023; Cairncross *et al.*, 2007; WHO, 2021).

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 emissions, background pollutant concentrations, pollution sources, physical processes, and photochemical reactions (Khan *et al*., 2022; Miao *et al*., 2023).

It is known that air pollution impacts particularly sensitive population – children, the elderly, and people with respiratory and cardiovascular conditions. Exposure to fine particulate matter (PM2.5), a dominant air pollutant, is associated with adverse health effects such as respiratory and cardiovascular diseases and premature mortality (*e.g.*, Anderson *et al*., 2012; Zhan *et al*., 2023).

The Air Quality Index (AQI) provides information between the relation of air quality and its impact on public health. AQI can be calculated for five pollutants, namely the low-level tropospheric ozone (O_3), particle matter (PMs), carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) (Cairncross *et al.,* 2007; Spyropoulos *et al*., 2021).

6.2 Law and guidelines

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 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.

NATURELAB selected, since the proposal stage, 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 6.1 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 6.1 – 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)]	[b)]	25 μg/m^3
	Annual	40 μg/m^3	10 μg/m^3
Particulate Matter: PM_{10}	24h[a)]	50 μg/m^3	45 μg/m^3
	Annual	20 μg/m^3	15 μg/m^3
Particulate Matter: $PM_{2.5}$	24h[a)]	25 μg/m^3	15 μg/m^3
	Annual	10 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.

6.3 Equipment used

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. (…) 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*."

The Portuguese ES coordinators from CMS and RN acquired AEROQUAL series 500 equipment, and sensors for the three air quality indicators chosen: NO_2; PM_{10} and $PM_{2.5}$. The equipment was tested with the support from the company, providing them during the kick-off meeting. It is important that the users of the equipment are well familiar with it before the measurements, including the process of downloading data to the computer.

Figure 6.1 and Figure 6.2 show the equipment being tested at the LNEC Campus. It was observed differences within locations but, apparently, NO_2 was more stable compared to the particle's measurements (PM_{10} and $PM_{2.5}$). Annex III depicts the AEROQUAL sensor specifications.

Figure 6.1 – Outdoor particle measurements at the LNEC campus with the AEROQUAL sensor. Differences within short-distance locations were observed, apparently correlated with emission sources (29th July 2023)

Figure 6.2 – Outdoor nitrogen dioxide measurements at the LNEC campus with the AEROQUAL sensor (29th July 2023)

6.4 Characterisation of the air quality at the Sintra ES

The four Experimental Sites are distinct in terms of setting and proximity to potential urban air pollution sources (*e.g.*, streets and roads). The ES1 Parque Natural Sintra Cascais/Forest (PT) and the ES2 Ribafria Park where one of the Healing Gardens of NATURELAB will be implemented, are the ones with a less urbanised surrounding. On the contrary, the ES3 Mira Sintra and ES4 Rinchoa Eco-Park, are inserted in a more urbanised context.

The preliminary assessment of air quality was done by the Sintra Municipality from July to October 2023. At each site, two different locations were chosen to implement the air quality measurements, and measurements were made on different dates, as established. The total dataset for the 4 locations encompasses around 50 measurements. Although it is not possible to directly compare instant measurements with a 24h average (the WHO standard, *cf.* Table 6.1), the conclusions are that all concentrations measured at the four ES are below the standard. For the case of $PM_{2.5}$ it is the indicator with the values much below the standard (<3 μg/m^3), with ES3 and ES4 depicting the highest values. For PM_{10} the results are slightly higher, with an average of 11 μg/m^3 for ES1 and ES2. Again, the ES3 and ES4 results are higher compared to the other two, reaching an average of 14 μg/m^3 for PM_{10} at the Rinchoa Ecopark (ES4).

The WHO standard for NO_2 is an annual average, being more difficult to make comparisons with instant measurements. Some results obtained are over 40 μg/m^3, and instantaneous peak values were registered (*e.g.*, around 400 μg/m^3), which may be due to external conditions (*e.g.*, wind, pollutant sources) or sensor reading uncertainty. Not many differences were observed among the ES, for the case of this parameter. It is likely that although the ES1 and ES2 represent a more natural setting, the fact that they are near urban activities and that measurements were done closer to the borders of the green infrastructures, and not in remote areas more protected from air sources, played a role in the results obtained.

In the Sintra territory there is a station form the APA (Portuguese Environmental Agency) network for Air Monitoring (https://qualar.apambiente.pt/en/). It is the Station with the Code 3089, located in the urban setting of Mem Martins (Figure 6.3 depicts the location of the 4 ES in Sintra and of this Station).

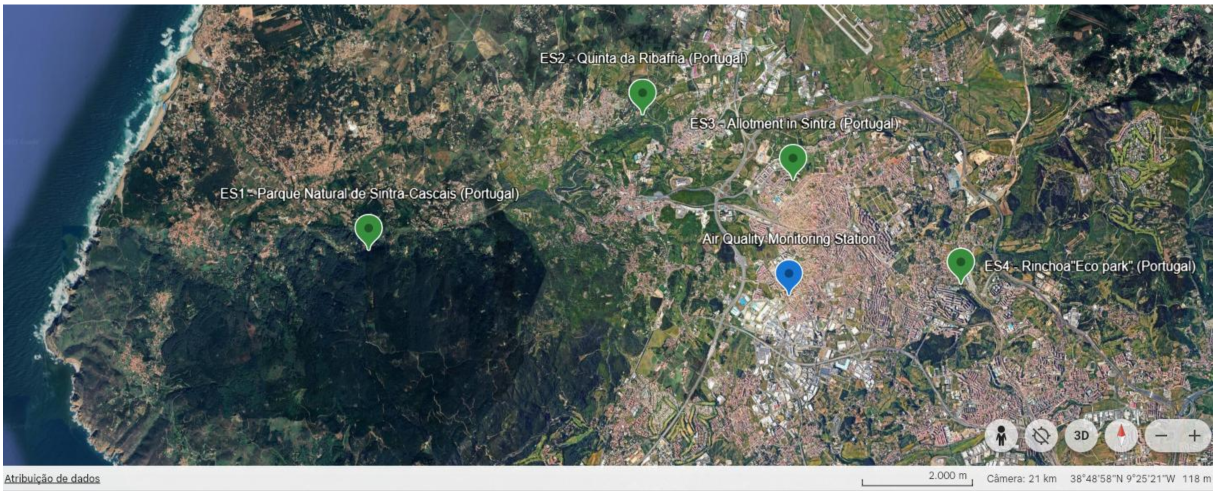


Figure 6.3 – Location of the air quality monitoring station in Sintra

As complementary information, data for this Station, measured from August to October 2023 (6 data points in total) were collected and is presented in Table 6.2.

Table 6.2 – Ambient air quality measurements. Source: Portuguese Environmental Agency.

Date	PM2.5 Daily Average (μg/m^3)	PM10 Daily Average (μg/m^3)	NO2 Hourly Max. (μg/m^3)
02/08/2023	6	18	10
08/08/2023	17	34	47
16/08/2023	5	10	7
22/09/2023	2	14	52
09/10/2023	13	31	103
16/10/2023	6	19	22
Average	**8**	**21**	**40**

An overview of the averages from Mem Martins (Sintra) air quality data (Table 6.2) allows understanding that they follow a similar pattern, in terms of magnitude of concentrations and differences among the parameters, for the three air quality indicators, compared to the measurements done with the AEROQUAL sensor by the project local partner.

Noteworthy, the monitoring at the Sintra ES was implemented in articulation with the Rio Neiva team that monitored two sites (presented in the coming section). This collaboration allowed overcoming doubts about operating the AEROQUAL sensor and downloading data from datalogger.

6.5 Characterisation of the air quality at the Rio Neiva ES

The two Experimental Sites located in Northen Portugal, ES5 and ES6, were monitored following the same approach as Sintra ES, and the guidelines given by LNEC.

The average $PM_{2.5}$ concentrations measured at the ES of 6 μg/m^3(ES5) and 13 μg/m^3 (ES6). For PM_{10} the results are higher, with an average of 23 μg/m^3 for ES5 and of 27 μg/m^3 for ES6.

The NO_2 average concentrations are similar for both locations 11 μg/m^3 and 12 μg/m^3, respectively for ES5 and ES6.

Again, not being possible to directly compare instant measurements with a 24h average WHO standard, the concentrations measured at the two ES are not likely to pose health risks, as being below the values depicted in Table 6.1. It was expected that the ES in Esposende would have significantly lower air quality parameters, compared to Sintra that is a more densely urbanised region.

6.6 Overview of air quality assessment results

The results obtained corroborated the relevance of assessing air quality and that more urban settings (such as Sintra) are likely to have higher concentrations of nitrogen dioxide. The results are consistent with the settings, and it is concluded that no air quality issue should hinder the potential of these six ES for promoting the health and well-being of populations.

7 | Sustainable and climate resilient water management at the urban Experimental Sites

7.1 Introduction and scope

Water is a resource needed for people, nature and the economy. Besides a vital need, water is a local and global resource, a transport corridor, a climate regulator, and home or provider to many species. Europe's rivers, lakes, seas and groundwater are under pressure from pollution, eutrophication, over-exploitation and climate change (EEA, 2023), similarly with other regions of the globe.

The water available for human use is limited to freshwater from groundwater aquifers and surface water (mostly rivers), which takes only about 0.003% of the global water (Gleick, 2014). The available water resources are irregularly distributed all over the world. Almost every country depends on freshwater resources to comply with domestic water supply and economic activities, particularly agriculture and industry. Agriculture (including irrigation, livestock, and aquaculture) is the largest water consumer, accounting for 69% of annual water withdrawals globally, while industry (including power generation) accounts for 19% and domestic (household) for 12% (WWAP, 2019). Recreational and environmental water uses have long been paid less attention in water resource allocation, but recently growing percentages are seen in many countries.

As urbanization continues to develop, sustainable development increasingly depends on effective planning of urban growth, particularly in hazard-prone regions. Traditionally, urban water systems, including water supply, distribution, treatment, drainage, and wastewater facilities, were developed and managed independently, often overlooking their interdependencies and broader socio-economic impacts (Fu and Butler, 2021). These systems were designed based on criteria that have since evolved with changing contexts.

Today, there is a broad recognition that urban water systems serve functions beyond water provision and wastewater management. Blue-green infrastructure, a key component of urban water infrastructure, contributes to climate change mitigation and adaptation by reducing urban heat island effects, enhancing biodiversity, and improving community well-being. Furthermore, it plays a critical role in advancing circularity by enabling the reduction, reuse, and recovery of resources (Fu and Butler, 2021).

The NATURELAB project proposes an innovative approach to contribute to resilient communities, by enhancing the green and blue areas' benefits, such as the resilience to climate change, the promotion of biodiversity and urban water management, and addressing air pollution and noise levels as well. As water is an essential component for the human activities and for nature, it is fundamental to address the sustainable and safe water use and management at the urban ES, as well as to evaluate the ES contribution, as nature-based solutions, to increase the resilience to climate change in urban areas - *e.g.* rainfall harvesting to irrigate the garden/allotment; NBS for *in situ* stormwater storage, treatment, controlled infiltration or discharge, and, whenever feasible, reuse in irrigation). For this, it is particularly relevant to consider the diverse ES contexts and needs.

7.2 EU policy recommendations and NBS legislation

The European Commission[8] defines NBS as:

"Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions."

Taking into account this importance, several regulations, policies, programmes and projects were developed by the EU or with its support.

NBS had gained visibility in urban planning and development, with several European cities incorporating green infrastructure, such as parks, green roofs, and urban forests, into their strategies to address urban challenges like heat island effects and air pollution.

Various existing environmental legislation in the EU, such as the Water Framework Directive and the Habitats Directive, indirectly supported NBS by emphasizing the importance of preserving natural ecosystems and their functions.

Some examples of the key aspects related to NBS in the EU policy, including the resume of more than 30 EU-projects and initiatives, were presented in NATURELAB D1.1.

7.3 Water sustainability and urban resilience under climate change

The European R&I Programme has been promoting projects related to NBS to increase knowledge and to create technical, political, and other conditions for cities' renaturalisation. These projects analyse several objectives and perspectives, such as the improvement of regulatory instruments, the increase of the natural capital through NBS, or the capacity to obtain a more sustainable and resilient urban ecosystem (Beceiro, 2021). In the context of urban resilience, some NBS studies were carried out focusing on some ecosystem's services enhancement or specific challenges, such as urban heat island mitigation (Panno *et al*., 2017; Zölch *et al*., 2016), air quality improvement, climate mitigation and adaptation (Calliari *et al*., 2019; Naumann *et al*., 2014) and water quality improvement (Hancz *et al*., 2018), among others. Particularly for stormwater water management, the NBS role for regulating urban surface runoff (Zölch *et al*., 2016) and benefits of NBS for water pollution control (Liquete *et al*., 2016) were analysed. To date, the NBS capabilities to build resilience have only been analysed from the standpoint of addressing climate shocks or increasing ecosystem's services in the urban area (Staddon *et al*., 2018; UNEP, 2014).

Nature-based solutions have been emerging as sustainable solutions that contribute to urban resilience while addressing climate change challenges in the water sector (Beceiro, 2021), in flood and drought risk management (Lallemant *et al*. 2021) and, in a broader sense, in the water management. They provide environmental natural or man-made infrastructures that benefit human well-being and economy.

[8] https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en.

Recently, the United Nations Educational, Scientific, and Cultural Organization highlighted the importance of NBS to address water availability in urban areas (UNESCO, 2018). NBS may also contribute to the maintenance, enhancement, and restoration of biodiversity and ecosystems in urban areas while addressing societal challenges and promoting sustainable and resilient urbanization (Wendling *et al*., 2018, EC, 2021). They provide an excellent opportunity to address a diversity of issues associated with anthropogenic impacts on the water cycle. These include poor water quality, water availability for extraction, groundwater and surface water levels, aquifer recharge, stormwater management, water treatment, wetland habitat management, soil water management, and ecological quality (EC, 2021).

WHO states that green spaces can positively affect physical activity, social, and psychological well-being, improve air quality and reduce exposure to noise; however, they can also be associated with an increased risk of injury due to increased recreational and sport-related use (WHO, 2016, 2023). Also presents as key-aspect of understanding links between green space and health, the understanding on how people's exposure to green space is conceptualised and measured. As with consideration of any health outcomes associated with an environmental exposure, how the exposure is measured is important in determining what relationships are apparent, and what causal pathways and mechanisms can be inferred (Morris *et al*., 2019 op. cited in WHO, 2023). Studies of green space and health to date have used a variety of measures and indicators.

The EC (2021) published a handbook on evaluating the impact of nature-based solutions with the objective to support the adoption of common indicators and methods for assessing the performance and impact of diverse types of NBS. The handbook is designed to be relevant for NBS implemented across a wide geographic area and at a multitude of scales. The integrated NBS assessment framework presented in the handbook has been developed with the three-fold objective of: serving as a reference for relevant EU policies and activities; orienting urban practitioners in developing robust impact evaluation frameworks for nature-based solutions at different scales; and providing a comprehensive set of indicators and methodologies. The indicators address impact across the 12 societal challenge areas: 1. Climate Resilience, 2. Water Management, 3. Natural and Climate Hazards, 4. Green Space Management, 5. Biodiversity, 6. Air Quality, 7. Place Regeneration, 8. Knowledge and Social Capacity Building for Sustainable Urban Transformation, 9. Participatory Planning and Governance, 10. Social Justice and Social Cohesion, 11. Health and Well-being 12. New Economic Opportunities and Green Jobs.

7.4 Methodologies to promote sustainable and climate resilient water management at the NATURELAB Experimental Sites

The green space characteristics may condition the potential for human activities, such as the type of specific activities or their duration. Additionally, they may require different solutions to ensure a sustainable water management, depending on the water availability in the space (*e.g.*, grey water, rainwater, stormwater) and the demand needs and respective purpose, *e.g.*, whether is a domestic or irrigation use, as requirements differ. These aspects will also inform the infrastructure (need for water storage) and maintenance needs, respective cost, and management responsibilities, including solutions that promote community involvement (*e.g.*, garden community maintenance).

To ensure sustainable and climate-resilient water management for the ES, it is important to consider the following steps:

1. Characterisation of the ES context and activities to be carried out
2. Characterisation 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 definition of the sustainability targets
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.

7.5 NATURELAB indicators for sustainable and climate resilient water management

A preliminary set of indicators was identified, related to sustainable and climate-resilient water management, based on previous developments from European projects and mainly addressing water-related aspects, complemented by other indicators to assess relevant aspects within this scope, identified from a literature review. The set of indicators is presented in Table 7.1, including an indication of whether each indicator is mandatory or optional, depending on the type of green space, as well as which assessment points of view are addressed.

Besides the aspects related to the sustainable and climate-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, and 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, and environmental education.

Table 7.1 – Indicators related to sustainable and climate resilient water management in an Experimental Site

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	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)	No. of operational physical access points to water supply (public drinking water fountains, cooling fountains, etc.) in the area *Answer: No../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 adequate? *Answer: yes/partially/no*	1	Monitor, maintain wastewater systems for environmental and public health	x	x	x
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	Further information: 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	Further information: B-WaterSmart, Silva *et al.* (2023); RESCCUE, Cardoso *et al.* (2020)	Is drinking water being significantly used for non-potable uses? *Answer (identify): a) irrigation, b) street cleaning, c) firefighting, d) other (specify)*	1	Implement greywater systems; optimize non-potable water usage wisely.	x	x	x
Water use from alternative sources	Further information: B-WaterSmart, Silva *et al.* (2023); RESCCUE, Cardoso *et al.* (2020)	Is water being used for non-potable uses (*e.g.*, a) irrigation, b) street cleaning, c) firefighting, 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	Further information: RESCCUE, Cardoso *et al.* (2020)	Which types of water supply sources are being used? *Answer (identify): a) surface water, b) groundwater (wells), c) rainwater, d) stormwater, e) reclaimed water, f) sea water, e) other (specify)*	1	Establish backup sources; ensure water supply resilience.		x	
Redundancy in rainwater or stormwater storage capacity	Further information: B-WaterSmart, Silva *et al.* (2023), RESCCUE, Cardoso *et al.* (2020)	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	

Indicator	**Description**	**Metrics and easy of determination***	*	**Recommendation**	**Potential relevance** T1**	**T2**	**T3**
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 flooding		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; effectively protect ecosystems from harmful contaminants		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 are met; monitor and maintain water quality for environmental health.		x	x
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	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)	No. of operational physical access points to water supply (public drinking water fountains, cooling fountains, etc.) in the area *Answer: no./km^2*	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
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	Further information: 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	Further information: B-WaterSmart, Silva *et al*. (2023); RESCCUE, Cardoso *et al*. (2020)	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

Indicator	Description	Metrics and easy of determination*	*	Recommendation	Potential relevance**		
					T1	T2	T3
Water use from alternative sources	Further information: B-WaterSmart, Silva *et al*. (2023); RESCCUE, Cardoso *et al*. (2020)	Is being used for non-potable uses (*e.g.*, a) irrigation, b) street cleaning, c) firefighting, 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	Further information: RESCCUE, Cardoso *et al*. (2020)	Which types of water supply sources are being used? *Answer (identify): a) surface water, b) groundwater (wells), c) rainwater, d) stormwater, e) reclaimed water, f) sea water, e) other (specify)*	1	Establish backup sources; ensure resilience for water supply.		x	
Redundancy in Rainwater or stormwater storage capacity	Further information: B-WaterSmart, Silva *et al*. (2023), RESCCUE, Cardoso *et al*. (2020)	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

8 | Final remarks

The report allows a clearer perception of the status and challenges of the work at the NATURELAB Experimental Sites in Portugal, particularly in monitoring more complex variables such as daylight and solar radiation, environment sound and air quality.

Daylight and solar radiation components of the outdoor environment and their influence on the health and well-being of individuals are new fields of research, and the first work done, with initial monitoring carried out at some ES in Sintra, provided useful understandings. More findings are expected in the coming months, based on additional monitoring actions, and the evaluation of the new indicators proposed.

For the case of environmental sound, a dual approach is needed since many sound sources of natural origin can have positive effects on human health. The results of preliminary measurements showed a variation between 44-47 dB(A) at Ribafria Farm and 40-47 dB(A) at the Parque Urbano da Rinchoa. These values will be used for optimizing the choice of locations for the coming monitoring campaigns. Nevertheless, the assessment of the sound environment and their potential does not depend solely on sound levels. Other factors, such as the qualitative assessment of the sound environment and proximity to urban housing are important. In this context, the future steps will encompass the characterisation of the sites already assessed, by using soundscape methodologies.

For the case of results of air quality measurements, the results are consistent with the settings of the six locations, and it is concluded that no air quality issue should hinder the potential of these six ES for promoting the health and well-being of populations, one of the NATURELAB project goals. Noteworthy, it is not possible to directly compare the instant measurements done (with the AEROQUAL portable sensor) with the 24h average WHO standard. Still, the initial measurements of nitrogen dioxide (NO_2), particulate matter < 10 microns (PM_{10}) and < 2.5 microns ($PM_{2.5}$) indicated that their concentrations at the six Portuguese ES are below the WHO standards. The overview of the averages from Mem Martins (Sintra) air quality data, obtained at the APA (Portuguese Environmental Agency) network for Air Monitoring, showed that these results follow a similar pattern (magnitude of concentrations and differences among the parameters) compared to the measurements done by NATURELAB with the AEROQUAL sensor which supports both the methodologic approach, and the use of the equipment.

Finally, the NATURELAB indicators for sustainable and climate resilient water management are based on sound knowledge and expertise from LNEC, and it is not expected major challenges in their application to the 6 Experimental Sites in Portugal, and beyond.

Lisbon, LNEC, April 2025

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ANNEXES

ANNEX I
Indicators regarding spatial characteristics, design, and conditions for the six Experimental Sites in Portugal

Table A1.1 – Indicators regarding Spatial characteristics, design, and conditions for Experimental Site 1 – Sintra-Cascais Natural Park

Accessibility	
Space Entries	Fit and sufficient
Fences	Fit and sufficient
Walking Paths	Fit and sufficient
Bike Lanes	Fit and sufficient
Handicapped Adaptations	Does not apply
Car Parking Spaces (i[9]: Possibility to reach the site by car)	Present in some areas
Guiding Signage	Present in some areas
Slope (i:Hillshade location, Inclination)	Present in some areas
Safety	
Lighting (i: streelights)	Almost no presence
Visibility from Ground (i: Could you be seen from outside the site?)	Almost no presence
Visibility from Surrounding Buildings	Almost no presence
Safety Adaptations from Cars	Almost no presence
Safety Adaptations from Bikes	Almost no presence
CCTV (Closed-Circuit Television)	No presence
Infrastructural issues (*e.g.*, high slopes)	Almost no presence
Maintenance	
General Litter	No presence
Alcohol Use	Does not apply
Drug use	Does not apply
Sex Work	Does not apply
Vandalism	Does not apply
Noise	Almost no presence
Unpleaseant smells	No presence

[9] "i" stands for "information" (as was input through the NATURELAB App Sites).

Table A1.2 – Indicators regarding Spatial characteristics, design, and conditions for Experimental Site 2 – Ribafria Farm

Accessibility	
Space Entries	Fit and sufficient
Fences	Fit and sufficient
Walking Paths	Fit and sufficient
Bike Lanes	Not present
Handicapped Adaptations	Not present
Car Parking Spaces (i: Possibility to reach the site by car)	Present in some areas
Guiding Signage	Present in some areas
Slope (i:Hillshade location, Inclination)	Present in some areas
Safety	
Lighting (i: streelights)	Almost no presence
Visibility from Ground (i: Could you be seen from outside the site?)	Present in some areas
Visibility from Surrounding Buildings	Almost no presence
Safety Adaptations from Cars	No presence
Safety Adaptations from Bikes	No presence
CCTV (Closed-Circuit Television)	No presence
Infrastructural issues (*e.g.*, high slopes)	Almost no presence
Maintenance	
General Litter	Mostly present
Alcohol Use	Does not apply
Drug use	Does not apply
Sex Work	Does not apply
Vandalism	Does not apply
Noise	Present in some areas
Unpleaseant smells	No presence

Table A1.3 – Indicators regarding Spatial characteristics, design, and conditions for Experimental Site 3 – Horticulture Allotment in Mira-Sintra

Safety	
Lighting (i: streelights)	Present in some areas
Visibility from Ground (i: Could you be seen from outside the site?)	Present in some areas
Visibility from Surrounding Buildings	Present in some areas
Safety Adaptations from Cars	Almost no presence
Safety Adaptations from Bikes	No presence
CCTV (Closed-Circuit Television)	No presence
Infrastructural issues (*e.g.*, high slopes)	Present in some areas
Maintenance	
General Litter	Present in some areas
Alcohol Use	Does not apply
Drug use	Does not apply
Sex Work	Does not apply
Vandalism	Does not apply
Noise	Present in some areas
Unpleaseant smells	Does not apply

Table A1.4 – Indicators regarding Spatial characteristics, design, and conditions for Experimental Site 4 – Rinchoa Eco-Park Sintra

Accessibility	
Space Entries	Fit and sufficient
Fences	Fit and sufficient
Walking Paths	Fit and sufficient
Bike Lanes	Not present
Handicapped Adaptations	Not fit for purpose
Car Parking Spaces (i: Possibility to reach the site by car)	Present in some areas
Guiding Signage	Present in some areas
Slope (i:Hillshade location, Inclination)	Present in some areas
Safety	
Lighting (i: streelights)	Present in some areas
Visibility from Ground (i: Could you be seen from outside the site?)	Almost no presence
Visibility from Surrounding Buildings	Present in some areas
Safety Adaptations from Cars	No presence
Safety Adaptations from Bikes	No presence
CCTV (Closed-Circuit Television)	No presence
Infrastructural issues (*e.g.*, high slopes)	Almost no presence
Maintenance	
General Litter	Almost no presence
Alcohol Use	No presence
Drug use	No presence
Sex Work	No presence
Vandalism	No presence
Noise	Present in some areas
Unpleaseant smells	Almost no presence

Table A1.5 – Indicators regarding Spatial characteristics, design, and conditions for Experimental Site 5 – Foz do Neiva

Accessibility	
Space Entries	Not fit for purpose
Fences	Fit and sufficient
Walking Paths	Fit, sufficient, and aesthetically pleasing
Bike Lanes	Fit, sufficient, and aesthetically pleasing
Handicapped Adaptations	Fit, sufficient, and aesthetically pleasing
Car Parking Spaces (i: Possibility to reach the site by car)	Always present
Guiding Signage	Always present
Slope (i:Hillshade location, Inclination)	Almost no presence
Safety	
Lighting (i: streelights)	Present in some areas
Visibility from Ground (i: Could you be seen from outside the site?)	Present in some areas
Visibility from Surrounding Buildings	Present in some areas
Safety Adaptations from Cars	No presence
Safety Adaptations from Bikes	No presence
CCTV (Closed-Circuit Television)	Always present
Infrastructural issues (*e.g.*, high slopes)	No presence
Maintenance	
General Litter	Almost no presence
Alcohol Use	No presence
Drug use	No presence
Sex Work	No presence
Vandalism	No presence
Noise	Almost no presence
Unpleaseant smells	No presence

Table A1.6 – Indicators regarding Spatial characteristics, design, and conditions for Experimental Site 6 – Esposende Municipality

Safety	
Lighting (i: streelights)	Almost no presence
Visibility from Ground (i: Could you be seen from outside the site?)	Present in some areas
Visibility from Surrounding Buildings	Almost no presence
Safety Adaptations from Cars	No presence
Safety Adaptations from Bikes	No presence
CCTV (Closed-Circuit Television)	Does not apply
Infrastructural issues (*e.g.*, high slopes)	Almost no presence
Maintenance	
General Litter	Almost no presence
Alcohol Use	No presence
Drug use	No presence
Sex Work	No presence
Vandalism	No presence
Noise	Present in some areas
Unpleaseant smells	No presence

ANNEX II
Bruel & Kajer sound analyser (model 2260) – Specifications

Technical specifications (summary)

The following is a summary of the technical specifications of the Bruel & Kajer sound analyser (model 2260), which makes it suitable for fulfilling the objectives of the measurements carried out.

Measuring Range
Octave and 1/3-octave: 90 dB A-weighted: 80 dB

Adjustable readings from 70 dB to 130 dB in 10 dB steps (A-weighted: 80 dB range)

Passive Attenuation: Microphone Attenuator ZF 0023 (included) effectively increases all full-scale readings by 20 dB

Under range Indication
Octave and 1/3-octave: 90dB below upper limit for each range setting, corresponding to less than 0.5 dB error.

Detectors
The sound level meter contains several detectors working in parallel on every measurement: Octave

Band Filters (8) or 1/3-octave Band Filters (24): Pre-weighted by Lin., each with a detector channel containing one linear averaging detector

Overload Detector: Monitors the overload condition

A-weighted: Broadband detector channel with Fast exponential time weighting. Single channel only.

Octave And 1/3-octave Band Filters
Conform to IEC 1260 (1995)

Octave Band Centre Frequencies: 63Hz, 125Hz, 250Hz, 500Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz (nominal)

1/3-octave Band Centre Frequencies: 50 Hz, 63 Hz, 80 Hz, 100 Hz, 125 Hz, 160 Hz, 200 Hz, 250 Hz, 315 Hz, 400 Hz, 500 Hz, 630 Hz, 800 Hz, 1 kHz, 1.25 kHz, 1.6 kHz, 2 kHz, 2.5 kHz, 3.15 kHz, 4 kHz, 5 kHz, 6.3 kHz, 8 kHz, 10 kHz (nominal)

Real-time Frequency Range: 50 Hz to 10 kHz center frequencies

Inherent Noise Level
Inherent noise is the combination of the electrical noise and the thermal noise from the microphone at 20 °C. Typical values using a microphone Type 4189 with a nominal sensitivity:
1/3-octaves: 2 dB at 1 kHz, 8 dB at 10 kHz

1/1-octaves: 6 dB at 1 kHz, 12dB at 8 kHz

Calibration
External (acoustic): Using the Sound Level Calibrator Type 4231/ 4226. Internal (electrical): Uses internally generated electrical signal combined with keyed-in value of microphone sensitivity

Supplied Microphone
Pre-polarized Free-field 1/2 " Microphone Type 4189

Nominal sensitivity: 26 dB ± 1.5 dB re1 1V/Pa

Capacitance: 14 pF (at 250 Hz)

ANNEX III
AEROQUAL Sensor specifications

Portable & Fixed Monitor Sensor Specifications

aeroqual

Gas	Sensor Code	Sensor Type[1]	Range (ppm)	Minimum Detection Limit (ppm)	Accuracy of Factory Calibration[2]	Resolution (ppm)	Response time (s)[3]	Operating Conditions[4]		Application Type[5]			Ranger	S3/500[6]	S900	S930
								Temp	RH	ENV	IAQ	IND				
Ammonia (NH_3)	NH	GSS	0-1000	2	<±5 ppm +15%	1	30	0 to 40°C	10 to 90%			✓	•	•	•	
Ammonia (NH_3)	ENG	GSE	0-100	0.2	<±0.5 ppm + 10%	0.1	120	0 to 40°C	15 to 90%			✓	•	•	•	•
Carbon monoxide (CO)	ECM	GSE	0-25	0.05	<±0.5 ppm 0-5 ppm <±10% 5-25 ppm	0.01	60	0 to 40°C	15 to 90%	✓			•	•	•	•
Carbon monoxide (CO)	ECN	GSE	0-100	0.2	<±1 ppm 0-10 ppm <±10% 10-100 ppm	0.1	30	0 to 40°C	15 to 90%	✓	✓	✓	•	•	•	•
Carbon monoxide (CO)	CO	GSS	0-1000	1	<±2 ppm + 15%	1	30	0 to 40°C	10 to 90%			✓	•	•	•	
Carbon dioxide (CO_2)	CD	NDIR	0-2000	10	<±10 ppm + 5%	1	120	0 to 40°C	0 to 95%	✓	✓	✓	•	•	•	
Carbon dioxide (CO_2)	CE	NDIR	0-5000	20	<±20 ppm + 5%	1	120	0 to 40°C	0 to 95%		✓	✓	•	•	•	
Chlorine (Cl_2)	ECL	GSE	0-10	0.01	<±0.02 ppm + 10%	0.01	30	0 to 40°C	15 to 90%	✓		✓	•	•	•	•
Formaldehyde (CH_2O)	EF	GSE	0-10	0.01	<±0.05 ppm 0-0.5 ppm <±10% 0.5-10 ppm	0.01	120	0 to 40°C	15 to 90%			✓	•	•	•	•
Hydrogen (H_2)	HA	GSS	0-5000	5	<±10 ppm + 10%	1	30	0 to 40°C	10 to 90%			✓	•	•	•	
Methane (CH_4)	MT	GSS	0-10000	10	<±20 ppm + 15%	1	60	0 to 40°C	10 to 90%			✓	•	•	•	
Hydrogen sulfide (H_2S)	EHS	GSE	0-10	0.04	<±0.05 ppm 0-0.5 ppm <±10% 0.5-10 ppm	0.01	30	0 to 40°C	15 to 90%	✓			•	•	•	•
Hydrogen sulfide (H_2S)	EHT	GSE	0-100	0.4	<±0.5 ppm 0-5 ppm <±10% 5-100 ppm	0.1	30	0 to 40°C	15 to 90%			✓	•	•	•	
Nitrogen dioxide (NO_2)	END	GSE	0-1	0.005	<±0.02 ppm 0-0.2 ppm <±10% 0.2-1 ppm	0.001	30	0 to 40°C	15 to 90%	✓			•	•	•	•
NMHC	VN	GSS	0-25	0.1	<±0.1 ppm + 10%	0.1	60	0 to 40°C	10 to 90%	✓			•	•	•	
Ozone (O_3)	OZS	GSS	0-0.05	0.001	<±0.002 ppm	0.001	240	0 to 40°C	10 to 90%			✓	•	•	•	•
Ozone (O_3)	OZU	GSS	0-0.15	0.001	<±0.005 ppm	0.001	60	0 to 40°C	10 to 90%	✓	✓	✓	•	•	•	•
Ozone (O_3)	OZL	GSS	0-0.5	0.001	<±0.008 ppm 0-0.1 ppm <±10% 0.1-0.5 ppm	0.001	60	0 to 40°C	10 to 90%	✓	✓	✓	•	•	•	•
Ozone (O_3)	EOZ	GSE	0-10	0.01	<±0.01 ppm + 7.5%	0.01	60	0 to 40°C	15 to 90%			✓	•	•	•	•
Ozone (O_3)	EOZH	GSE	0-30	0.01	<±0.05 ppm + 10%	0.01	60	0 to 40°C	15 to 90%			✓	•	•	•	
Particulate Matter ($PM_{2.5}$ and PM_{10})	PM	LPC	0.001-1.000 mg/m³	0.001 mg/m³	± 0.005 mg/m³ + 15%	0.001 mg/m³	5	0 to 40°C	0 to 90%	✓	✓			•		

Notes
1. Sensor Types: Gas Sensitive Semiconductor (GSS), Gas Sensitive Electrochemical (GSE), Non-dispersive Infra-red (NDIR), Laser Particle Counter (LPC), Photo Ionization Detector (PID).
2. The accuracy is valid for the conditions stated in the calibration certificates, not including calibration gas tolerance. Relative errors are % of reading.
3. Response time is the time to reach 90% of final reading in response to a step change in gas concentration (T90). In practice response times vary due to air mass transport factors and concentration gradients.
4. Sensor performance may degrade outside of stated conditions. Avoid condensation which may damage sensors. Sensors may exhibit temperature and humidity interferences which will affect accuracy. Additional enclosure protection may extend operating environmental conditions, please contact Aeroqual for further information. Note sensors are designed to operate in environments with oxygen levels similar to ambient air.
5. Application type: ENV = outdoor environmental monitoring, IAQ = indoor air quality, IND = industrial health and safety
6. Not all sensors can be used with the Series 300 and 500 when inside the water and dustproof enclosure (HH ENC). Please contact Aeroqual for advice on your specific application.

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