D2.2 Setting the stage for ecological and socioeconomic status & disparities profiles in the CiPeLs

JUSTNature | Work Package 2, Task 2.2

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION LIST

Term	Description
AI	Artificial Intelligence
BOA	Bottom-Of-Atmosphere
CiPeL	City Practice Lab
D	Deliverable
DEM	Digital Elevation Model
DHM	Digital Height Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EO	Earth Observation
ESA	European Space Agency
EU	European Union
Fc	Fractional Cover
GDPR	General Data Protection Regulation
GIS	Geographical Information System
GHG	Green-House Gases
HRL	High Resolution Layers
IPCC	Intergovernmental Panel On Climate Change
LC	Land Cover
LGBM	Light Gradient Boosting Model
LPI	Largest Patch Index
LST	Land Surface Temperature
LULC	Land Use Land Cover
MAE	Mean Absolute Error
ML	Machine Learning
MLC	Machine Learning Clustering
NbS	Nature-based Solutions
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
RA	Relative Abundange
SMA	Spectral Mixture Analysis
SVF	Sky View Factor
SUHI	Surface Urban Heat Island
T	Task
TIR	Thermal Infrared Range
UHI	Urban Heat Island
WP	Work Package
Ws	Walkability Score

EXECUTIVE SUMMARY

This deliverable aims to elaborate and describe the methodology used to define ecological and socioeconomic status and disparities profiles, useful to support the planning, implementation and wide use of Nature-based Solutions (NbS) in cities. The deliverable addresses the municipal technicians and officials, city experts and professionals in the field of strategic and urban planning in the CiPeLs, and the same actors in other cities that would like to reproduce the analysis as well. This document has quite a technical language and perspective, while the results and the profiles will be presented to a wider public and other stakeholder in future through more user-friendly documents (e.g., info cards).

This deliverable is structured in several parts. First, the introduction links the definition of the ecological and socioeconomic status and disparities profiles with the conceptual work done in T2.1 and presented in D2.1. Second, the concept of ecological and socioeconomic status and disparities profiles is elaborated and defined, providing the reader with a guidance on why and how the profiles can be useful for the strategic planning of NbS in cities. Data are relevant for the creation of the profiles and the third and fourth chapters focus on how data are collected and elaborated with the aim to create the ecological and socioeconomic profiles, building on the justice components. The fifth chapter provides a description of the methodology to build the profiles, based on a cluster analysis and the calculation of distances to analyze the disparities among clusters (or profiles). The sixth chapter proposes a first step to include the stakeholders' narratives into the building of the profiles, considering that ecological and socioeconomic disparities can sometimes turn into inequalities and that NbS can contribute to solve certain social issues (e.g., vulnerabilities, marginalities). The seventh chapter contains an example of results of the methodology included in this deliverable for the Bolzano case study. At the end, a concluding chapter draws a first link to future project activities, especially with the aim of further including city stakeholders' preferences and narratives in the results of this activity.

1 INTRODUCTION

1.1 Scope and outline of the report

The overall objective of the Horizon 2020 project JUSTNature is the activation of NbS by ensuring a just transition to low-carbon cities, based on the principle of the right to ecological space. The focus is on the cities since they represent a complex system where impacts related to big challenges such as climate change, biodiversity loss and human well-being are not distributed evenly, where low-income households are more often exposed to environmental issues, and environmental amenities are increasingly exclusive to high-income households [1].

This report is delivered as part of Task 2.2 "Creating ecological & socioeconomic status and disparities profiles". Being part of Work Package 2 on "Recognizing Low carbon | High air quality NbS potentials", the overall objective of the Task 2.2 is the development of ecological and socioeconomic profiles to assemble evidence on the spatial distribution and disparities of Low carbon | High air quality potentials in the CiPeLs (City Practice Labs). The development of the profiles is ongoing and builds on a mix of quantitative and qualitative methods and data, integrating the results of two subtasks, to conceptualize and provide practical guidance on how to identify disparities across various ecological space dimensions.

Subtask 2.2.1 concerns the assessment of the status of NbS underlying ecosystems, functionings, ecological disturbances and potential (spatial) disparities, while Subtask 2.2.2 develops a quantitative and qualitative evaluation of environmental and socioeconomic parameters driving needs and wants, and related spatial disparities.

This report addresses the municipal technicians and officials, city experts and professionals in the field of strategic and urban planning that would like to understand the method behind the creation of the profiles in the CiPeLs, and the same actors in other cities that would like to reproduce the analysis as well. In this regard, the report's specific objectives are to provide guidance on how to apply a mixed-methods approach and how this would help municipal planning departments and consultancy organisations, and to present and describe the way forward developed for setting the stage in terms of:

- Exploiting the possibility offered by the Copernicus data (i.e. free satellite data) and by the GEOSS platform to analyse and synthesise ecological parameters and to determine a first set of priority urban ecosystem conservation and restoration areas (supply potentials).

- Combining the supply potentials with socioeconomic data layers (e.g., population density) to better understand the distribution of needs and accessibility to functionings (demand potential).
- Applying a mix-methods approach to provide further in-depth insights into the CiPeLs in relation to the socioeconomic factors potentially affecting the needs and wants of marginal and vulnerable social groups for Low Carbon | High air quality NbS.
- Integrating and refining the results with a qualitative investigation of ecological and social needs and wants of actors daily dealing with inequalities in the urban area (semi-structured interviews to key actors).

In the following, a brief summary on how the report is structured into chapters is presented.

Chapter 1 gives an introduction into the report's scope and objectives and the connection with the preceding Deliverable 2.1 (D2.1) about conceptual and action framework on Low carbon | High air quality NbS potentials. It also outlines the various chapters, as well as interlinkages with other project activities.

Chapter 2 describes the concept of ecological and socioeconomic status and disparities profile and its usefulness for strategic planning activities.

Chapter 3 presents the collected data for the development of ecological and socioeconomic status and disparities profiles and the related challenges.

Chapter 4 defines how each component of justice (air quality, thermal, carbon, flora-fauna-habitat inclusiveness, spatial, and temporal) has been treated in the creation of the profiles, from a practical perspective.

Chapter 5 provides a description of the methodology for the building of the ecological and socioeconomic status and disparities profiles. The methodology is based on a cluster method and uses distance calculation and other analysis among and of clusters.

Chapter 6 investigates stakeholder narratives on needs and wants about NbS in cities, using semi-structured interviews to key actors. This chapter allows to start integrating the profiles with the perspectives of those actors who daily live in the city.

Chapter 7 describes the methodology to build the ecological and socioeconomic status and disparities profiles.

Chapter 8 presents an example of results, namely ecological and socioeconomic profiles for the Bolzano CiPeL.

Chapter 9 concludes and provides further insights to be collected in CiPeLs' workshops; it also presents a first explication on how the CiPeLs can use the profiles and the presented methodology.

1.2 Background: the conceptual and action framework on Low carbon | High air quality NbS potentials (D2.1)

As main output of the Task 2.1 "Determining the scientific knowledge base and developing a framework for assessing Low carbon | High air quality NbS potential and possible spatial disparities", D2.1 aimed to define:

- A conceptual framework, with focus on key concepts such as the various dimensions of justice, why ecological (space) justice, and how to activate NbS to inform other project activities; and
- An action framework for the activation of Low carbon | High air quality NbS potentials in a city, taking into consideration how NbS categories sustain defined functions while accounting for how these are spatially distributed and are reflecting needs or demands.

In this sense, this report, Deliverable 2.2 (D2.2), aims to go further and transform into a practical framework the conceptual and action framework developed in Task 2.1 and described in D2.1. This in particular relates to make spatially explicit the Low carbon | High air quality NbS potentials, considering the level of integration possible in relation to the use of defined indicators. The methodology presented starts from the need to create the ecological and socioeconomic status and disparities profiles, considering the justice perspective that contains different elements related to the conceptual and action framework previously developed.

First, the principles or legs of justice considered for NbS [12]: (i) distributional justice that addresses the question 'who gets what'; (ii) procedural justice, related to the decision-making process and to the question 'who gets asked'; (iii) recognition justice that relates to the question 'who gets asked and considered how'; (iv) contributive justice that considers what type of work is evaluated as contribution to the common good; and (v) corrective justice that is meant as a rectifying function that relates one person to another according to the concept of equality or fairness.

Secondly, the key challenges to be claimed and which the NbS are intended to address, i.e. the six (in-)justice components for activating Low carbon | High air quality solutions: air quality, carbon, thermal, spatial and temporal (in-)justices as well as flora, fauna habitat (non-)inclusiveness. Among these challenges, there are strong interlinkages, including synergies and trade-offs. However, each one represents a specific point of view for assessing in a strategic way the Low carbon | High air quality NbS potentials in a city. These potentials, according to the developed conceptual and action framework, can be described as follows.

Low carbon | High air quality NbS potentials are defined by the extent to which:

- They allow addressing more than one of the identified 6 key challenges.
- They reflect the action hierarchy of first removing the problem at its root (e.g., air pollution).
- Take duly into account substantive principles as well as procedural principles.
- Build on a range of NbS categories and measures.

By not focusing on defined functions provided by different ecosystem services as key components of the 6 challenges, the authors aim to better capture the multi-dimensional space of ecological (space) justice and its complex system of interactions, not only including environmental conditions, but also including the social space, socio-economic conditions, or conditions of the built environment.
The next sections and especially the Annex 3 - Indicators provides a brief insight into the indicators identified in D2.1 for evaluating the different justice challenges.

1.3 From conceptual to analytical framework

Within the effort to provide key knowledge that can guide the strategic process of assessing Low carbon | High air quality NbS potentials in a city, in the D2.1 several indicators (a so-called "basket of indicators") were identified for each of the six (in-)justice components/challenges briefly presented above.

This selection of indicators aims to be the starting point to assess the potential contribution to address the challenges. For each (in-)justice component and for each suggested indicator, the following elements were defined: which drivers it considers, whether the NbS contributions are integrated, which leg of justice it (mainly) addresses, the level of integration with other components, and the potential for spatial mapping (to evaluate the feasibility of visualising the indicator on a map).

To have the full picture of these suggested indicators, please refer to Section 3 of D2.1. What is worth to be mentioned here is that among the indicators with the highest spatial mapping potential, some were then recognized to be the most suitable ones for stepping from the conceptual to the analytical framework and developing the ecological and socioeconomic status and disparities profiles. The list and explanation of these indicators are illustrated later in this report, specifically in Sections 4 and Annex 3 - Indicators. The list is just a possible example to inspire the reader, as each CiPeL needs to select and calculate the indicators based on the local context and considering data quality and availability.

1.4 Interlinkages with other project activities

The development of this deliverable and of the ecological and socioeconomic status disparities profiles has been informed by the activities and outputs of Task 2.1 ("Determining the scientific knowledge base and developing a framework for assessing Low carbon | High air quality NbS potentials"). Furthermore, this report, together with the outputs of Tasks 2.1 and 2.3 ("Defining and implementing Low carbon | High air quality NbS potentials and scenarios for meaningful future development trajectories in the CiPeLs"), will feed into the final deliverable of WP 2, the Handbook on identifying Low carbon | High air quality NbS potentials in cities (D 2.4).

In addition, the following interlinkages with other Work Packages need to be especially highlighted:

- ➔ Work package 3 (Life-cycle monitoring and evaluation of Low carbon | High air quality NbS impact): the generated knowledge base informs the development of the indicator framework for the life-cycle monitoring and evaluation (Deliverable 3.1).
- ➔ Work package 4 (Design, facilitation and evaluation of City Practice Labs): the ecological and socioeconomic status and disparities profiles will be used to inform the collaborative CiPeL workshops and the local decision-making processes (Task 4.2).
- ➔ Work package 5 (Low carbon | High air quality NbS design and implementation in CiPeLs): the needs and spatial disparities identified for the CiPeLs, and resulting Low carbon | High air quality NbS potentials serve as backbone of the co-design and co-creation process carried out in Task 5.1.
- ➔ Work package 6 (Evolving data networks, applications and interventions): the findings of Task 2.2.1. will inform the improvement of the digital twin software capabilities, and the identification of the most relevant visual layers types to be

added (Task 6.1), and the development of governance platform for NbS operation (Task 6.3). Furthermore, the generated knowledge base from Task 2.2 will also inform the definition of criteria and experiment design for the deployment of digital twins & governance platform in the CiPeLs (Task 6.4).

- ➔ Work package 7 (Low carbon | High air quality NbS systems governance): the evaluation of environmental and socioeconomic parameters defined in Task 2.2 will be part of the process of co-governance strategies assessment for Low carbon | High air quality NbS linking top-down and bottom-up approaches (Task 7.2).

The ecological and socioeconomic status and disparities profiles are developed to represent a support for an effective planning, implementation, and maintenance of appropriate and just NbS. Therefore, the created knowledge is relevant for many other project activities that address these phases for the NbS design process.

2 THE ECOLOGICAL AND SOCIOECONOMIC STATUS AND DISPARITIES PROFILE AND ITS USEFULNESS

2.1 The concept of ecological and socioeconomic status and disparities profile

The city is an entity that can be described through its socioeconomic and ecological characteristics. Indeed, it is a system that combines physical (natural, infrastructural, etc.), social (population, vulnerabilities, etc.), cultural (preferences, beliefs, etc.), and economic (enterprises, services, etc.) elements. When planning a city, introducing new technologies and infrastructures or activating NbS, it is important to get an understanding of the city, its characteristics, needs and wants.

Increasingly it is recognised that, considering the complexity of the endeavour, a rational approach to planning, which separates the planning of a city into distinct 'manageable' linear steps (e.g., analysis of status quo, identification of options, implementation and monitoring) and often siloed areas (e.g., mobility, urban green, energy), is not sufficient to address several challenges a city is facing simultaneously [2]. This especially applies to its 'strategic planning', which can be described as a process of reflecting intentions, developing objectives and actual options to frame future activities (and operative planning). Although no common understanding of strategic planning exists, besides agreeing that it needs to be tailored to the context and conditions of a city, [3] defines it as '… *a transformative and integrative, (preferably) public-sector-led socio-spatial process through which a vision, coherent actions, and means for implementation are produced that shape and frame what a place is and what it might become*'. It is expected that the development of ecological and socioeconomic status and disparities profiles contributes to enhancing the integrative knowledge base in relation to the strategic planning and activation of NbS. This chapter aims to present what is an ecological and socioeconomic status and disparities profile and why it can be useful.

The profile is here considered an agglomeration of urban units that are homogeneous in terms of morphology, presence of infrastructures (green and others), demographic (e.g., age of the population, percentage of foreigners, etc.) and economic characteristics (e.g., economic activities). The population and urban characteristics used to create the profiles are all recognized by scientific literature (D2.1) as relevant to address justice impacts of NbS.

The creation of user/customer segments/profiles is a technique applied for several years in the private sector to improve and better suit the product features to the customers' needs [4]–[8]. Recently the segmentation approach has been applied to better characterize habits, needs and wants of citizens. The cluster analysis was applied to characterized household food waste composting habits and behaviours in Hungary, the results might support the creation of policy to promote home composting with a particular focus on young people and families with children [9]. Furthermore, citizens segmentation was used to analyse citizen's perspective and attitudes towards Urban Air Mobility and to define citizens expectations on its possible role, the design clusters require different policies and practices for both policymakers and transport operators [10]. This report aims to apply the same approach to the (co-)design and (co-)implementation of NbS to the urban context. The idea is to highlight the common wants and needs of the citizens in terms of NbS. Furthermore, the creation of the profiles aims to stress the existing disparities for different urban justice dimensions, as identified in D2.1, to better understand the role that urban interventions might play in reducing the justice gaps among different urban zones and different social groups.

Considering all these elements might have an impact on how the interventions are planned and designed. Indeed, concerning the relevance of defining ecological and socioeconomic status and disparities profiles in strategic planning, in some urban neighbourhoods characterized by multiple social, economic, and ecological urban challenges, NbS can consistently contribute to strengthening urban justice processes and contexts [46].

2.2 The methodology to build the profiles

The structure of the profiles is strictly connected to six different justice components concerning: air-quality justice, thermal justice, carbon justice, flora, fauna and habitat inclusiveness, spatial justice and temporal justice. The justice components are identified in the D2.1 and this deliverable should be read as a continuation and proposed implementation of the more conceptual work included in D2.1. Due to the use of the ecological space concept, its describing functionings and ecosystem conditions, no direct link to the ecosystem services concept and categorisation is provided, though lays at the basis of a range of considered studies (e.g. [14], [15], [16], [17]).

For each of the justice components, one or more indicators have been identified as a qualitative proxy for a specific justice dimension (Annex 3 - Indicators). Not all the indicators in the list are used for the building of the profiles. Indeed, the indicators have been selected also considering the availability of data, avoiding highly specialized datasets that might not be available at the temporal and spatial resolution of interest (e.g., raster map with the monthly and yearly average concentrations of the main air pollutants). However, the intent of this report is to define a process that can then be adapted to a single city or zone based on the specific conditions and the data available.

Table 1 summarises the methodological steps used for building the ecological and socioeconomic status and disparities profiles.

Table 1: Description of the methodology used to create the ecological and socioeconomic status and disparities profiles.

Goal	Phases	Steps	Outcomes	Section
Creation, analysis, and description of ecological and socioeconomic status and disparities profiles. (*One profile corresponds to a cluster)	**Data collection and analysis** of the ecological and socioeconomic status and disparities of the urban context, using separately the available indicators.	STEP 1 Data **collection** based on: • ecological and • socioeconomic indicators, with the support of CiPeLs. (*Indicators are transversal to all justice components elaborated in D2.1)	**Dataset** integrating ecological and socioeconomic indicators relevant for NbS planning.	Ch. 3
		STEP 2 **Mapping the indicators** for having a first idea of the status quo *plus* a descriptive analysis for the creation of the profiles.	**Maps** describing the city based on single indicators (e.g., existing green spaces).	Ch. 4
	Cluster analysis for an understanding of the ecological and socioeconomic **status** of the urban context, grouping urban units in homogeneous **profiles,** and defining differences and **disparities** among profiles.	STEP 3 **Building the profiles: clustering** of urban units and quantitative description of the clusters.	**Profiles**	Ch. 5
		STEP 4 Calculation of **distances** among clusters and quantitative description of distances.	**Assessment of disparities** among the profiles.	Ch. 5
	The addition of **qualitative information** from interviews makes first considerations whether a disparity can be considered an **inequality** and whether some of them can be alleviated by	STEP 5 **Interviews** to collect key stakeholders' narratives on urban inequalities (e.g., house access, gender). (*Disparities does not necessarily mean inequalities)	**First considerations on inequalities** issues in the urban context.	Ch. 6
		STEP 6	**Informative sheets** explaining	Ch. 6

	the planning of appropriate and just NbS. (*This phase should be considered a starting point of further discussion with stakeholders of CiPeLs on inequalities)	**Qualitative description** of clusters and preparation of informative sheets for supporting the planning of NbS.	how to interpret profiles for an effective support in the planning of NbS.

The creation of profiles is based on mixed-methods approach, integrating both qualitative and quantitative methods. Starting from the quantitative part of the analysis, secondary physical/infrastructural data and data on the population and related activities are collected to create the profiles. The data is initially spatialised on maps to get a view of the distribution of key features. The different informative layers per justice dimension are subdivided in five different qualitative class of conditions (i.e. very low, low, medium, high, very high). Then, the urban zones are clustered according to similar features, based on justice-related indicators, and with the aim to identify common socio-ecological patterns within the city and to analyse the actual socio-ecological urban environment (Figure 1). Clustering methods are able to unite urban units on the basis of their similarities, and are then able to explain what is similar and what is not, i.e. the variance around the mean or median. In a second step, by analysing the differences between profiles found in the same city, it is possible to understand the existence of disparities or differences of some kind (e.g., the presence of foreigners may prevail in some areas as well as the presence of green areas). When differences between urban areas incur into *unfairness* and *injustice*, an inequality arises [18]. Therefore, the profiles give a picture of the city by looking at their current characteristics (status), the differences or disparities among them and the situations of inequality. Focusing on differences, it is possible to acknowledge how different parts of the city have different needs, also in terms of NbS; consequently, the profile method is often used to understand different needs.

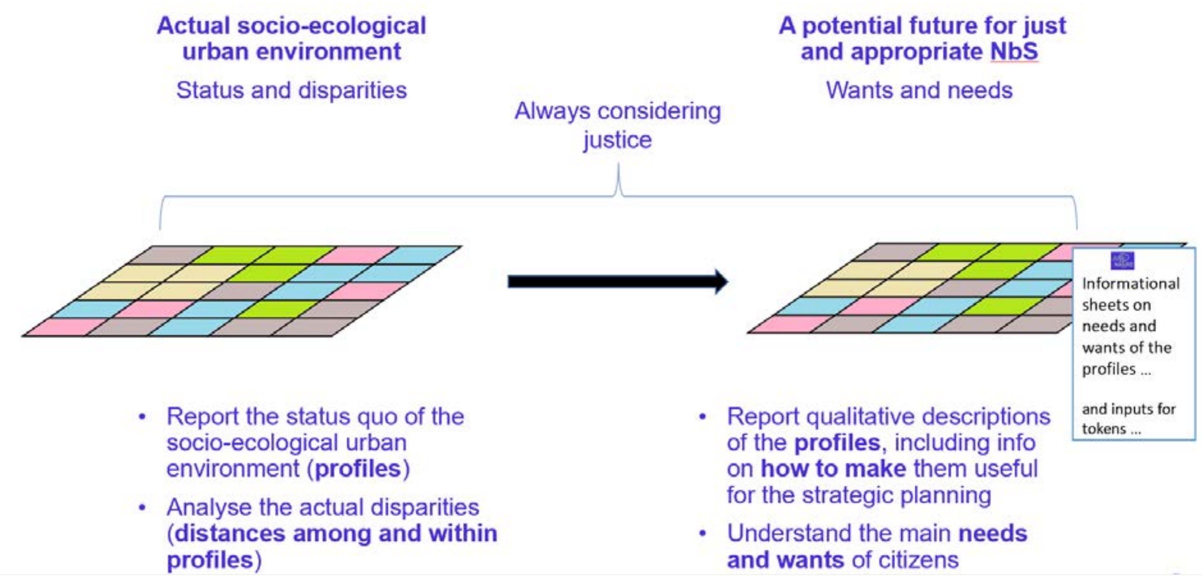


Figure 1: The creation of profiles supports the understanding of the actual socio-ecological urban environment in terms of both status and disparities, and the potential future for just and appropriate NbS.

The profiles are complemented by a qualitative analysis, which is based on narratives gained in interviews with selected stakeholders in each CiPeL to understand the interactions between ecological and socioeconomic urban elements and on how disparities can turn into inequalities, contextualizing the work on the specific city. In this study, given the importance of the justice components, the focus is on actors who work daily on issues of (in)justice, inequality, marginality (e.g., day care centers for homeless or drug addicts), vulnerability, and gender. This part of the analysis helps to read and interpret the profiles and add relevant information to those provided by quantitative analysis. The results of this activity support the definition of appropriate and just NbS in future, coherent with all the elements of justice (Figure 1).

2.3 The shift from status to disparities to inequalities in the profiles

The first step in the methodology is to create knowledge about the city's actual characteristics in terms of ecology and society. To do this, the necessary information and data were collected to describe and analyze the ecological and socioeconomic status of urban units (e.g., census units in the Italian case study). The interconnection between socioeconomic status and ecological status is a dynamic one, often evolving, which must be interpreted. The two statuses are in fact interdependent. For example, interconnectedness between ecological and social elements can be expressed through the positive impact that a green area can have on a person's social and psycho-physical well-being or, on the contrary, how the characteristics of a population can affect the experience (positive or negative e.g., incurring gentrification) of the green area. The analysis of the two statuses is based on quantitative and qualitative methods. On the one hand, secondary data allow us to make a quantitative assessment (cluster analysis) of the main ecological and socioeconomic characteristics of the city. On the other hand, the interviews describe how the two statuses can reveal situations of inequality.

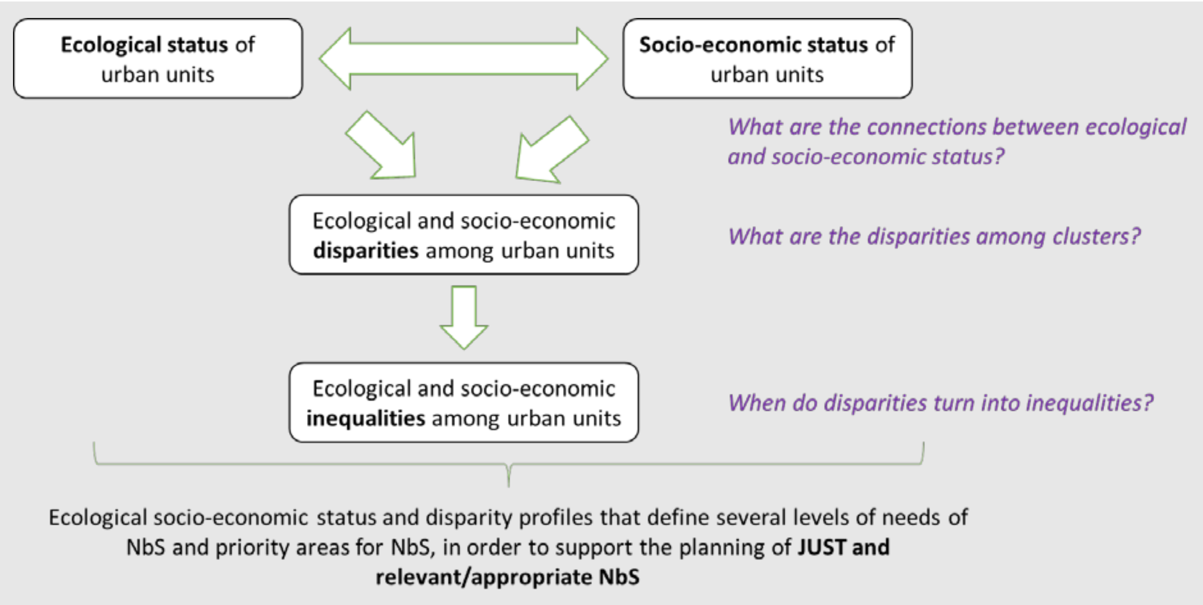


Figure 2: Steps in the building of profiles, considering the shift from status to disparities to inequalities.

The second step of this method consists in analyzing the distances within and between clusters, to establish the disparities between urban units/zones. In this case, the knowledge on disparities is integrated with the key actors' perspectives on how disparities are transformed into inequalities. The generated data allow us to check and validate some hypotheses, for instance, whether a statistical correlation between income and access to common services like health infrastructure and cultural centers can be detected. More generally, the existing correlation between the main socioeconomic variables and the urban morphology and context can be highlighted. All the information and analysis will inform the choice of just and appropriate NbS for a certain city (Figure 2).

3 DATA COLLECTION

This section presents the collection of data, i.e. the Step 1 of the methodology to build the ecological and socioeconomic status and disparities profiles, concerning satellite data, and socioeconomic and sociodemographic data.

3.1 The role of Earth Observation

Over the past few decades, the fast-growing developments in Earth Observation (EO) technology have led to the recognition of its unique role in climate change monitoring, thanks to the capability of capturing changes across the entire Earth System. Satellite-based data in fact allow the provision of spatially continuous, accurate and regular measurements of various biological, physical, and chemical parameters at the global scale, including areas that are difficult to reach.

The Copernicus programme, coordinated and managed by the European Commission in partnership with the European Space Agency, is probably the most ambitious EO programme to date aiming to improve the management of the environment, understand and mitigate the effects of climate change, and ensure civil security, through accurate, timely and freely accessible information.

In this context, the potentialities of freely available Copernicus data to support the definition of urban ecological and socioeconomic status and disparities profiles were assessed. User requirements were collected by interacting with the CiPeLs and two sets of required EO products have been identified: 1) Multi-temporal landcover (LC) mapping and 2) Multi-temporal Land Surface Temperature analysis (LST). The first ones, LC, will allow monitoring the evolution of different urban typologies, including the following 5 land cover types: urban tree canopy, pervious surfaces (e.g., open fields, grass, etc.), impervious surfaces (e.g., roads, buildings, parking lots, etc.), bare soil, and water. On the other hand, the LST analysis will picture the temporal evolution of temperature within the city at sub-urban level, including the identification of urban heat stress zones or urban heat island hotspots. Both product packages are composed of multiple products, described in the following paragraphs.

3.2 Land Cover (LC) package

3.2.1 Multitemporal LC mapping

A process of multitemporal LC mapping over a period of three years has been implemented for the six European cities selected by the project (i.e., CiPeLs). Annual LC maps have been realized for the years 2018, 2020 and 2022 starting from the Sentinel-2 (S2) time series accessible from the European Space Agency (ESA) hub. The output land cover maps provide information on nine classes, described in Table 2.

Table 2: List of the classes included in the Land cover product.

	Class code	Land Cover class name
	110	Very dense urban area
	120	Medium-low dense urban area
	211	Deciduous arboreous green areas
	212	Evergreen arboreous green areas
	220	Shrubland
	230	Grassland
	300	Agricultural areas
	400	Bare soil/rocks
	500	Water

Input data

For each reference year, four seasonal S2 Level-2A images have been selected (i.e., one for each quarter) among the cloud free scenes over the six cities areas. The Level-2A product type provides Bottom-Of-Atmosphere (BOA) corrected reflectance images in cartographic geometry (UTM/WGS84 projection).

The following ten spectral bands have been used for the classification: Band 2 – Blue (0.490 μm), Band 3 – Green (0.560 μm), Band 4 – Red (0.665 μm), Band 5 – Vegetation Red Edge (0.705 μm), Band 6 – Vegetation Red Edge (0.740 μm), Band 7 – Vegetation Red Edge (0.783 μm), Band 8 – NIR (0.842 μm), Band 8A – Vegetation Red Edge (0.865 μm), Band 11 – SWIR (1.610 μm), Band 12 – SWIR (2.190 μm). For the spectral bands B5-6-7-8a-11-12, originally at 20m of spatial resolution, a resampling process is performed in order to reach a homogenous resolution of 10m. As a result, from assembling forty bands (i.e., ten spectral bands for four seasonal images) a multilayer data stack is generated for each year.

It is worth to note that, for the year 2022, the complete seasonal series has been composed by two images taken from the first and second quarters 2022 and by two images taken from the third and fourth quarters of 2021(as the production has been performed mostly around July 2022). For each city, the three annual data stacks 2018, 2020 and 2022 have been then submitted to the automatic process of land cover classification.

Methodology

The approach for the LC classification adopted for the multi-annual mapping of the six CiPeLs is presented in Figure 3. The main classification algorithm, based on Machine Learning (ML) method, is called Light Gradient Boosting Model (LGBM) [19]. LGBM is largely used in EO applications, for land cover classification [20], for plastic litter detection with hyperspectral data [21], demonstrating higher accuracy in several applications, as compared to classical ML approaches [22]. Furthermore, LGBM results more time efficient, performing 25% quicker on average, as opposed to Random Forest and Support Vector Machine [22].

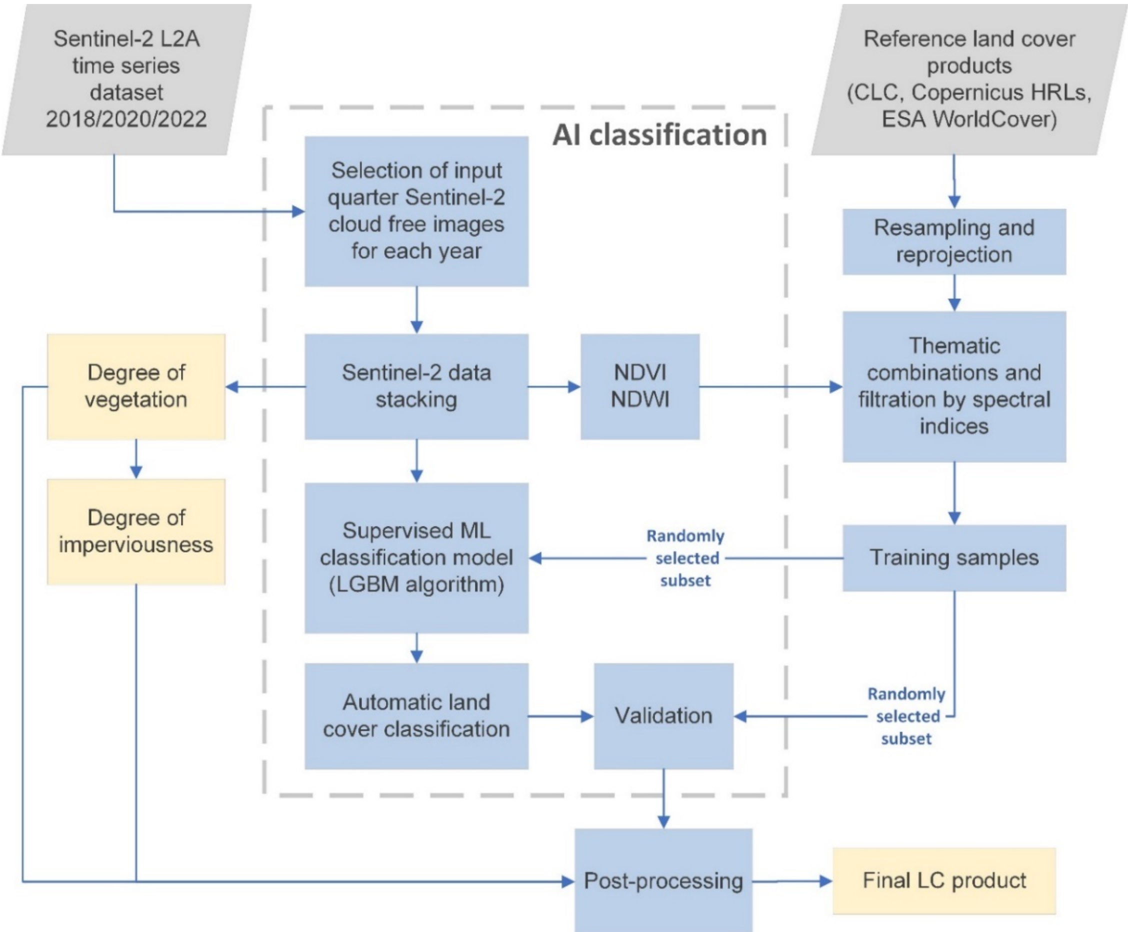


Figure 3: Land cover processing workflow.

The training samples used to train the ML model have been extracted automatically from other existing land cover products, following the approach described in recent applications at local to global scale [22]. The existing land cover products used for training samples selection were: Corine LC 2018 [23], [24], Copernicus High Resolution Layers (HRL) 2018 [25] and ESA World Cover 2020 [26]. They have provided a complementary and homogenous level of information on land cover over the six CiPeLs across Europe.

The reference datasets were respectively re-projected and resampled to the spatial resolution of Sentinel-2 data. From the intersection of the source datasets, the samples of all the classes have been assigned. For instance, for the class of "Artificial areas" the training samples were derived by intersecting high value pixels of Imperviousness HRL (i.e., 70%) with low value pixels of Tree cover density HRL (i.e., 10%) and the Artificial areas of ESA World Cover. As an example, for the natural areas, the training samples of the class "Deciduous arboreous green areas" resulted from the intersection of Corine LC 3.1.1 class with Dominant Leaf Type HRL labeled as "Broadleaf" and the "Tree cover" class of ESA World Cover.

The samples resulting from the intersection between the reference land cover products, have been further refined. Different combinations with the spectral indices (i.e., normalized difference vegetation index (NDVI) and normalized difference water index (NDWI)) have been tested over the different sites in order to define a set of filtration rules for all the land cover classes. For instance, the NDVI was used in the following cases to improve the quality of the samples and prevent from having wrong assignments in the final training mask:

- samples labeled into the "green classes" (e.g., Deciduous arboreous green areas, Evergreen arboreous green areas, Shrubland, Grassland) but characterized by low NDVI values;
- samples labeled into "not green classes" (e.g., Artificial areas, Bare soil) but characterized by high NDVI values.

Furthermore, NDWI index has been used to filter the Water samples derived by the intersection of Corine LC "Water" classes (i.e., 5.1.1, 5.1.2, 5.2.1,5.2.2, 5.2.3) with the class "Permanent water bodies" of ESA World Cover.

Table 3: Example of confusion matrix calculated from the validation for land cover map 2022 for Chania city area.

Classifications								
Reference		*100*	*300*	*500*	*211*	*212*	*230*	*220*
Artificial areas	100	94.00%	0.10%	0.50%	0.20%	0.00%	1.20%	0.20%
Agricultural areas	300	1.30%	84.00%	0.00%	0.20%	0.00%	7.30%	0.60%
Water	500	0.10%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%

Deciduous arboreous green areas	211	0.20%	0.50%	0.00%	81.00%	9.40%	0.70%	1.80%
Evergreen arboreous green areas	212	0.00%	0.00%	0.00%	10.00%	89.00%	0.00%	0.20%
Shrubland	230	3.50%	8.80%	0.00%	0.70%	0.00%	78.00%	1.80%
Grassland	220	0.30%	0.40%	0.00%	0.19%	0.10%	2.50%	91.00%

The final training masks were used as input for the ML model of the pixel-based classification of the annual Sentinel-2 data stacks 2018, 2020 and 2022. Each annual stack was associated to a correspondent training mask. The filtration rules applied to each mask were built using the spectral indices calculated on the S2 data stack to be classified.

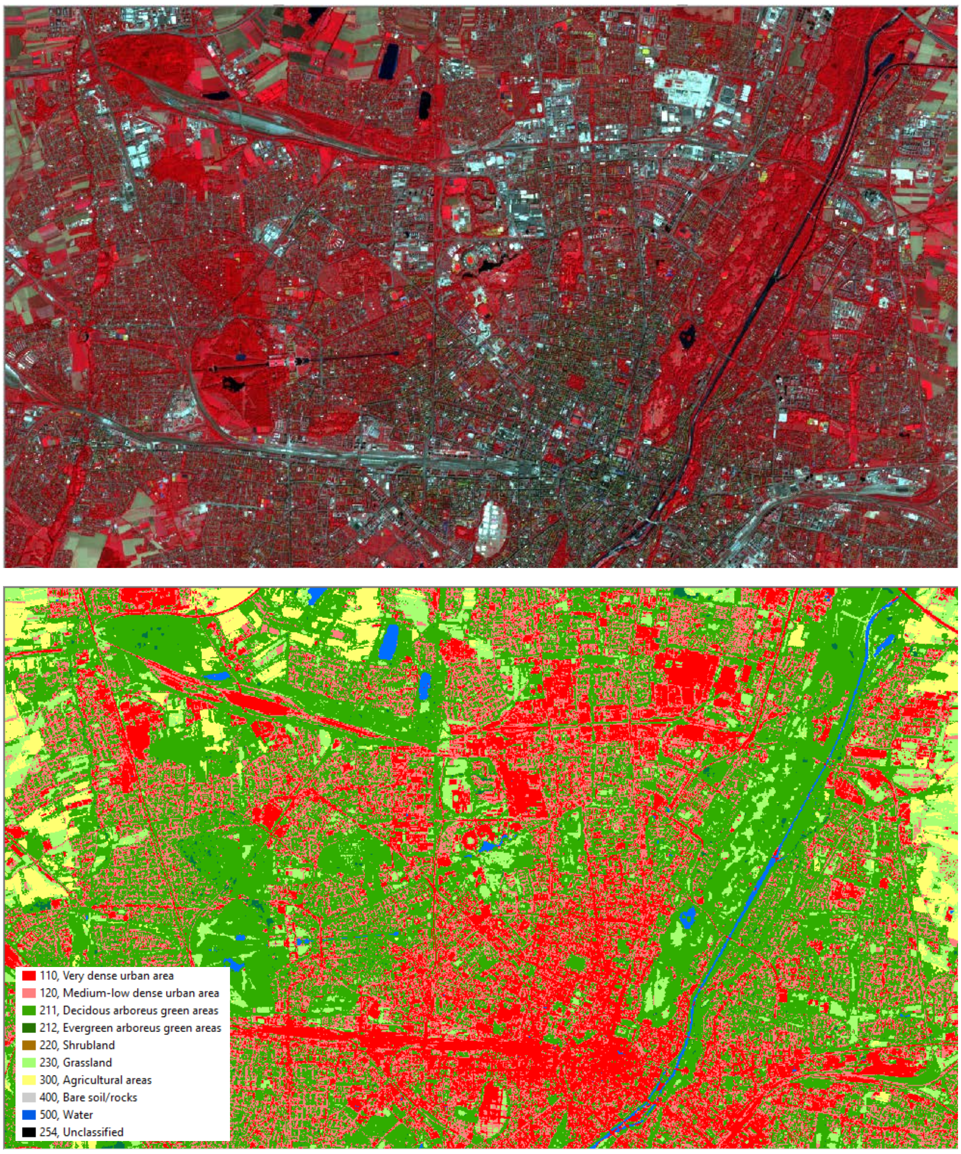


Figure 4: Example of LC product realized for Munich 2022 (Top image: Sentinel-2 NIR (i.e. near infrared) false colour combination, 2022; bottom image: LC mapping results).

This helped to actualize the samples assignment to the date of S2 data and to mitigate the issue of having reference training data not always coeval with the input data. After the training and running the ML model, the output of the automatic classification was checked by a validation process performed applying a subset of the training samples not used during the classification process. For each classification output, a confusion matrix has been calculated with information on the accuracy of each land cover class. The target overall accuracy of 80% has been reached for all the land cover maps produced for the six CiPeLs. An example of the obtained confusion matrix is presented in Table 3.

The output of the automatic classification has been further improved by a post-processing step. This phase is based on cleaning operations aimed to reduce misclassification especially between artificial and bare soil or between agricultural areas and natural vegetation classes in the urban areas. A set of cleaning rules derived by spatial queries and based on plausibility criteria have been applied to the automatic land cover maps produced over the entire time series 2018, 2020, 2022 (e.g., some examples of misclassification can be small patches of green areas surrounded by very dense urban areas and wrongly assigned to agricultural class or, built-up areas mapped in 2018 and unlikely disappeared in 2020 or 2022).

As final step, for the finalization of the land cover maps, an enhancement of the Artificial surfaces is performed based on the imperviousness degree characterization. The Artificial surfaces have been differentiated into Very dense urban areas (i.e., pixels having imperviousness degree greater than 85%) and Medium-low density urban areas (i.e., pixels with imperviousness degree less than 85%). An example of the obtained results is presented in Figure 4.

3.2.2 Degree of vegetation

The information about the Degree of vegetation is related to the measurement of the fractional cover at sub-pixel level, meant as the fraction of ground covered by green vegetation. Among this algorithm, the fractional cover is used to account for the minimum percentage of tree crown cover (10%) according to the FAO definition of forest. According to [27], methods for deriving fractional cover based on remotely sensed data can be categorized into six groups: (1) relative vegetation abundance (RA) algorithms scaled by maximum and minimum vegetation index values; (2) spectral mixture analysis (SMA) algorithms; (3) spectral-based supervised classification algorithms; (4) physically based models; (5) machine learning algorithms; (6) other approaches.

From the listed algorithms, a linear NDVI model has been selected as a the most robust and easy to implement method even over large areas. RA algorithms provide the simplest fractional cover estimation approach; among RA algorithms, the linear NDVI model is a highly-simplified formulation for the calculation of fractional cover (Fc) from NDVI [28]:

$$Fc = (NDVI - NDVI_{soil}) / (NDVI_{veg} - NDVI_{soil})$$

NDVI = NDVI value on the pixel;

$NDVI_{veg}$ = value of NDVI for full vegetation cover;

$NDVI_{soil}$ = value of NDVI for bare soil.

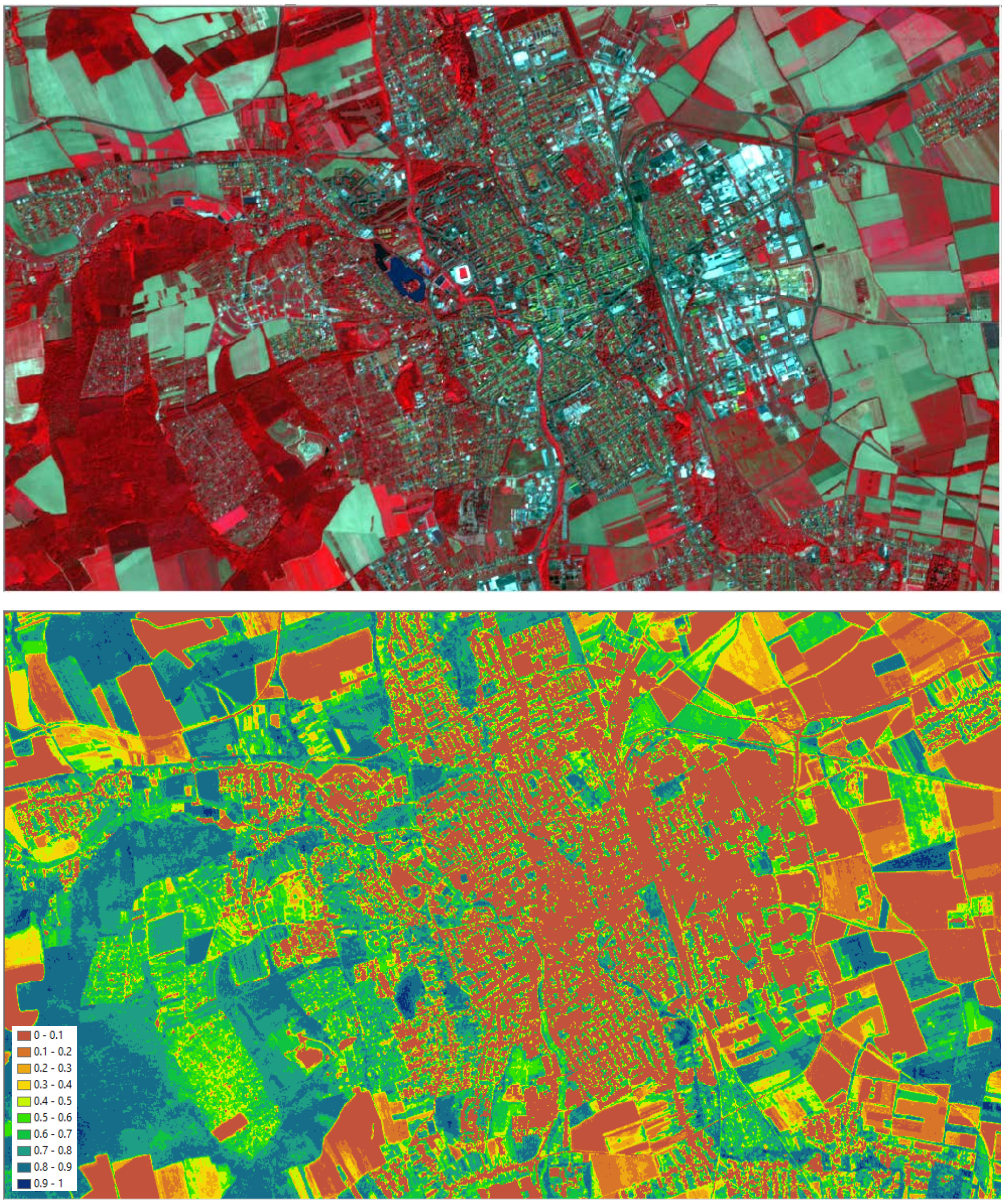
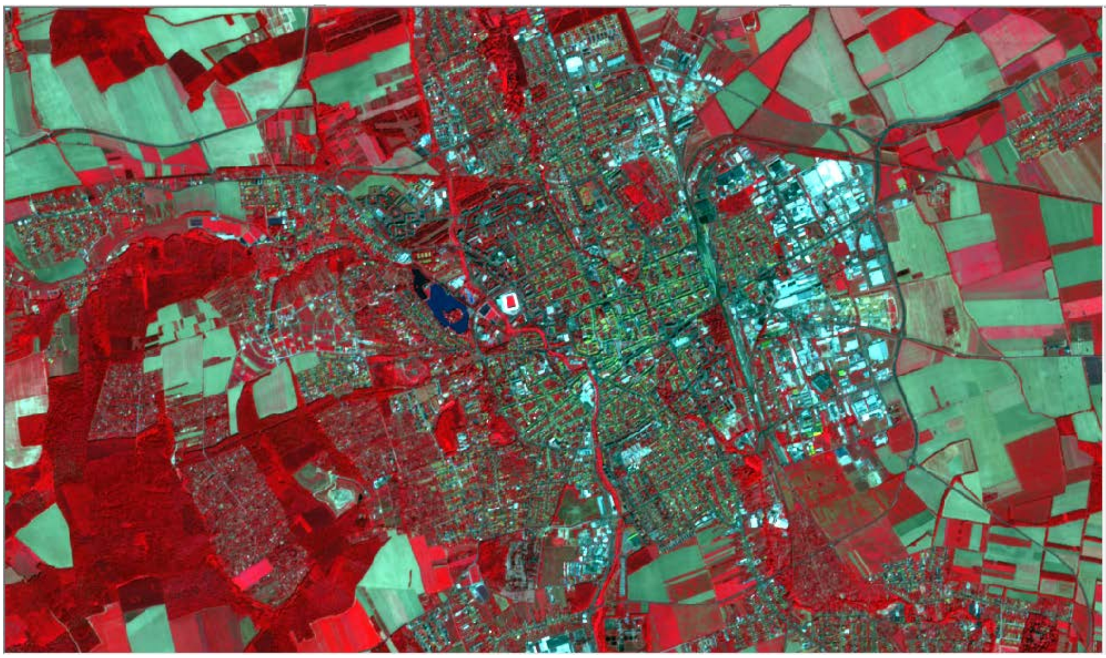


Figure 5: Example of Degree of vegetation layer realized for Szombathely 2022 (Top image: Sentinel-2 NIR false colour combination, 2022; bottom image: Degree of vegetation).

The appropriate definition of $NDVI_{veg}$ and $NDVI_{soil}$ values can be challenging where local reference data are not available. In those cases where a priori knowledge of NDVI values for full vegetation and bare soil is missing, mean values of 0.05 and 0.9 could be respectively considered as a reasonable reference basis [29].The degree of vegetation has been calculated for each quarter Sentinel-2 image of the three years 2018, 2020, 2022. In order to normalize the results and make more reliable the times series analysis, the four output layers of each year have been merged applying the maximum function. As a result, a unique degree of vegetation layer representative of each mapping year has been produced. An example is presented in Figure 5.

3.2.3 Degree of imperviousness layer

The degree of imperviousness can be estimated with proxy parameters that quantify the cover of green vegetation, which can be considered inversely correlated with the degree of surface imperviousness in urban or built-up areas. Consequently, vegetation indices such as the NDVI have frequently been used to estimate % of imperviousness surface area in urban environments [30]–[33]. For calculating the imperviousness degree on the six CiPeLs, the inverse of the Degree of vegetation was applied (Figure 6 presents an example of results).



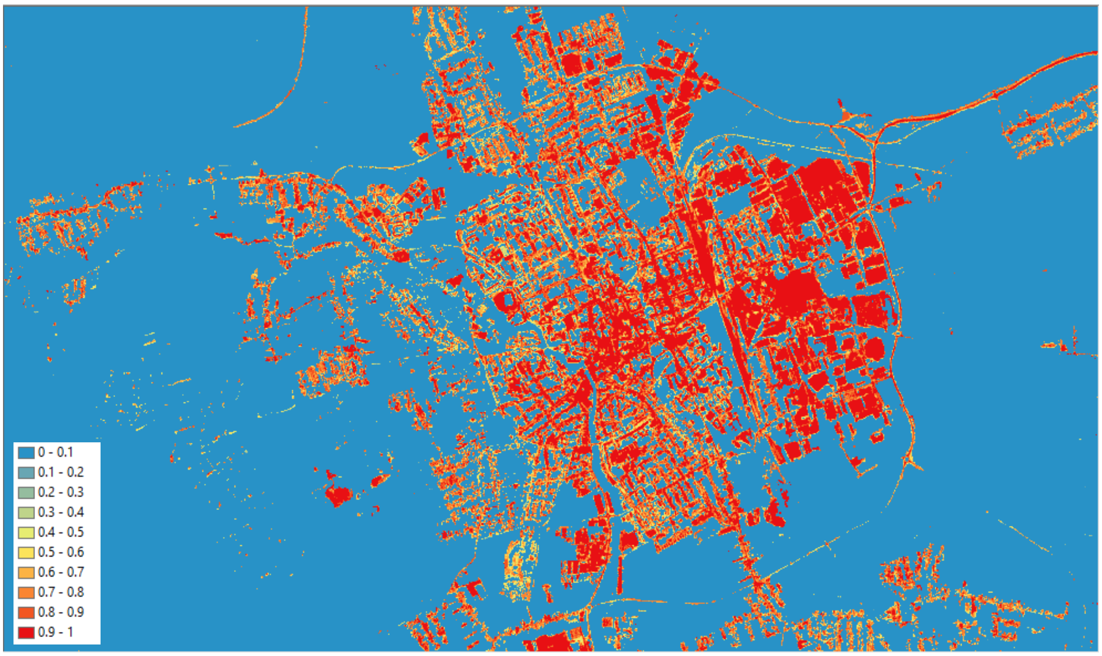


Figure 6: Example of Imperviousness degree layer realized for Szombathely 2022. (Top image: Sentinel-2 NIR false colour combination, 2022; bottom image: Imperviousness degree).

3.2.4 Multi-temporal Land Surface Temperature (LST) package

Land Surface Temperature (LST) is the radiative skin temperature of the land surface. It is a mixture of vegetation and bare soil temperatures, which also depends on albedo, vegetation cover and soil moisture. Since the LST responds to changes in incoming solar radiation due to cloud cover aerosol load modifications and diurnal variation of illumination, it displays quick variation too. The correct determination of LST is the starting point to understand and analyze energy and temperature changes on our planet, which in turn influence our world's weather and climate patterns. LST influences the energy distribution between soil and plants, as well as buildings. It is also an indirect measure of the temperature of the air layers near the Earth's surface. A detailed understanding of this parameter helps to model climate models and the variables that depend on them.

Low resolution LST from satellite has been used in hydrological equilibrium assessments, global warming studies, urban heat island effect assessments [34] and surface evapotranspiration calculations. LST is actually measured by satellite using sensors in the Thermal Infrared Range (TIR, usually between 8 and 12μm). Such sensors need to be cooled and are difficult to be miniaturized, so at present satellite TIR sensors are quite limited in spatial resolution and spatial frequency. An example of satellite missions equipping a TIR sensor for LST measurement are:

- Geostationary satellites: for example, Meteosat Second Generation satellites are able to provide a LST measurement every 15 minutes with a spatial resolution of 3km;
- Low Earth Orbit satellites: most of them have a spatial resolution of 1km. Copernicus Sentinel-3 provides global coverage every 2-3 days, while NASA MODIS/VIIRS sensors onboard several satellites can provide up to 5-6 measurements per day. Another example are VHRR sensors onboard NOAA satellites. At present the Landsat8/9 satellites from USGS equip a TIR sensor with a spatial resolution of 100m resampled to 30m, with a temporal frequency of 7 days or more.

TIR sensors measure the brightness temperature at top of atmosphere at one or more channel. The most common methodologies to measure LST, include at pixel level estimation of the land surface emissivity and then the separation of the atmospheric upwelling and downwelling thermal radiances from the one due to the temperature of the ground [35]–[37].

Methodology

The new proposed product takes S2 images as input and applies machine learning algorithms to estimate the LST with a spatial resolution of 10 meters. The training is performed using couples of Landsat-derived LST and Sentinel-2 data with the objective of increasing spatial resolution to 10m, while still having the high temporal frequency (every 5 days) of the latter. From validation works in urban environment, the method can provide state-of-the-art results [38], with Mean Absolute Error (MAE) of 1.8 °C. This is a very innovative approach exploiting Sentinel-2 data, which is in line with the recent advancements for improving spatial resolution of satellite data [39].

3.2.5 Multi-temporal LST from Sentinel-2

The methodology described above has been applied for all CiPeLs, on the full Sentinel-2 time series going from January 2017 up to June 2022. Sentinel-2 images with a cloud coverage lower than 5% have been processed to obtain the LST maps at 10m spatial resolution. Missing values within the LST maps have been filled using the average value of adjacent pixels. At the end, depending on the season, from 2 to 5 valid values per month resulted available.

3.2.6 Monthly LST

LST time series were subsequently aggregated on a monthly basis by computing the monthly average of the available LST maps, with the aim to generate a more significant monthly product. In Figures 7, 8 and 9, the maps over Bolzano for months May, June, and July are available.

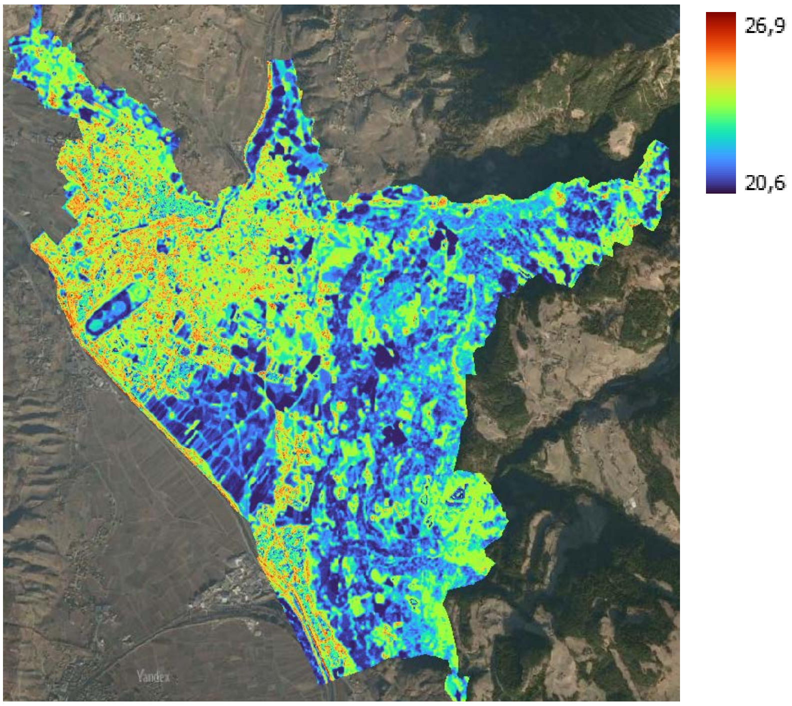


Figure 7: Monthly LST (°C) maps over Bolzano for months May 2019.

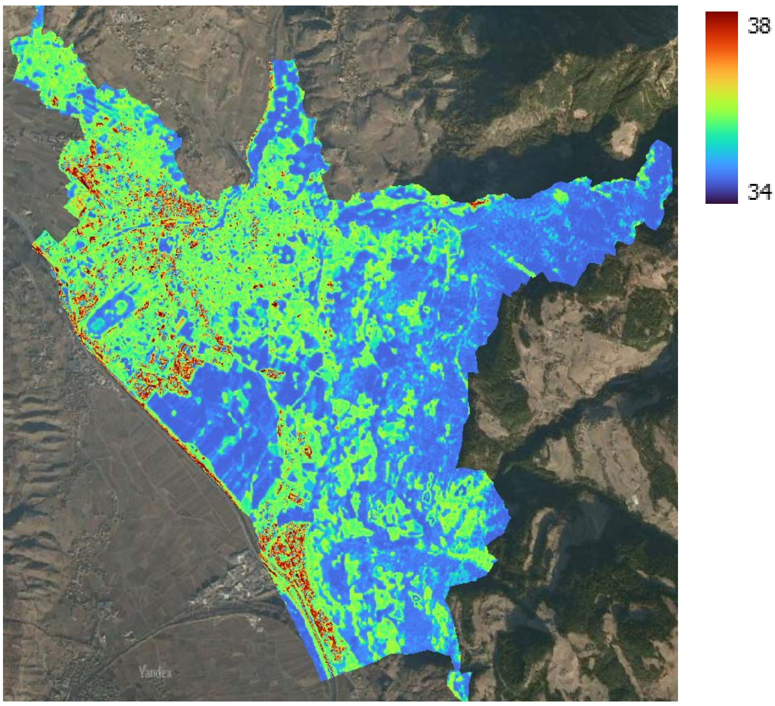


Figure 8: Monthly LST (°C) maps over Bolzano for months July 2019.

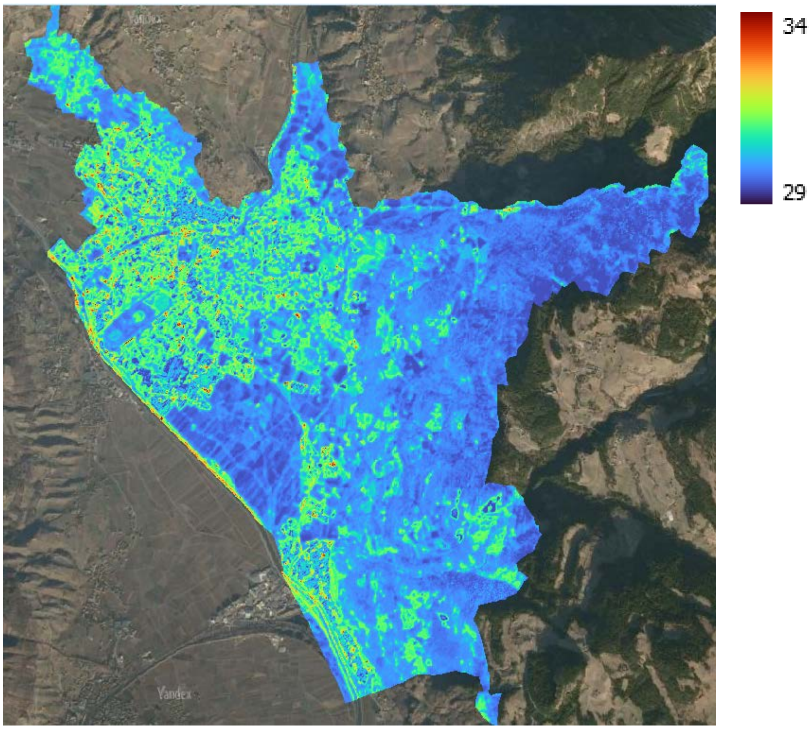


Figure 9: Monthly LST (°C) maps over Bolzano for months September 2019.

3.2.7 Heat Stress Zones

Due to the different properties of artificial surfaces (e.g., metals, concrete, etc.) the surface temperature of different urban areas show very different LST values and temporal behavior during the year (typically at seasonal level).

With the aim to highlight significant temperature patterns within the urban context, the LST monthly time-series dataset was subsequently analyzed by applying an unsupervised Machine Learning Clustering (MLC) algorithm [40]. This analysis was performed after applying an urban filter, using the LC products described above (Section 3.2) and only using the LST maps for the summer months, since the objective was to characterize urban areas with respect to the Surface UHI (SUHI) phenomenon that mostly occurs in summer. Furthermore, effects such as snow, building heating, etc. can affect the LST estimation of winter months.

It is important to highlight that UHI is usually referred to the difference of air temperature between urban and rural areas, especially during the night, when the latter is minimum. SUHI can be considered a proxy of the UHI, even if several factors influence the transfer of the heat from the ground to the air. In JUSTNature, "daily" SUHI has been considered, since

Sentinel-2 acquires only during the day (more or less between 9 and 12 UTC in Europe). This was a necessary trade-off in order to benefit of the 10 m spatial resolution.

The MLC approach allows for automatic identification of pixels having a similar temporal pattern in the LST time series, providing as a result a static map, herein called Heat Stress Zones map (*Figure 10* and Figure 12). In this map, areas with similar LST temporal and spatial patterns are grouped together under the same class (or cluster). Being an unsupervised approach, the nature and meaning of the different classes, as well as the number of possible distinguishable classes, are unknown.

Different attempts were made in order to identify the optimal class number. It is important to identify the optimal number of clusters, because a larger number of clusters would result in too similar clusters and very low inter classes variance, while fewer clusters (2-3) would merge areas that are significantly different, such as dense urban areas and green areas (parks, fields). For most of the analyzed cities, the most meaningful results were obtained by using four clusters, hence the same number was applied for all CiPeLs.
Afterwards, with the aim of giving a meaning to the four classes, the information content of each class was analyzed by an expert operator. The results showed that each class was characterized by different temperature values and by very similar temporal trends year after year (see Figure 11 and Figure 13). As a further verification, by sorting the centroids of each cluster according to temperature, it becomes clear that each cluster could represent a different level of Heat Stress within the urban spatial context, hence a value from low thermal stress to high thermal stress was assidgned to each of the cluster.

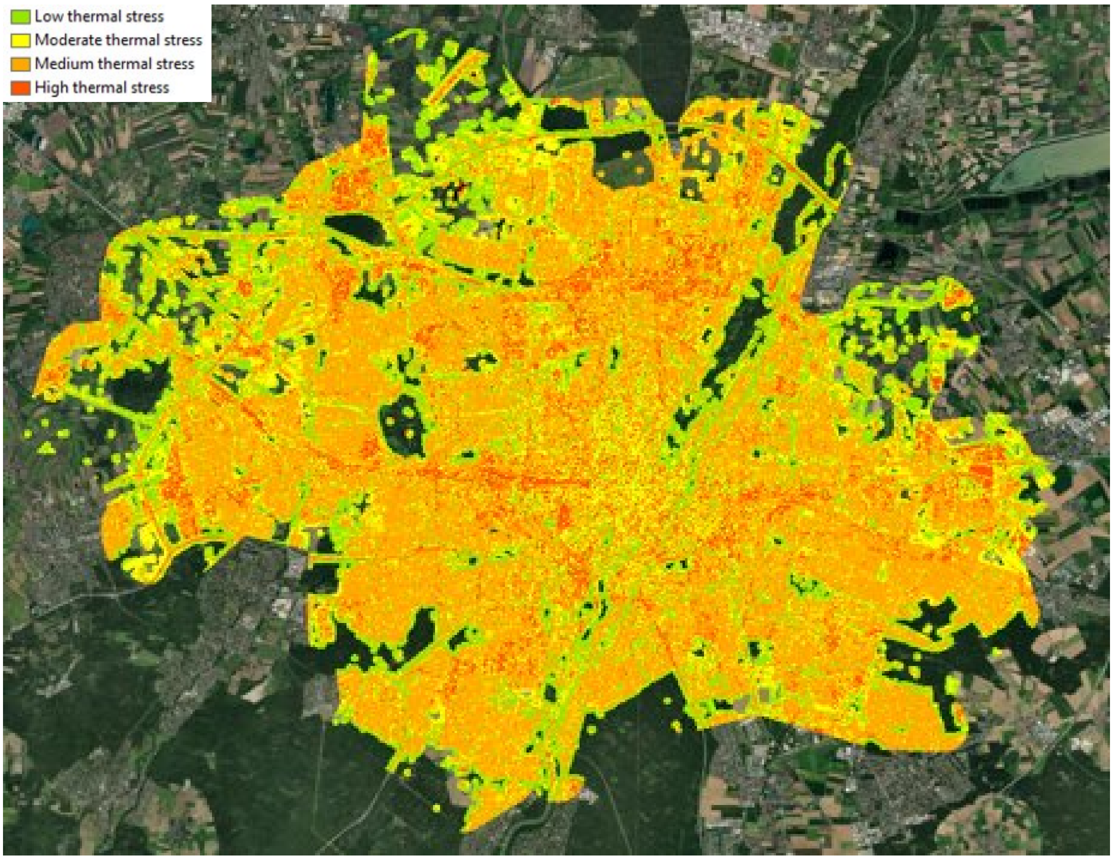


Figure 10: Heat Stress Zones map, München.

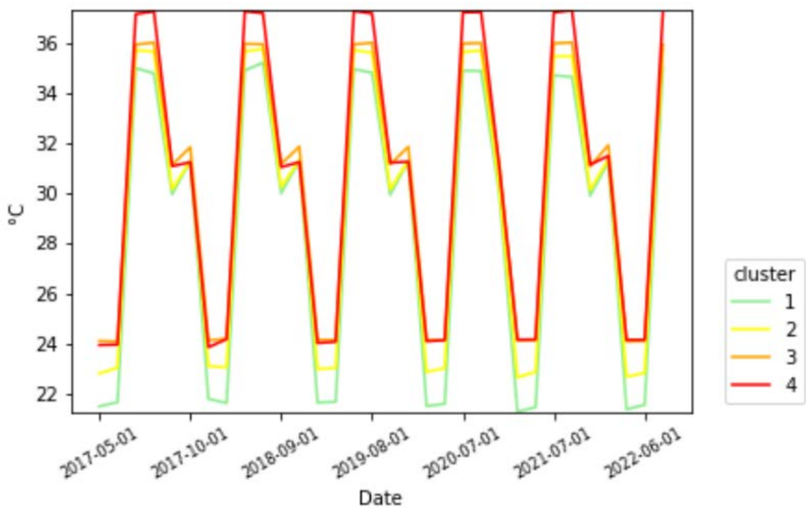


Figure 11: Time series of the different cluster centroids for München.

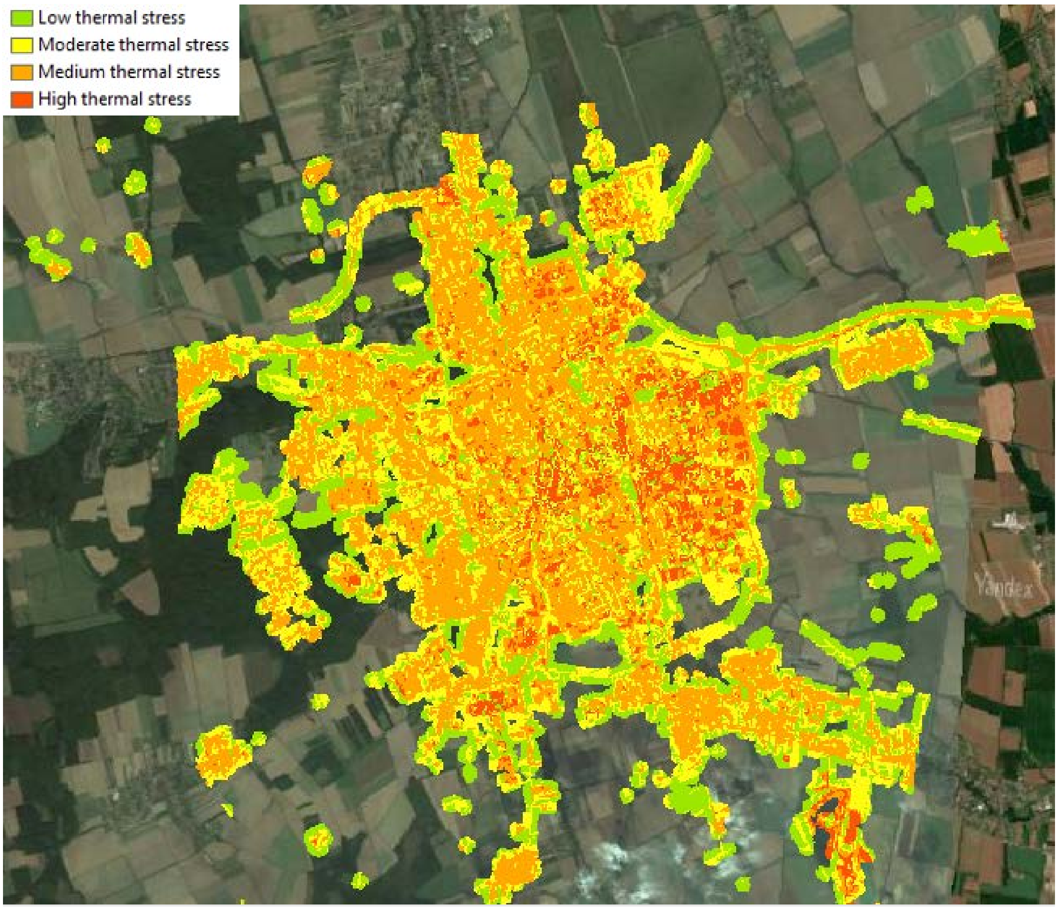


Figure 12: Heat Stress Zones map, Szombathely.

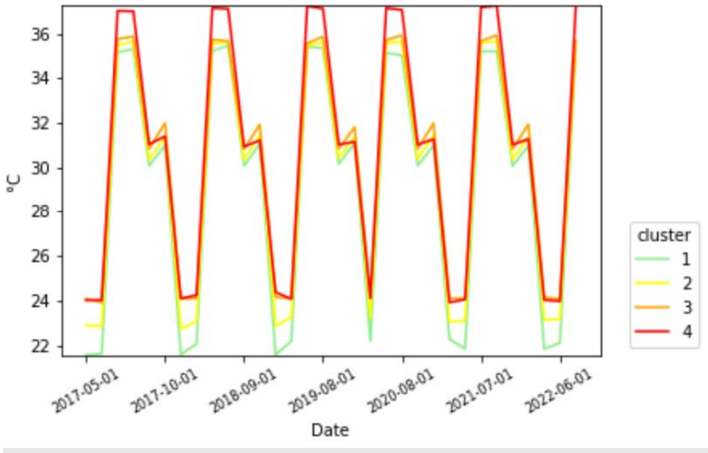


Figure 13: Time series of the different cluster centroids for Szombathely.

3.2.8 Monthly Surface Urban Heat Island Effect

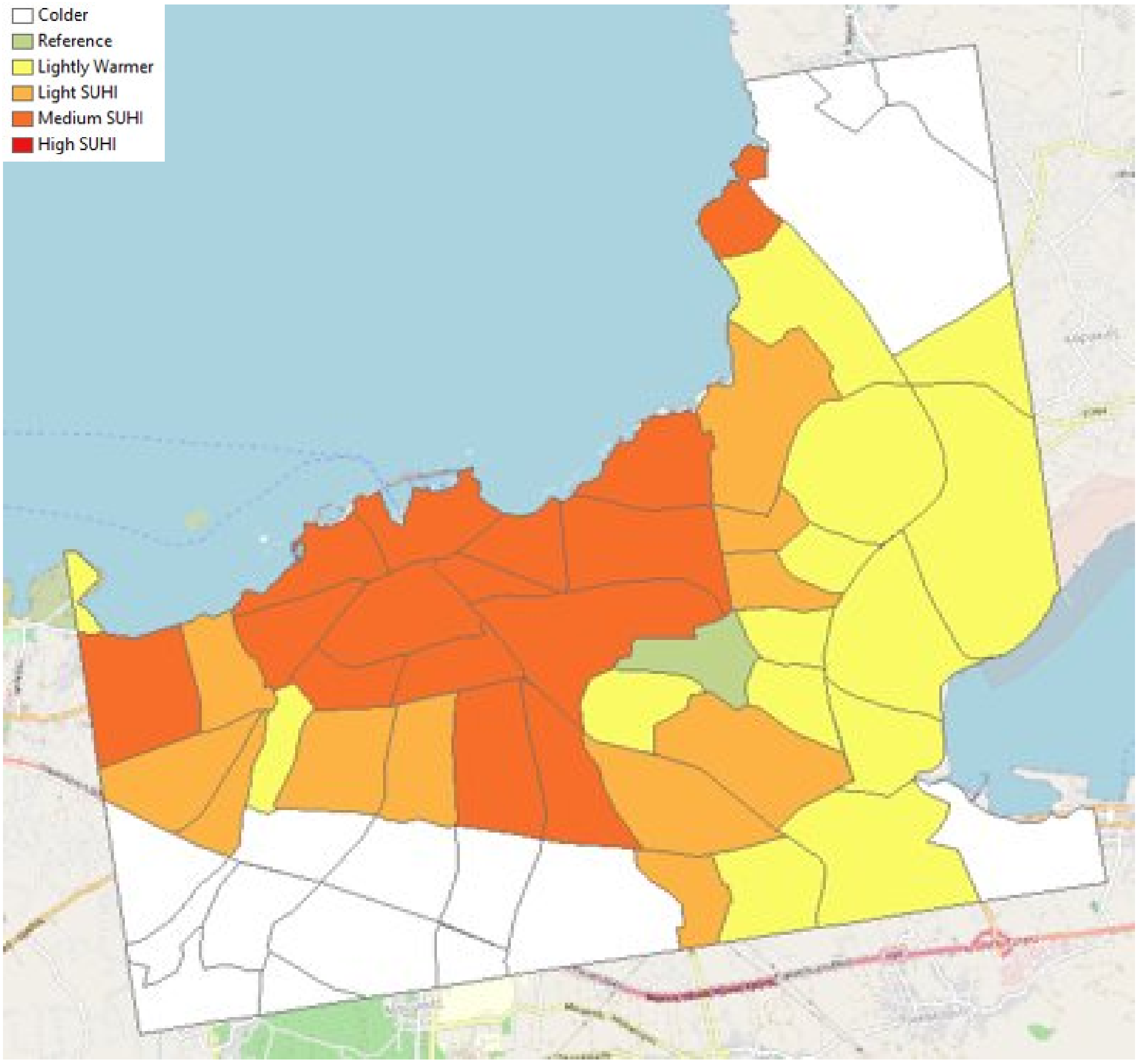


Figure 14: SUHI map for August 2021, Chania.

These maps, one for each month, intend to show the occurrence of the surface urban heat island effect over a partitioning of the city according to a specific zoning, such as different districts or zip-code areas. This is done at monthly level, in order to reduce fluctuations and noise that can be present on a single image.

The first step was to perform a spatial average of the monthly LST over each zone. Then a reference zone is chosen by visual inspection of the time series. In order to select a representative area, the considered zones were not inside or near the urban center, mostly rural (but not woody) and possibly with some settlements. The temporal behavior of the zones was also considered, by excluding zones with high fluctuations.

Finally, for each month and each zone, the LST of the reference zone was subtracted to the one of the considered zone and the result was stored in a new vector. These values represent the measured SUHI and were classified in 6 levels as displayed in Figure 14.

3.2.9 Surface Urban Heat Island Likelihood

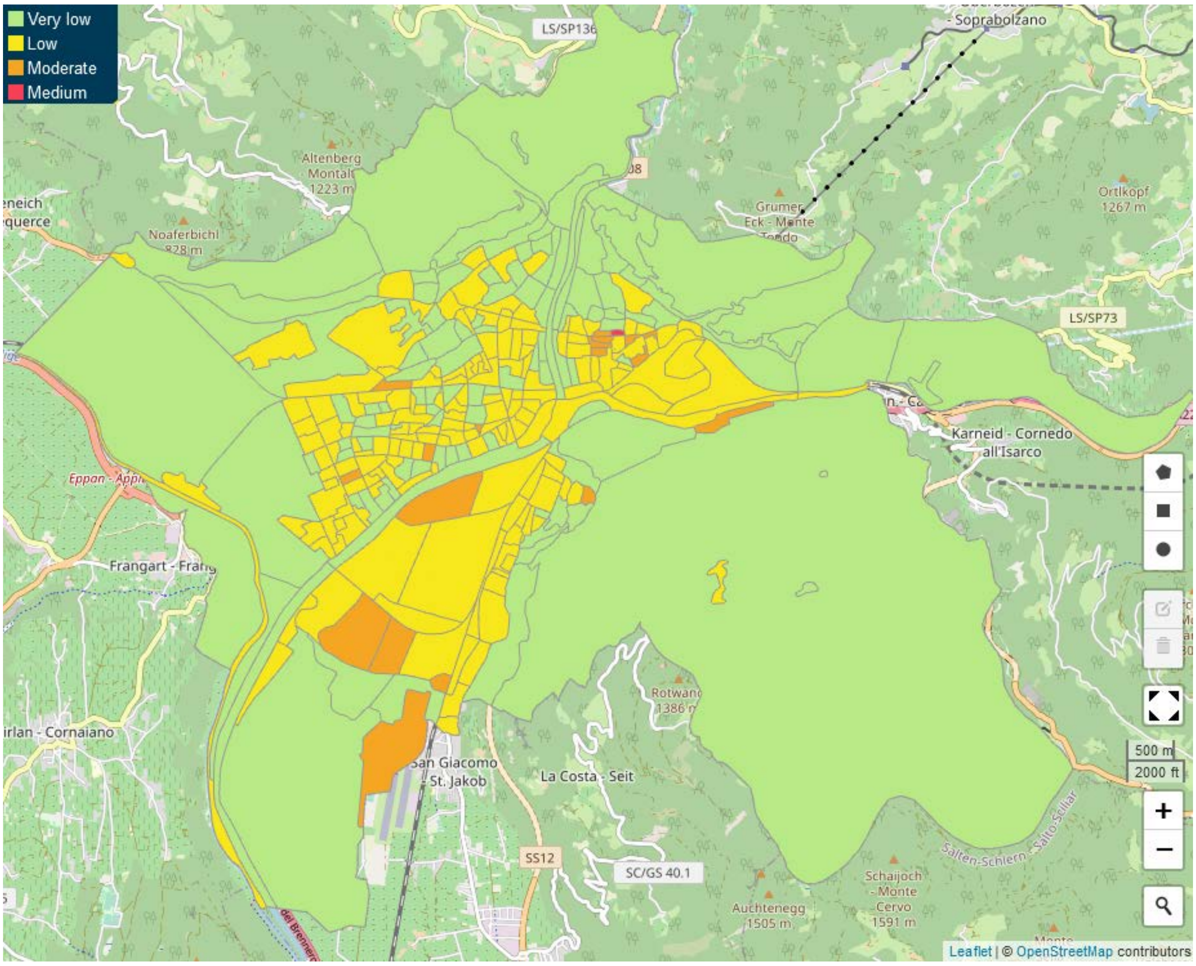


Figure 15: Surface Urban Heat Island Likelihood map, Bolzano.

Once the occurrence of the surface urban heat island effect is calculated in monthly maps at sub-urban zone level, a further analysis can be made in order to evaluate the overall likelihood of a SUHI over the area of interest. This is done by averaging, for each zone, the maximum monthly values of SUHI that have been observed within the time-series. Resulting values can then be classified in *n* levels in order to produce a SUHI Likelihood map, representing an overall picture of the SUHI phenomenon over the entire time-series analyzed, from 2017 up to 2022 (see Figure 15).

3.3 Strengths, weaknesses and limitations of using satellite data in relation to other monitoring data

When comparing different methods and technologies for data sensing, strengths and weaknesses of each of them have to be taken into account. Table 4 presents a non-exhaustive analysis of identified strengths and weaknesses when measuring LST from main remote sensing technologies.

The main advantage of using satellite data rather than ground or aerial data when assessing and monitoring LST-related phenomena, relies on the opportunity to acquire spatially continuous data, repeatedly and at lower costs. Regarding the use of LST data at the urban scale, indeed remote sensing technologies ensure spatial continuity of the acquisition, so that information for every point of the area of interest is directly sensed, in contrast to discrete in-situ data coming from available sensors (if any) that require an interpolation. Although ground sensors can provide temporally continuous data and more accurate measurements compared to remote sensing, the quality of the integration and interpolation of data coming from different sensors, depends on several factors such as their technical specifications, calibration and installation. Moreover, the costs of this technology are relevant and are based on single-installed-sensors or on field campaigns.

As previously stated, remote-sensed data can cover large areas in a single acquisition but their characteristics can vary considerably between satellite and airborne/drone remote sensing. Aerial data is characterised by higher spatial resolution of the data, thanks to their much lower flight height, at the cost of higher price of acquisition that are even less sustainable when considering operational monitoring.

In addition to the above presented satellite advantages (spatially continuous and repeated observations at lower costs), additional potentials come from available open data archives and their global coverage. The historical in-orbit presence of satellites carrying Thermal InfraRed sensors led to the creation of a deep data archive with global coverage, enabling the possibility to perform both historical analysis and present/future trends evaluation, at every location.

Table 4: Synthetic comparison of main Strengths (+) and Weaknesses (-) between satellite LST data and more in-depth monitoring.

	Spatial continuity and coverage	Spatial resolution	Cyclic acquisition	Historic data depth	Measurements accuracy	Costs
Satellite data	+	-	+	+	-	+
Aerial data	+	+	-	-	+	-
In-situ data	-	-	+	+	+	-

The combination of two open satellite data sources (Landsat and Sentinel-2), as already described within the LST package section of this document, aims at facing weaknesses without negatively affecting strengths. Such combination provides an increased spatial resolution of data, up to 10 m, while maintains a high temporal frequency of acquisitions. Even though the accuracy of such measurements is not as good as it would be if sensed on the ground, this method allows the identification of relative criticalities at sub-urban level based on a solid dataset of historical observations. This can represent both a direct information base for decision making, and a preliminary analysis for further in-depth studies that can be focused on already identified criticalities.

3.4 Opportunities and challenges of using higher resolution and stratification of data

The combination of two satellite sources for retrieving a higher resolution dataset, represents a state-of-the-art solution regarding currently available satellite-based LST data. In particular it represents a smart trade-off between spatial resolution, temporal resolution, and historical depth of data. It is worth mentioning that currently there is no civil satellite data provider able to acquire and distribute/sell Thermal InfraRed products having higher resolution.

On the other hand, this method faces some challenges such as the presence of a certain degree of measurement uncertainty that can come from data fusion, as it is not directly sensed but rather affected by the contribution of single Machine Learning inputs and by the difference between lowest input resolution and the desired output resolution. Considering currently available thermal data and their coverage (both spatial and temporal), higher resolution solutions could be based: 1) on the future availability of higher resolution in-orbit sensors; 2) on data acquired from planes or drones or on a ground sensors network, at the cost of lowest revisit time in case of aerial phenomenon monitoring and, in general, higher data acquisition costs. However, the opportunities of more in-depth analysis coming from integration of satellite and higher resolution data, are undeniable and can provide detailed results at higher scales. Finally, it is worth to highlight the importance of identifying a proper relationship between available data/techniques and user requirements. When addressing Surface Urban Heat Islands phenomenon, data stratification is crucial to identify proper homogeneous thermal zones from historical and downscaled data, and to increase usability of products within decisional and operational procedures of local authorities. Therefore, the use of higher spatial resolution data in similar applications has to face same challenges when dealing with analysis objective and user requirements, thus likely requiring stratification of data that can partially inhibit benefits coming from resolution.

3.5 Socioeconomic and sociodemographic data

Society in cities can be described using data related to social, cultural, socioeconomic, and sociodemographic characteristics of the population. Historically, each State periodically proposes a *census* with the objective of knowing the main structural and socioeconomic characteristics of the population at national, regional, and local scales. By combining the data collected from censuses with other types of data from other administrative and research sources, it is possible to ensure a knowledge of intervention and planning needs, preferences, and requirements. This information is relevant to ensure informed and useful choices at political, strategic, and planning levels.

This work aims to understand on the one hand the characteristics of the urban population in which NbS will be included, and on the other hand to understand the link between the characteristics of the population and the impacts (on the dimensions of justice) of a NbS. In the Annex 3 - Indicators", the list of socioeconomic, sociodemographic, and social indicators chosen for this research activity is provided. The data linked to each indicator can be qualitative and/or quantitative.

For example, according to the concept of recognitional justice, when planning an NbS, there is the need to understand the characteristics of the population that will use the NbS and recognize that, for example, the needs and preferences of people over 65 and people aged 0-17 may be different. In a neighborhood where both many people aged 0-17 and over 65 live, an NbS could be included to promote intergenerational relationships (e.g., a new garden providing services and attractions for both youths and elderlies).

Figure 16, Figure 17, Figure 18, and Figure 19 provide information on the distribution of the population according to certain age groups (e.g., 0-17; over 65), the housing situation (e.g., people living alone) and the situation related to cultural background (e.g., non-Italian nationality).

Figure 16: Population by age class 0-17 per census unit, n° (quantile classification method).

Figure 17: Population by age class 65+ per census unit, n° (quantile classification method).

Figure 18: Foreign population per census unit, n° (quantile classification method).

Figure 19: Population living alone per census unit, n° (quantile classification method).

However, data collection is a long and non-linear process. Censuses, collecting geographical, demographic, social, economic, and household and family characteristics, take place in each State every 10 years[1]. To obtain more frequent data, it is possible in some States to request support from the city's public administration, such as the municipality's demographic office, or public services of various kinds. However, several issues can be encountered in data collection.

There could be lack of:

- Homogeneity or possibility to compare data among cities. Data may belong to different time periods or be collected differently (e.g., gender may be collected through a list of different categories such as Male or Male; Male, Female; Other; etc.; data are not available at the same scale e.g., city, neighborhood, or smaller scales).
- Capacity to collect enough data in a way that provides a broad view of the characteristics of the population. Where, for example, there is a high percentage of non-resident students, data on such students does not exist and therefore no comprehensive picture of the city population is available.
- Easy access to data that should be public due the guarantee of privacy protection e.g., number of people living in a part of the city and their sociodemographic characteristics. Access to this data may not be easy even for the public administration. However, it is good practice for the public administration to make decisions based on comprehensive information and data on its city. Furthermore, the culture of data privacy is also limited.
- More availability of data e.g., it is very difficult to collect data about income, because there is not a single actor collecting and sharing this kind of data in many cities. For the partial availability of data in each CiPeL, it was not possible to collect the entire list of indicators in Annex 3 - Indicators.

The issues encountered are different in the seven CiPeLs and further understanding on how to deal with these aspects will be done in future.

[1] For more details about census, please refer to https://ec.europa.eu/eurostat/web/population-demography/population-housing-censuses.

4 THE COMPONENTS OF JUSTICE IN THE CREATION OF THE PROFILES

The six justice components identified describe the key aspects to consider regarding the extent to which environmental, social and economic individual and social vulnerability conditions drive injustices. D2.1 discussed, for each of these components, NbS potential to address these specific challenges, emphasizing synergies and trade-offs between them, by developing a basket of (in-)justice indicators. A list of the identified basket of indicators for each justice components is reported in Annex 3 - Indicators.

The methodology described below is built on the definition of such indicators, which purpose was to pursue a better and more comprehensive understanding of the different aspects under the concept of justice. It suggested what drivers should be considered, whether NbS contributions are integrated, which justice dimension it predominantly targeted, the level of integration with other challenges and the spatial mapping potential. Note that indicators have been selected also based on their feasibility and replicability in the JUSTNature context.

Initially, in order to build an assessment of the status of NbS underlying ecosystems, functions, ecological disturbances and potential (spatial) disparities in the CiPeLs, each (in-)justice indicator found in the literature has been further investigated to understand its methodology and identify the required informative input layers.

The construction of the informative layers faces the need to identify and retrieve data from a range of different sources. The availability of remote sensed satellite data provides an essential contribution to the development of the ecological and socioeconomic profiles, offering the opportunity for a standardized and consistent baseline for the evaluation of the socio-ecological status of the different CiPeLs. It has been tried therefore to fully exploit the processes and elaborations delivered by PKI in terms of high-frequency and high-resolution satellite data, by integrating them with other spatial and socioeconomic information (see Section 3).

The analysis has been performed using Geographical Information Systems (GIS) to refine insights into the ecological and socioeconomic status.

The selected (in-)justice indicators were computed to understand the distribution of NbS needs and accessibility and therefore to identify potential disparities profiles. The list of the final selected indicators computed is reported in Annex 3 - Indicators.

The following paragraphs describe, for each justice component, which spatial analysis has been performed, what input layers were needed, and (eventually) what additional data might have been useful. Finally, a tentative clusterization of the collected information to build the profiles is provided.

4.1 Air-quality justice

Air quality (in)justice is described as responding to the higher exposure to average values of air pollutants (e.g.,NO_2, O_3, SO_2, CO and PM_{10} and $PM_{2.5}$) among different groups of the population and also takes into consideration procedural impacts on the distribution of an Air Quality Monitoring Network and potentially resulting blind spots [1].

The main critical aspects related to air quality conditions at city level are identified in the unequal distribution of air pollutants within the city and the uneven distribution of environmental ills due to air pollutants exposure. The uneven distribution of vegetation within the city is another element of injustice due to the contribution of vegetation in mitigating air pollution impacts removing pollutants from the atmosphere.

Within the environmental justice studies, several GIS techniques have been used to address the uneven distribution to air pollution across the city and to identify areas at major risk of exposure. Traffic emissions are one of the major sources of air pollution and roadside pollutants concentration is usually higher than their ambient counterparts because of the proximity to emission source [41].

Proximity analyses to air pollution sources are one of the most basic approaches and provide a simple and straightforward application to measure differential exposure within the urban context. These methods use the nearness to emission sources as proxy for exposure in human populations [42]. Buffer analysis is the most widely used method. Buffer generation around emission sources can have different radii that can range from few meters to more than 1 Km distance [42], [43]; other studies have used multiple circular rings at increasing distance from hazard sources [44].

Such methods have been widely used to estimate the relationship between road proximity and air pollution-related diseases [42], with focus on distance to road and traffic counts, often combining proximity measures with measure of road type or traffic density to differentially classify exposure based on both potential emissions and distance from source.

Despite providing straightforward application for exposure analysis, these methods have considerable limitations. They do not consider other variables that might affect the exposure and related impacts; indeed, the basic assumption of isotropic dispersion does not allow to take account of the effect of wind and topography in pollution dispersion across the city.

Urban street canyons' location is another parameter that can be used to monitor the impact of harmful emissions on human health (Figure 20). Urban morphology in fact strongly influences the air pollutants concentration; ventilation and pollutant removal in a street depend on many factors, such as weather conditions, the presence of green infrastructures and the street characteristics; vehicular emissions in less ventilated roads, such those edged by tall buildings, pose adverse health impacts for pedestrian, drivers, and residents in naturally ventilated buildings [41].

The Sky View Factor (SVF) is a common indicator to describe urban structure and identifying the presence of urban canyons. It is defined as the ration of sky hemisphere visible from the ground (not obstructed by buildings, terrain or trees) and it is calculated from a given point considering all surrounding obstacles to the sky hemisphere.

The proposed methodology for the identification of the urban street canyons relies on the use of the free and open-source GIS software SAGA-GIS. The input data required by the tool is raster elevation data. The algorithm performs the analysis based on two input parameters, the number of sectors, which define the number of directions, and the distance of search to detect obstacles limiting the sky view. The larger their value and the more accurate the SVF of each pixel. According to the literature, 16 different directions and a search radius of 100 m are good enough input parameters for performing the analysis [45].

The resolution of the raster is another critical parameter that affects the output accuracy. For the development of the methodology, a very high resolution (0.5 m x 0.5 m) digital elevation model (DEM) retrieved from available airborne laser scanning data for the area of Bolzano has been used as input.

SVF can provide useful information on air pollution risk exposure especially when combined with traffic volumes data. Levels of sky view factor and traffic volumes can be combined in order to generate a risk matrix and finally provide a road classification based on the level of risk associated with vehicle emissions. Traffic volumes data collected at local level are needed; alternatively, assumptions on traffic volumes can be made based on road type.

In order to identify the areas at risk of exposure to traffic-related emissions, a 50 m buffer has been performed from the roads thus classified. The buffer has been computed to calculate the proximity area to roads for each level of risk.

The result will provide information on areas within the city where high traffic volumes are associated with specific morphologic characteristics that might determine higher risk of pollutants concentration, allowing the decision-makers to identified areas at risks and take actions in this direction. Such information can be also combined with information on the presence of vegetation in the identified areas at risk and allow considerations on the type of vegetation that is the most appropriate case-by-case.

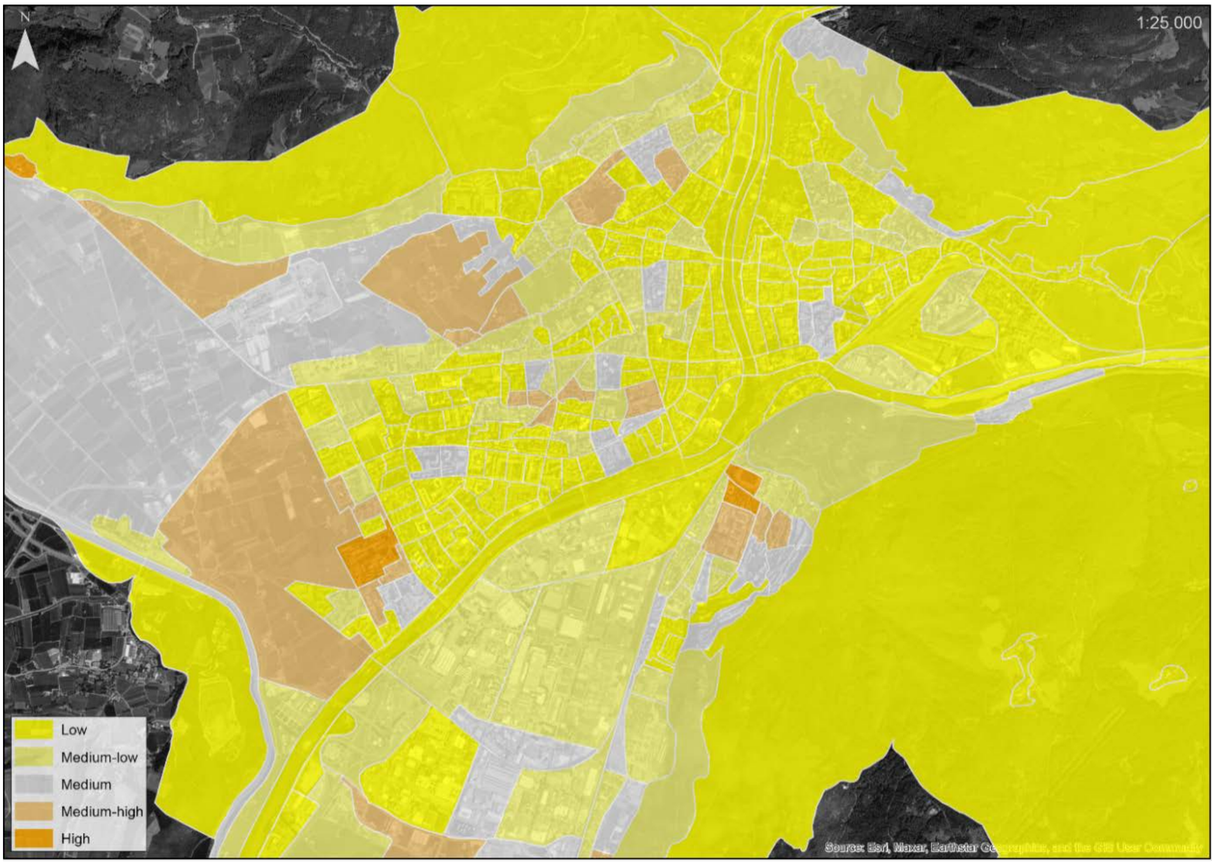


Figure 20: Street canyon risk per census unit, unitless (Jenks classification method).

4.2 Thermal justice

Thermal justice refers to the reduction of the inequitable distribution of extreme heat conditions and related risks across different areas within the same city and the vulnerable population [1].

Within urban areas, this phenomenon of urban heat island (UHI) is particularly evident and occurs simultaneously to the increase of the global temperature baseline, hence exacerbating the health risks [46] (Figure 21). Its magnitude can be quite large – depending on weather conditions, urban physical characteristics, and anthropogenic heat sources – and it is characterized by an uneven spatial distribution [47].

It is possible to identify two key aspects for the strategical assessment of this justice components:

- Air temperature
- Land Surface Temperature

There is a strong relationship between them (LST influences air temperature), although they have different physical meaning and response to atmospheric conditions [48]. However, since LST is a mixture of vegetation and bare soil temperatures, it can be used as an indicator for UHI. Moreover, LST information is easier to retrieve, as it is derived by processing satellite images.

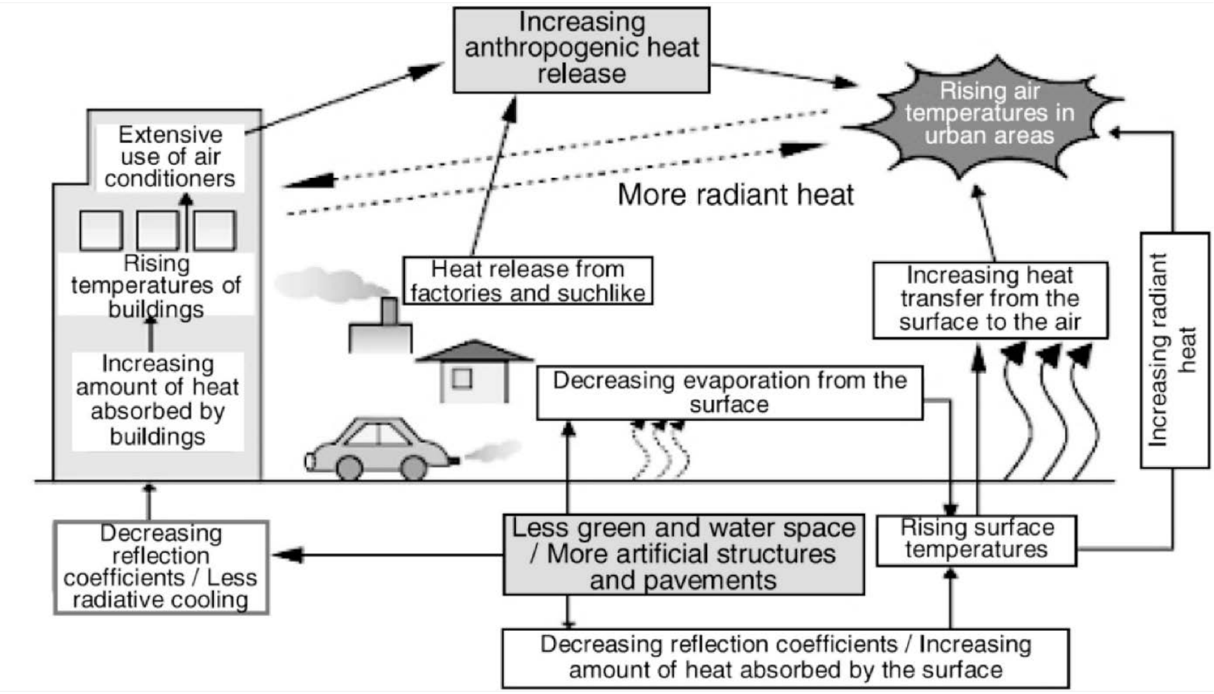


Figure 21: Causal chain of UHI phenomenon [49].

Two of the different raster datasets elaborated by PKI for each CiPeLs have been included in the list of thermal (in-)justice indicators. The first one contains the thermal stress zone, obtained by temporal analysis of LST summer monthly maps in order to identify zones with a similar heating/warming behaviour (10 m spatial resolution) (see Paragraph 3.2.7).

The second one contains the surface urban heat island (Figure 22), obtained by evaluating the monthly LST difference against a reference zone for summer months (census unit resolution) (see Paragraph 3.2.9).

4.3 Carbon justice

Carbon justice refers to the responsibility for greenhouse gases (GHG) emissions, accountability for the distribution of the related environmental ills, and considerations on climate change mitigation potential of different ecosystems and their distribution across the city [1]. At the urban level this concerns different types of GHG – or carbon dioxide equivalent – (mainly CO_2, CH_4, NO_2 and SF_6) that are mainly caused by three sectors: building, transportation and waste [50].

Given the above-mentioned definition, it is possible to identify two key aspects for the strategical assessment of this justice components:

- Carbon generation potential
- Carbon mitigation potential

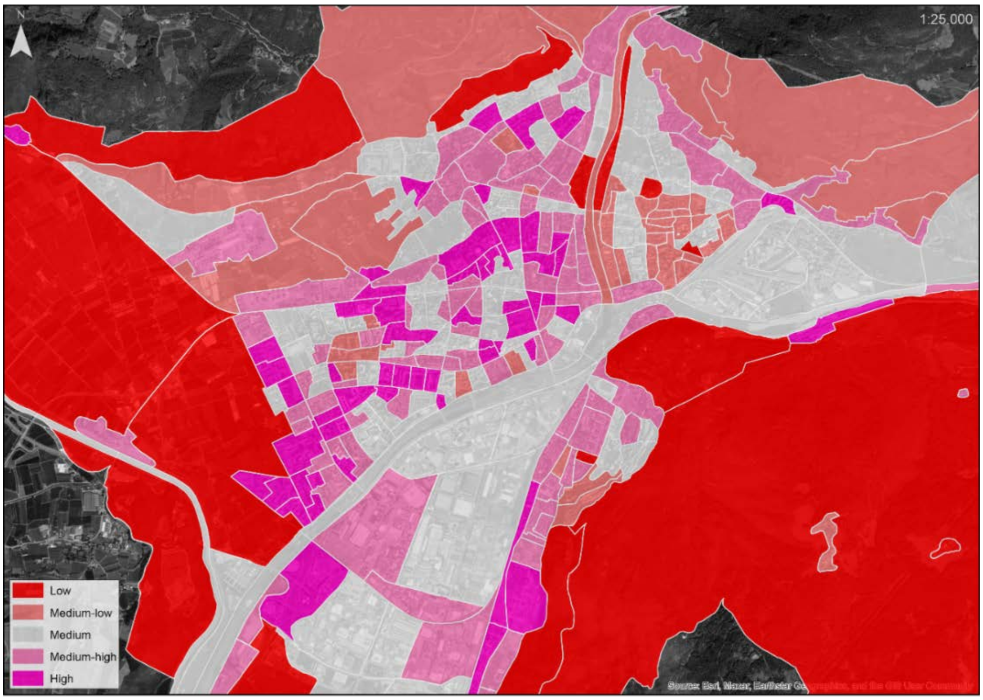


Figure 22: Surface urban heat island per census unit, unitless (Jenks classification method).

Regarding carbon generation, focus has been placed on the emissions related to building cooling and heating, since they constitute around half of the EU energy consumption [51].

Given that statistical disaggregated data are not available on a city-scale basis, already-processed information from the toolbox of the Hotmaps project - where Eurac Research was one of the partners involved - have been used [52]. Two raster dataset (with 100m spatial resolution) have been collected; these contain i) the final energy demand for heating and ii) the final energy demand for cooling of buildings in EU (MWh). Then, local information about the main types of source used to produce that energy with their percentages have been retrieved; in the case of cooling only electricity has been considered. Successively, the different fractions and the relative carbon dioxide equivalent emissions have been calculated using IPCC (i.e. Intergovernmental Panel on Climate Change) standard conversion factors (t CO_2 eq./MWh) [53].

Table 5: Standard emission factors per type of sources.

Source	Emission factor (t CO2 eq./MWh)
Methane	0,202
LPG	0,227
Diesel	0,268
Biomass	0,410
Electricity	0,467

The output is a map showing the total amount of carbon dioxide emitted (t CO_2 eq.) from the building sector per census unit (Figure 23).

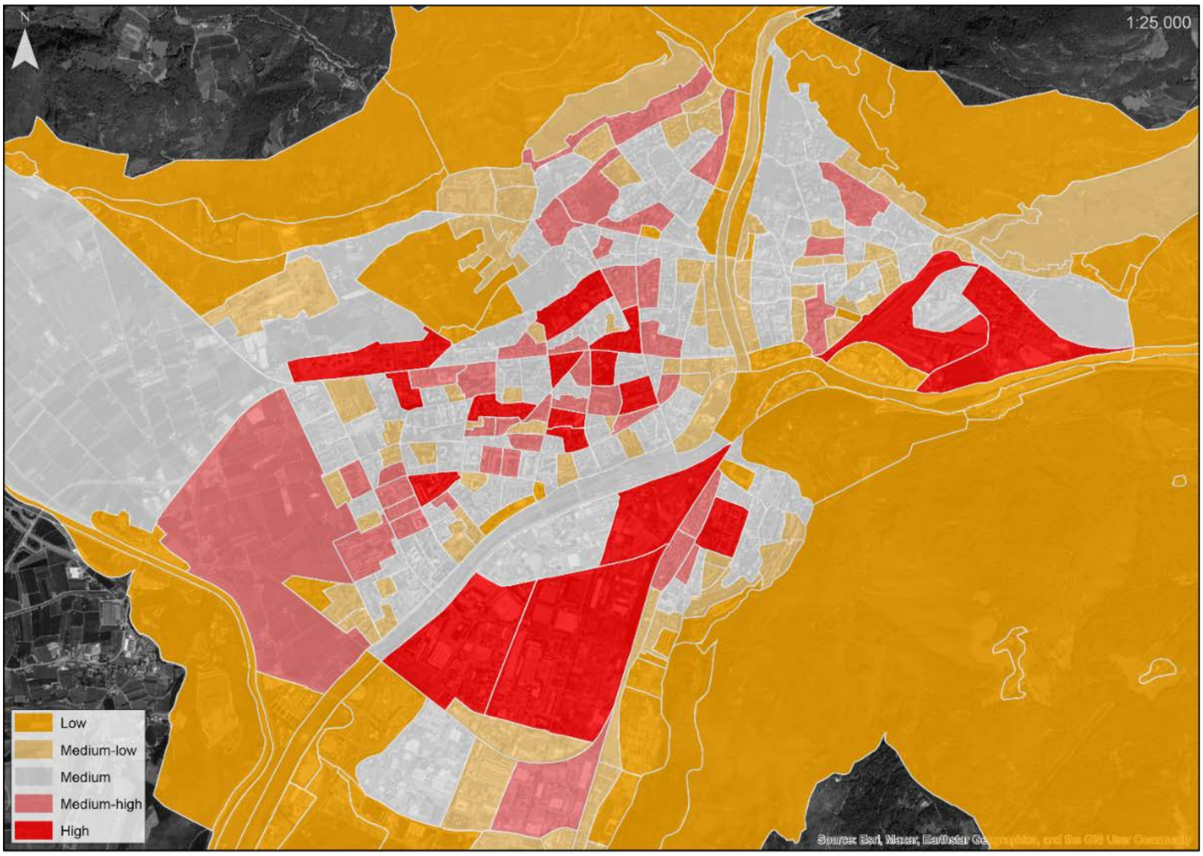


Figure 23: Carbon emission related to building sector per census unit, t CO_2 eq. (Jenks classification method).

Regarding carbon mitigation, focus has been placed on the absorption by above-ground vegetation.

First, the Digital Surface Model (DSM) and the Digital Terrain Model (DTM) of the studied area have been downloaded from the local geodatabase. Successively, a difference between them was computed (using a map algebra expression) to retrieve the Digital Height Model (DHM) of the territory. The land cover map provided by PKI (with 10 m spatial resolution) was used to exclude from the analysis all built environment elements (note that it if the spatial resolution of the DHM is different than 10 m, a preliminary resample process is needed); then, a filter was applied to the obtained file to extract only the cells where height > 5 m, i.e. trees. Finally, based on the assumptions that each remaining cell potentially represents a single tree, and knowing that an average tree can absorb 15 kg CO_2, the absorption potential of the above-ground vegetation within the city was calculated by multiplying this factor with the overall number of remaining cells.

The output is a map showing the total amount of carbon dioxide absorbed (kg CO_2) from the vegetation per census unit (Figure 24).

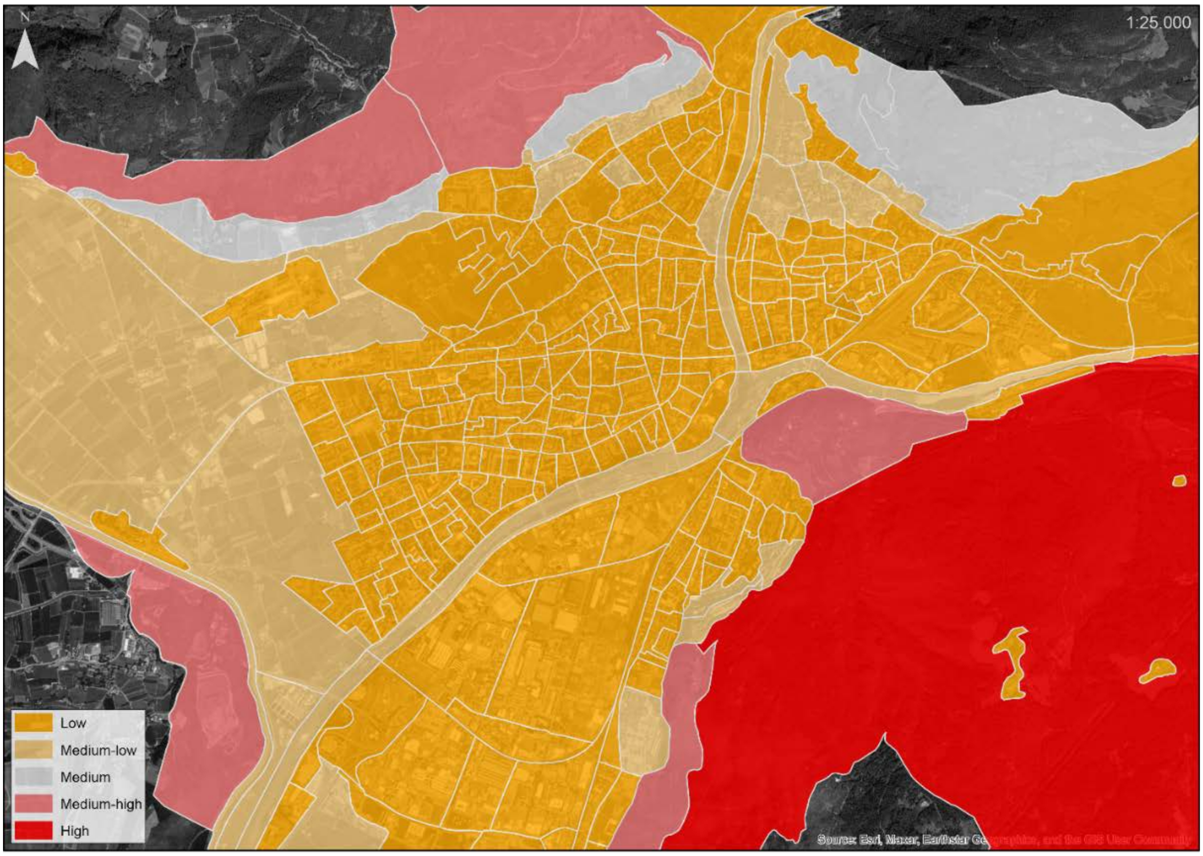


Figure 24: Carbon absorption related to vegetation per census unit, kg CO_2 (Jenks classification method).

4.4 Flora-Fauna-Habitat inclusion

Flora-Fauna-Habitat refers to the extension of justice considerations to nonhumans that prioritizes the environment at the species-, individual-, or the ecosystem level [1].

As deeply described in D2.1 this can refer to the unequal distribution of common environmental goods (like protected areas and elements with specific non-human value) and disturbances, and the uneven distribution of urban development the alteration and fragmentation of habitat.

In order to assess the underlying conditions that might be symptom of a greater or lesser inclusion of nature within the city context, the following aspects have been considered:

- Natural areas fragmentation
- Distribution of protected areas

Urban vegetation, from isolated trees to large patches, can play a fundamental role in conserving the biological diversity of urban areas.

Urban vegetation is highly fragmented and heterogeneous, and understanding its composition, quality and connectivity is crucial to guarantee the biodiversity assets that human and non-human well-being requires in urban environments.

Some studies have tried to identify those factors that play a role in determining the biodiversity levels in urban context. [54] presents a meta-analysis on intra-urban biodiversity variations across 75 cities worldwide and a large variety of taxonomic groups, showing how patch area and corridors represent the strongest determinants of biodiversity in urban context. Although many other variables, considered together, explain the urban species richness, highlighting the role of species-area relationship also in urban landscape, some thresholds can be identified according to the conservation objective. Species richness has been found to decline rapidly at an average of ca. 27 ha; however, smaller areas, with an average 4.4 ha, can be considered sufficient if the declared goal is to minimize the loss of urban adapter species [54].

The lack of vegetation inventories and information about urban habitats is a major impediment for the assessment of ecological connectivity and strongly limits the conservation efforts in urban context.

The availability of high-resolution imagery can play an important role in connectivity studies allowing vegetation detection and quantification, and the assessment of changes in land use and land cover and their impacts on structural and functional connectivity.

Vegetation indices are widely used for monitoring vegetation cover, globally including intra-urban vegetation [55].

The degree of vegetation, introduced in Section 3, measures the fraction of ground cover by green vegetation. Allowing to quantify the spatial extent of vegetation, it is a very good indicator for monitoring vegetation over time.

Land use land cover (LULC) maps derived from remotely sensed images can also play an important role in urban vegetation studies, allowing to identify landscape structure and evaluate the contribution of each green tract to the connectivity in the city.

In the proposed methodology, a series of structural metrics have been computed using the LC map produced for Bolzano for 2022 as input data in FRAGSTATS 4.2 to assess the landscape structure in relation to the different land covers.

FRAGSTATS is a spatial pattern analysis program that computes statistics to quantify the landscape structure at three different levels: patch, class and landscape [56].

Patch level metrics are calculated for individual patches, i.e., discrete areas with similar characteristics; class level metrics are calculated from all patches of a particular type and evaluate elements in the landscape as if they were independent; landscape level metrics are the combination of all patch and class type in a given area and allows to understand how the landscape's elements interact with each other.

The classes identified for the class metrics computation are thus the land cover classes and the patches are identified based on the belonging class. In line with the aim of the analysis, the urban classes and arboreous green areas classes have been merged into two single classes: Urban and Woody Vegetation.

According to the literature, a patch area higher than 4.4 ha has been chosen to identify those areas that might affect the biodiversity levels within the city.

For each of the vegetation classes the class area and the mean patch size were further estimated to quantify the overall abundance across the landscape. The cohesion index was also computed; this can be used to assess if patches of the same class are located aggregated or rather isolated and thus characterizes the connectedness of patches belonging to each class giving information about the configuration of the landscape. At the landscape level the Largest Patch Index (LPI) was calculated. The LPI ranges from 0 to 100; 100 indicates that the landscape consists of a single patch [56] (Figure 25).

Table 6: The computed class and landscape metrics for the case of Bolzano

	Class metrics			Landscape metrics
Land Cover Classes	Class Area (ha)	Mean Patch Area (ha)	Cohesion	LPI
Urban	1375.03	0.6267	99.4295	34.7224
Woody Vegetation	5884.01	1.5076	99.7496	
Grassland	627.94	0.1397	89.4678	
Agricultural areas	2030.76	2.8969	99.3192	
Bare soil/rocks	0.58	0.02	38.4623	
Water	92.91	0.6636	97.5287	

Although simple structural metrics based on topological relationship are not adequate in providing meaningful ecological information about landscape, the easiness of calculation with readily available land-cover data and little or no parameterization makes them particularly suited for exploratory and descriptive analysis [57]. Nevertheless, the availability of multi-temporal satellite images for the computation of structural metrics can provide useful information in relation of the changes in landscape structure allowing a better understanding of how these changes affect landscape fragmentation and valuable information for the introduction of NbS in the urban environment.

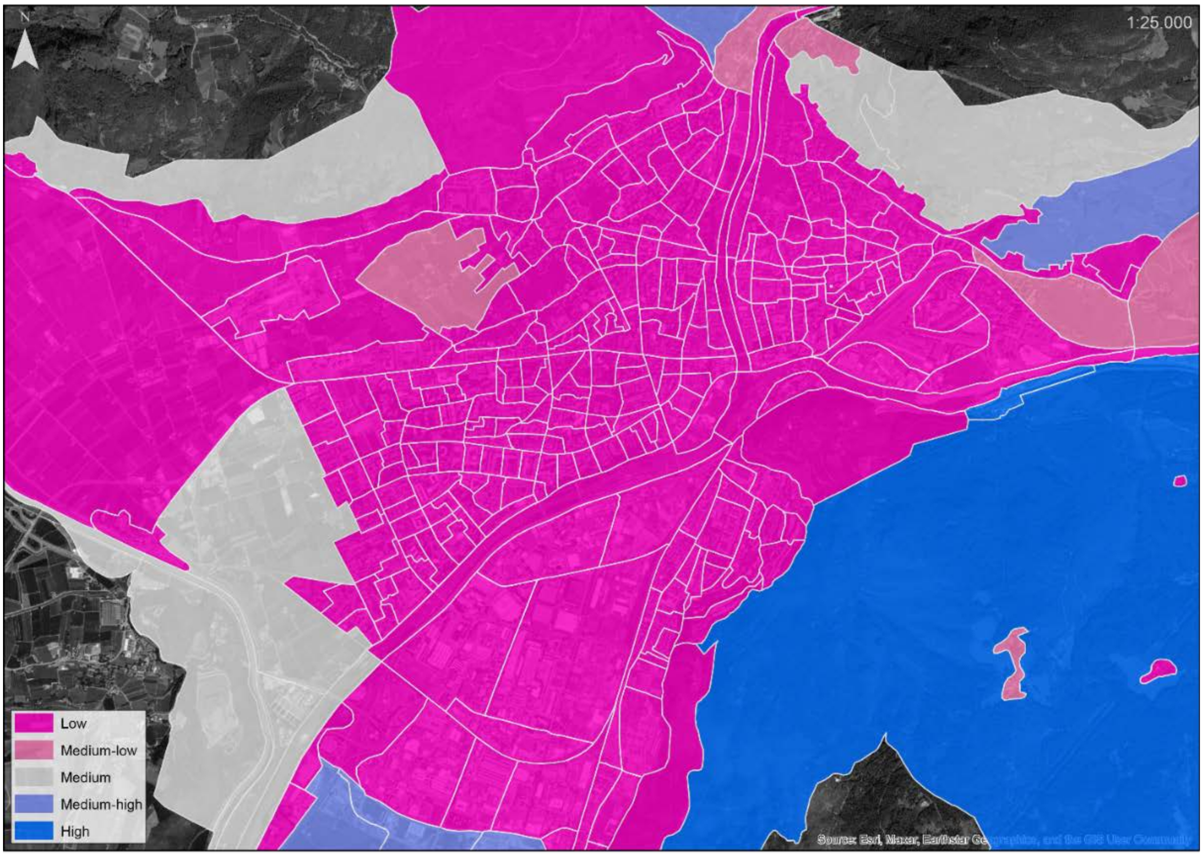


Figure 25: Vegetation patches with area > 4.4 ha, percentage on total area (m^2) (Jenks classification method).

Protected areas are defined as geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values [58].

Data on protected and designated areas is usually included in local geodatabase and provide information about the presence and distribution of green areas within the city boundary to which ecological, geological, historical or cultural value is attributed and efforts are made in ensuring their protection and maintenance.

To allow an evaluation of protected area distribution across different parts of the city, the percentage area of protected sites on the total per area per census unit is computed. The example for Bolzano is showed in Figure 26.

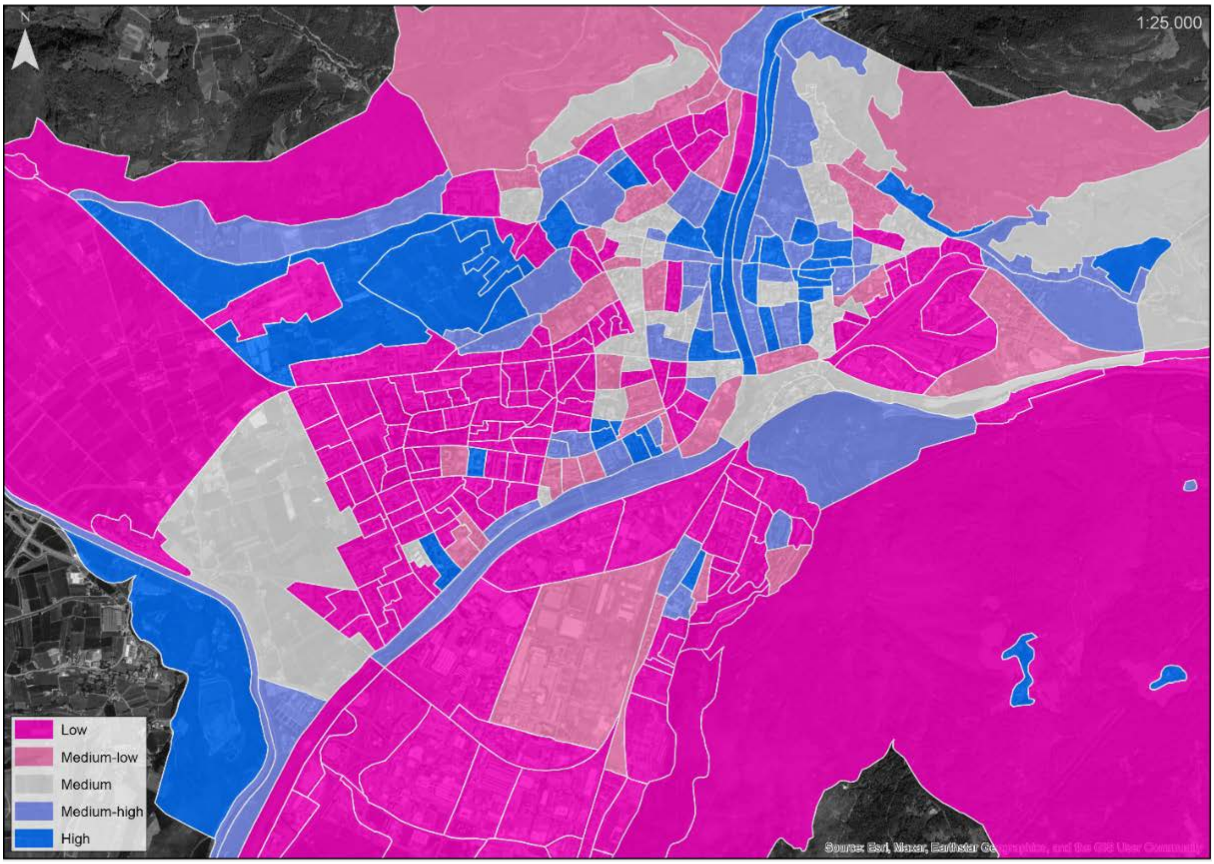


Figure 26: Protected area per census unit, % (Jenks classification method).

4.5 Spatial justice

Spatial justice refers to the distribution of environmental amenities and disamenities, such as socio-spatial segregation, sorting of urban population and gentrification impacted by the socioeconomic context, individual and social vulnerabilities [1].

The evaluation of spatial (in)justice conditions within the city strongly relies on a series of detailed information about the presence and distribution of services, the distribution of green spaces and their qualification, detailed information about sociodemographic and socioeconomic conditions at sub-municipal level.

Accessibility has been identified as the main indicator to provide the baseline information on possible disparity conditions within the urban area. It is recognized as an essential criterion to investigate environmental justice issues within the city context as it describes the opportunity to access a series of destinations that satisfy the daily life needs of neighborhood residents.

Accessibility has been addressed for many years within the urban studies as a transport-related problem, however, in recent years the accessibility studies increasingly approach the topic as a multidisciplinary issue that involves the localization and distribution of opportunities and resources within an urban area [59].

Using GIS for network analyses, accessibility can be measured by calculating traveling times and distance from different destinations, e.g., green spaces and urban facilities.

The analysis carried out on accessibility to green spaces has been conducted using the network analyst toolbox in ArcGIS 10.8. Network analysis accounts for both geometry and topology in the input networks, using metric distance or topological distance as impedance factors in the analysis.

Input data required for the evaluation of green spaces accessibility are:

- Urban green areas
- Transportation network
- Elevation data (optional)

The first two input data required can be retrieved extrapolating the Urban Green Areas class included within Urban Atlas LULC 2018 or using local source data for green areas. The higher the level of detail in the information provided the more accurate the accessibility analysis will be in accordance with the different green area typologies.

The Network analysis is based on the construction of a Network Database, which will provide the essential information about the road networks. Firstly, the shapefile of transportation links has been modified in order to identify those links accessible for pedestrian use, excluding high-speed roads and including pedestrian and cycle paths and trails. The shapefile thus created was used as input for the Network Dataset construction.

Secondly, the intersection between the selected links and the green areas was calculated in order to identify access points to green spaces. Such intersectional points were used for the development of the Service Area analysis as destination/origin points.

Finally, the Service Area analysis has been performed using distance as Impedance and assuming two distance measures for estimating the accessibility to green areas: 400 m (5 minutes) and 800 m (10 minutes).

In order to provide useful information, the distribution of green spaces should be accompanied by the identification of the type of green spaces and their specific uses by different groups of users.

As shows in the literature, possible challenges and critical aspects in terms of accessibility to green spaces might go beyond the physical accessibility to specific areas and refers to social barriers, e.g., the availability for children parks in areas with high children populations or presence of schools, or the availability to safe access for women to parks and gardens, as well as the presence of urban green explicitly encouraging resident's participation such as allotment or community gardens. The identification of green area types would be valuable information in the planning and design process of a NbS in line with specific needs and preferences of the population involved. An example of mapped indicator related to the accessibility to urban green areas is showed in Figure 27

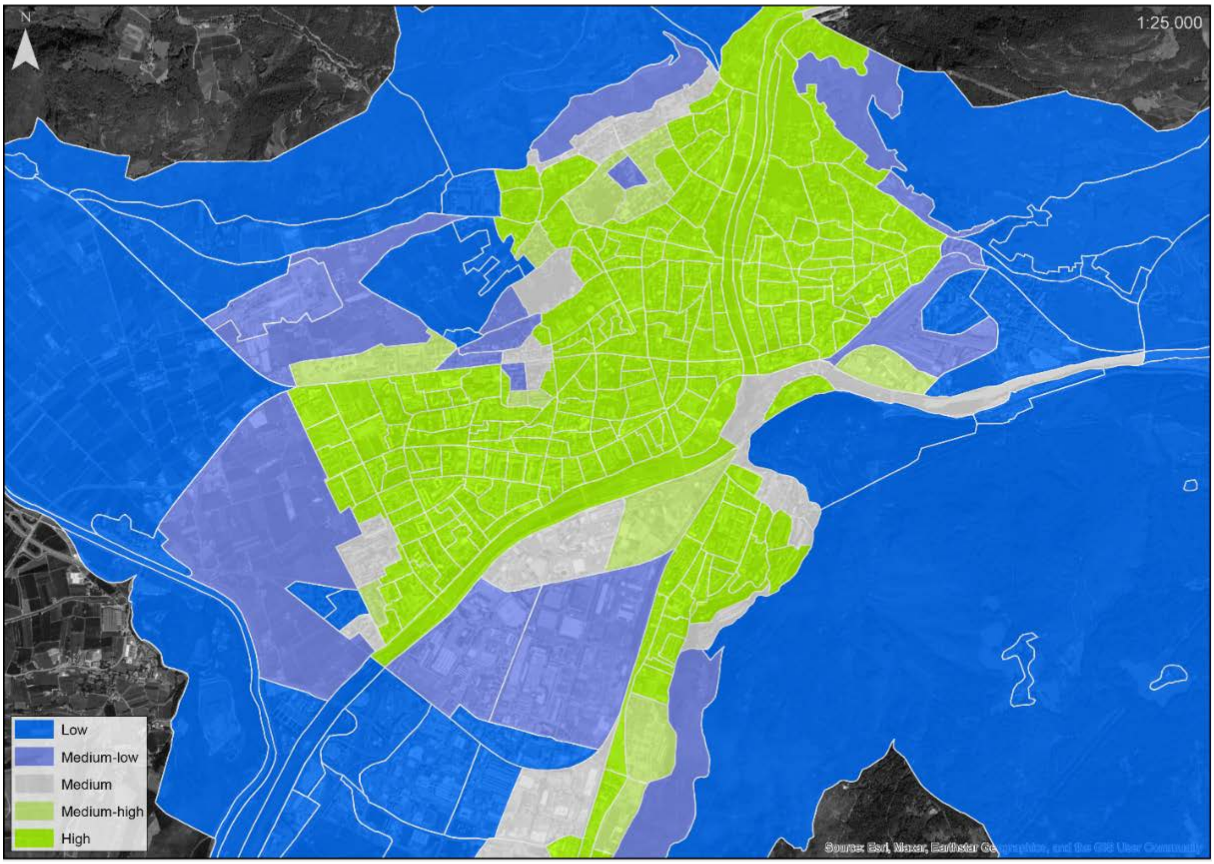


Figure 27: Accessibility to urban green areas per census unit – 5 minutes walking, % (Jenks classification method).

The accessibility to urban facilities – such as healthcare facilities (Figure 28) and cultural facilities (Figure 29) - has also been included as an indicator of spatial (in)justice, as it allows to evaluate the presence of sociodemographic disparities in relation to the accessibility within the urban context. It is thus used to feed the assessment of the socioeconomic underlying conditions at sub-municipal level.

The methodology used for the assessment of the accessibility to urban facilities recalls the network analysis in ArcGIS 10.8.

The input data in this case will be a series of facilities, or points of interest, classified per category. Four categories of urban facilities have been identified:

- Cultural facilities (Theatres, museums, cinema, libraries, etc.)
- Educational facilities (Schools, universities)
- Social facilities (Nursery schools, youth and elderly centers, nursing homes, etc.)
- Healthcare facilities (Pharmacies, hospitals, medical practices and clinics)

The input data can be retrieved from OpenStreetMap (OSM), which includes information on points of interest that can be classified according to the needs and requirements. Being provided by the users, the quality of the OSM data may change hugely from one place to another. When available, detailed data on facilities provided by the municipalities can be used.

Figure 28: Accessibility to healthcare facilities per census unit – 5 minutes walking, % (Jenks classification method).

The points of interest represent the input facilities for the Service Area Analysis, which will use again the Network Dataset developed from the transportation layer. The assessment of the accessibility to urban facilities has been developed considering the different facilities' categories separately. The service area has been computed based on distance and travel time and calculated as 5 minutes (400 m) and 10 minutes (800 m) walking from and to facility points. Finally, the percentage of accessible area per census unit for each of the four services categories was computed.

The last method proposed to address accessibility within the urban context is based on a recently developed Walkability plugin, OS-WALK-EU. The tool is open-source and freely available for QGIS software and offers the possibility to account for a series of conditions that affect and shape accessibility in cities.

Figure 29: Accessibility to cultural facilities per census unit – 5 minutes walking, % (Jenks classification method).

The strength of the OS-WALK-EU plugin is the opportunity to assess the walkability based on free and open data; it also offers the opportunity to replace such data with local information that better represent local realities. It allows the definition of parameters by the user that can thus define social groups' preferences, e.g., in the choice of amenities, and deviation from theoretical assumptions that might not be applied locally [60].

Table 7: OS-WALK-EU input data

Input Data	Source	Resolution
Population Density	Global Human Settlement – Population Grid	100 m x 100 m
Pedestrian Network	OSM – Transportation Links	-
Amenities	OSM – Points of interest	-
Green Urban Areas	OSM – Urban green areas	-
Digital Surface Model	Aerial Lidar (Light Detection and Ranging)	0.5 m x 0.5 m

Five components of walkability have been identified:

- Population density
- Pedestrian network

- Slope
- Green Infrastructure
- Amenities

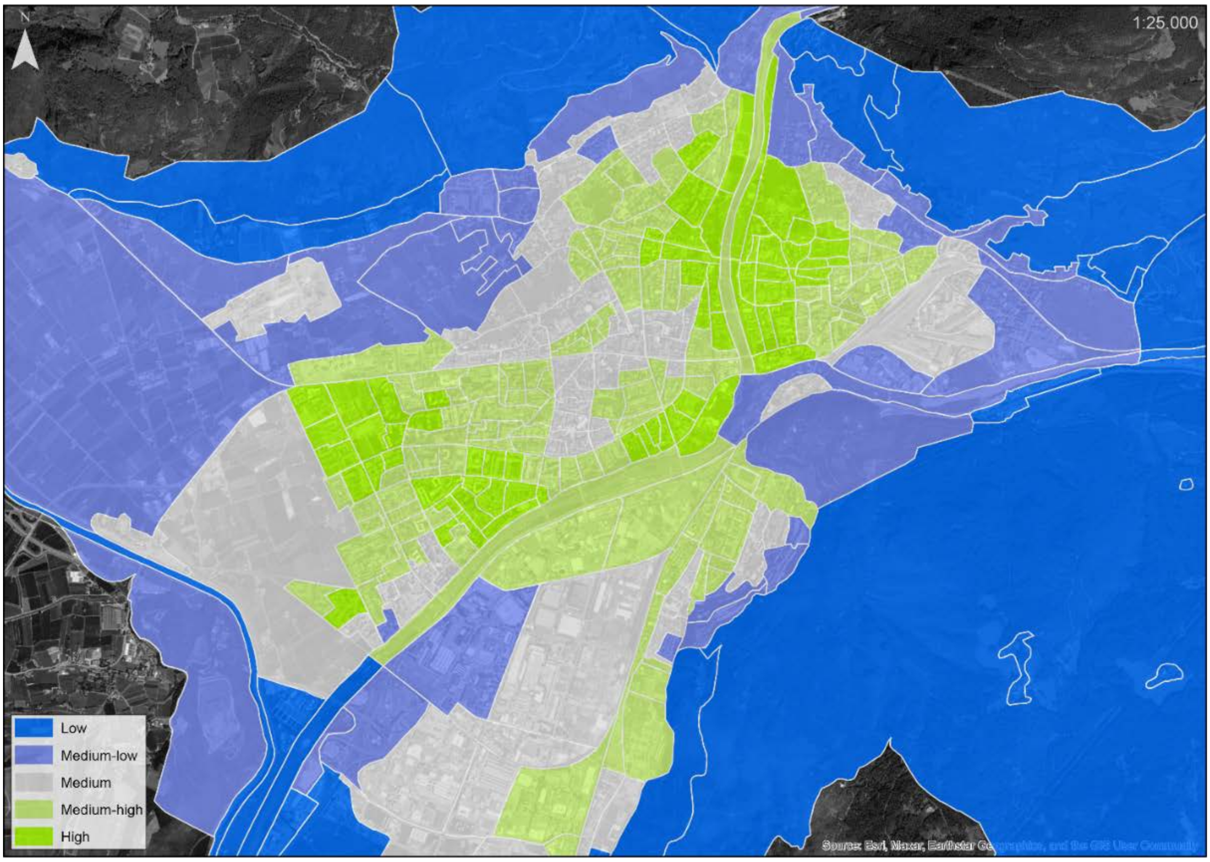


Figure 30: Walkability Index per census unit, % (Jenks classification method).

The Walkability score is calculated based on a weighting system that associates different values to different classes of each of these components.

The Walkability points (Wp) are computed through the following formula:

$$Wp = Pn * Pn_w + Pd * Pd_w + Gi * Gi_w + A * A_w$$

The table below shows the description of each variable and Figure 30 shows an example of the mapped indicator for Bolzano.

The Walkability Score (Ws) is finally calculated as:

$$Ws = Wp * 100/ Wp_{max}$$

Table 8: Variables to compute the Walkability points (Wp).

Pn	Pedestrian Network
Pn_w	Pedestrian Network weighted
Pd	Population Density
Pd_w	Population Density weighted
Gi	Green Infrastructures
Gi_w	Green Infrastructures weighted
A	Amenities
A_w	Amenities weighted

4.6 Temporal justice

Temporal justice refers to the interrelations between past, present and future conditions of injustices and inequalities, considering lock-ins and path dependency processes occurring in cities as well as the consequences of today's actions on future generations [1].

The spatial configuration of the city, and its modification over time, can provide information on areas where particular conditions of exposure and vulnerability exist and might be exacerbated by future climate changes, and therefore on aspects to consider when implementing NbS [61].

Given the above-mentioned definition, it is possible to identify two key aspects for the strategical assessment of this justice component:

- Land use change impacts
- Climate change impacts

Land use and climate changes are deeply interrelated and influence each other at various temporal scales [62]. However, since improper land uses are the primary causal factor on climate change and terrestrial ecosystem degradation, focus has been placed on this aspect and on the analysis of time-series pattern of built and natural environment, as well as their thermal behaviour, using input layers elaborated by PKI. Examples of Degree of imperviousness, Degree of vegetation, and Soil sealing are shown in Figure 31, Figure 32, and Figure 33.

A pixel-by-pixel comparison between raster dataset of two different years (2020 and 2018) was computed to retrieve punctual information about the qualitative changes that occurred in the urban environment, using the following expression:

$$\text{Imperviousness changes} = \text{Degree of imperviousness}_{2020} - \text{Degree of imperviousness}_{2018}$$

$$\text{Vegetation changes} = \text{Degree of vegetation}_{2020} - \text{Degree of vegetation}_{2018}$$

Figure 31: Imperviousness change between 2020 and 2018, unitless (Jenks classification method).

Then, soil sealing (i.e., the covering of the soil surface with impervious materials as a result of urban development) has been estimated in the studied areas by extracting impermeable surfaces from the Land cover classes and calculating the differences between one year to another:

$$\text{Soil sealing} = \text{Impermeable surfaces}_{2022} - \text{Impermeable surfaces}_{2018}$$

The output is a map showing the percentage of soil sealing per census unit.

4.7 Synthesis

Information collected through these (in-)justice indicators allowed us to assess the ecological status of the CiPeLs, but they were not exhaustive to build the profiles and meet the purpose of the analysis. Thus, they have been integrated with specific socioeconomic and sociodemographic data supplied by the local administrations (see Section 3.5), and their relationships have been investigated. The idea was to assemble evidence on the spatial distribution of Low carbon | High air quality NbS potentials and to identify clusters with similar needs, giving the CiPeLs a preliminary indication to implement JUST and appropriate solutions. The synthesis of the profiles elaborated for the Bolzano case study is presented in Section 7.

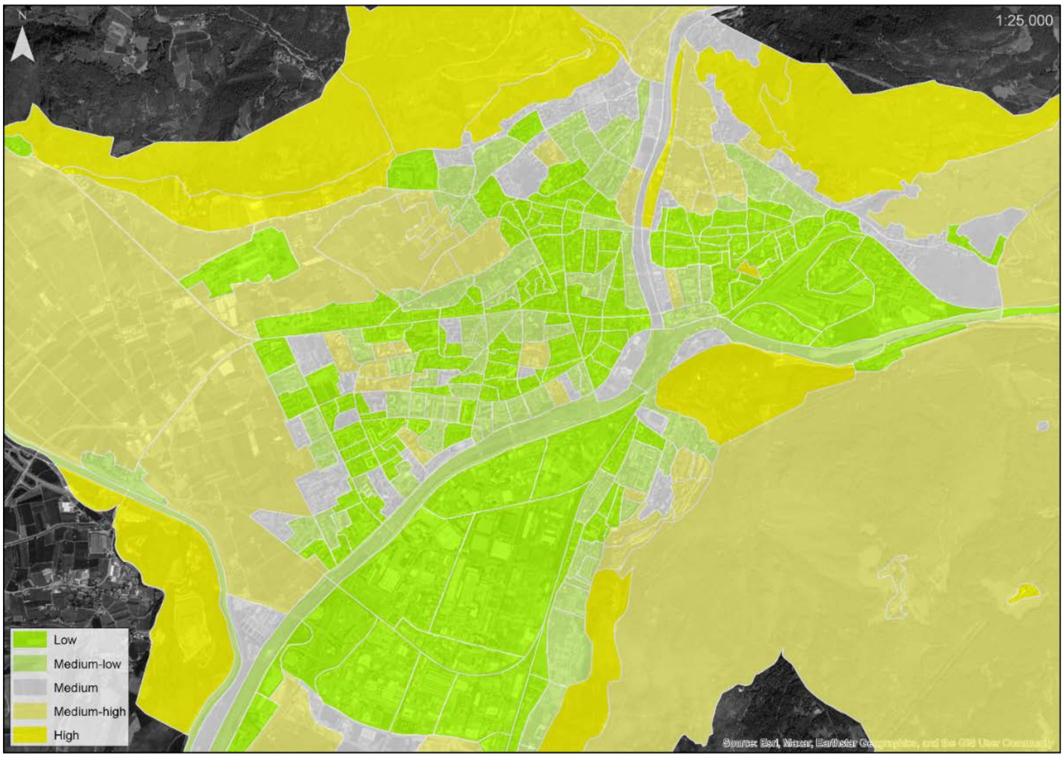


Figure 32: Vegetation change between 2020 and 2018, unitless (Jenks classification method).

Figure 33: Soil sealing between 2022 and 2018, unitless (Jenks classification method).

5 BUILDING THE ECOLOGICAL AND SOCIOECONOMIC STATUS & DISPARITIES PROFILES

5.1 Source code and tool development

The ecological and socioeconomic status and disparities profiles are created using Python [63], a popular programming language for data-analyses tasks. The source code is released as open-source software under the Apache2 license and is publicly available at: https://gitlab.inf.unibz.it/URS/justnature/clustering.

The developed tool can be used to explore how different clustering algorithms and options might affect the clustering result. At this stage, the code is developed to support WP2 activities, and it is not meant to be used by external users to process their own data sets.

5.2 Data centering and scaling

The selected data have different units and different ranges of values, these differences might affect the clustering process (depending on the algorithm of choice, some are more sensitive than others). Typically, the pre-processing is centering the mean values to 0 and scaling from −1 to +1 using the min and max values. However, outliers can often influence the sample mean/variance in a negative way. To avoid such influences, often the median and the interquartile range give more stable results without scarifying information that might be useful to identify extreme conditions (and/or outliers). Based on this consideration, the Robust scaler has been selected to harmonize the data set.

The Robust scaler, center and scale each feature independently, scaling the values from −1 to +1 respectively, for the values within the inter-quantile range of 0.1 and 0.9, and centering the values around 0 using the median value, all the values not in the selected interquartile range are divided by the threshold quartile value.

5.3 Data weighting and decomposition

The selected features have a different number of variables for each justice dimension, to avoid overweighting a justice dimension over another, the scaled variables are weighted to give the same weight to all the justice dimensions. Several decomposition algorithms (mainly dimensionality reduction techniques like: Principal Component Analysis (PCA), fast algorithm for Independent Component Analysis (FastICA), Factor Analysis (FA), Dictionary Lerning) are tested to see if their application improve the cluster tendency of the dataset evaluated with the Hopkins statistic [64].

5.4 Data clustering

A cluster identified a group of similar elements, in JUSTNature the elements considered are urban areas. Clustering is the act of grouping similar elements based on a set of criteria and properties.

There are several clustering algorithms available that are based on different principles, a first differentiation is the hard/soft clustering:

- each object belongs to a cluster or not (Hard clustering);
- each object belongs to each cluster to a certain degree (Soft clustering).

Furthermore, the clustering algorithms can be distinct in [65]:

- Strict partitioning clustering: each object belongs to exactly one cluster
- Strict partitioning clustering with outliers: objects can also belong to no cluster, and are considered outliers
- Overlapping clustering (also: alternative clustering, multi-view clustering): objects may belong to more than one cluster; usually involving hard clusters
- Hierarchical clustering: objects that belong to a child cluster also belong to the parent cluster
- Subspace clustering: while an overlapping clustering, within a uniquely defined subspace, clusters are not expected to overlap

Several models are available taking and combining different approaches to find different sets of pros, cons and assumptions.

The clustering algorithm selected for this analysis is the Hierarchical Density-based spatial clustering of application with noise (HDBSCAN) [66].

The HDBSCAN transforms the multi-dimensional data to a density space performing a single linkage on the transformed space. As for the DBSCAN algorithm, the HDBSCAN assumes clusters for dense regions and it does not require that every point is assigned to a cluster (no data partitioning), but instead, based on the density, assigns the object to a specific cluster or as noise/outliers. The HDBSCAN algorithm condenses the dendrogram by minimizing the number of points that are classified as not belonging to any cluster. The created tree is then used to select the most stable clusters. The hierarchical approach allows cutting the dendrogram tree at different heights.

The main advantage of the HDBSCAN algorithm in performing an Exploratory Data Analysis are [67]:

- The algorithm does not force all the points to belong necessary to a cluster, but identify only the clusters that satisfied the user selected criteria;
- The algorithm does not require knowing in advance the number of clusters to be identified. The parameter to identify the cluster are quite intuitive, they are:
  - the minimum cluster size, all the cluster with less component will be classified as unclassified with an integer value of -1;
  - the minimum number of samples in a neighbourhood for a point to be considered a core point;
  - the metric to compute the distance/similarity (e.g., Euclidean distance, Canberra distance, city block distance, correlation, etc.).
- The algorithm is stable and is not sensitive to the different random initializations. Moreover, changing the parameters change the clustering result in a stable and predictable way;
- The algorithm identifies clusters with different densities with fewer assumptions regarding the input data.

Several combinations of parameters are tested to identify different number of clusters, each set of clusters is then evaluated based on percentage of urban areas that belong to a cluster and evaluating three different scores:

- Silhouette [68],
- Davies Bouldin [69],
- Calinski Harabasz [70].

As the number of identified clusters increases, the elements within each cluster become more similar. However, working with numerous clusters becomes impractical and challenging. For instance, in Bolzano 89 clusters are identified (with 86.9% of the statistical units assigned to a cluster) with the following scores: Silhouette of 0.7; David Bouldin of 0.3 and Calinski Harabasz of 544.5. While selecting the solution with 9 clusters the percentage of statistical units assigned to a cluster can range from 95.4% using a correlation as metrics with scores respectively of 0.16, 1.78, 16.33, to 61.4% using Chebyshey inequality metric with scores of 0.60, 0.54, 131.65.

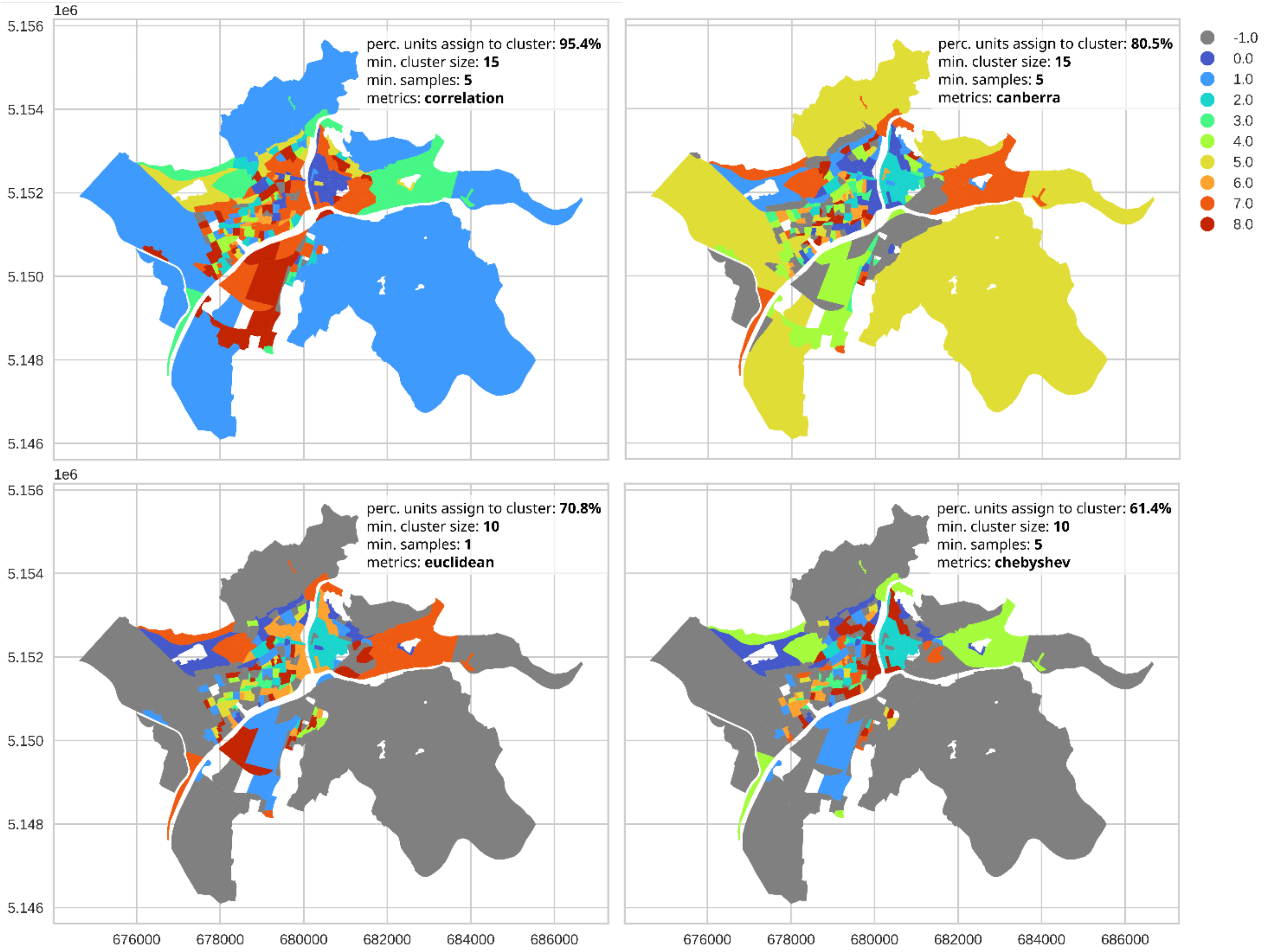


Figure 34: Different cluster parameters provide the same number of clusters (9, from 0 to 8).

In Figure 34, the grey areas (cluster: -1) are the statistical units that are considered as not belonging to any cluster. Ignoring the colour that changes because the cluster id changes, it is possible to see that there is a spatial pattern of the urban area that is preserved. Based on the foreseen use of the profiles it is possible to decide to be more conservative and to exclude more areas or if it is fine to be more inclusive.

Once that the right set of clusters is identified, the feature importance for each cluster has been computed based on the Random Forest classifier. The feature information can be used to better understand which are the main variables used to distinguish a single cluster from the others.

5.5 Cluster characterization and description

The identified cluster are characterized computing the main statistics (i.e. mean, std, min, 25%, 50%, 75% and max). To make it easier to interpret the results and highlight the difference that exist between the clusters, the normalized difference, defined as follow, is used:

$$\frac{\left(\mu_f^c - \overline{\mu}_f\right)}{\overline{\mu_f}}$$

With μ_f^c that is the median value per feature per cluster, while the $\overline{\mu}_f$ is the median value for the selected feature of the whole population. Therefore, the normalized difference is 0 if the value of the cluster is exactly equal to the median value of the whole distribution, negative if it is below the value of the distribution and positive if it is above. The median value is used because the distribution of the features is not always symmetrical and there might be the presence of outliers.

6 STAKEHOLDER NARRATIVES ON NEEDS AND WANTS RELATED TO NBS

The profiles, built on quantitative data and methods, could not be sufficient to make relevant urban planning decisions. For this purpose, the quantitative data analysis was complemented with a series of interviews with actors working daily with inequalities in the city (e.g., with vulnerable or marginalized social groups). The information gathered from the interviews supports further interpretation of the proposed profiles, indicating which are the main social and ecological needs and wants to be addressed.

6.1 Inequalities, vulnerabilities, and marginalities

A qualitative investigation on inequalities, vulnerabilities, and marginalities is proposed to widely understand the social implications, benefits, and risks of implementing a new NbS. The issues of vulnerability, marginality and inequality are universal, and it is important to define what are the interactions between these and the NbS. The perspective proposed can contribute to design and implement NbS that decrease and not exacerbate certain inequalities, supporting the strategic planning on defining where and what type of NbS is to promote.

Inequalities are based on the different distribution of resources (e.g., infrastructural, social, economic ones) leading some social groups or some areas of the city to be vulnerable or marginalized. Vulnerability is a wide and complex multidimensional process that touches themes and social aspects related to resource access, governance, culture, and knowledge [71]. Social and material vulnerability means living in a condition of uncertainty, which can turn into real economic and social deprivation (e.g., poor health, substance use, lack of economic resources for a minimum quality of life, etc.). This process is affected by social, political, economic, and technological-infrastructural forces interacting at all scales (from local to global) [71] and may differ among different urban areas. Furthermore, some sociodemographic groups are traditionally considered as vulnerable – such as elderlies, families with children, people with chronic illnesses – and others are raising or being strongly recognized – such as vulnerabilities related to gender (LGBTIQA+), different degrees of urbanization, education, and skill proficiencies (e.g., NEET or Not in Education, Employment or Training), immigration backgrounds, and others. Inequalities between social groups or between urban areas may increase where vulnerabilities are already present [72]. Therefore, when defining the characteristics of a new NbS, it is important to consider the main social and ecological vulnerabilities present in a city in a given historical period. This could help alleviating these vulnerabilities and avoid reinforcing them by implementing green infrastructures. For example, there are households widely vulnerable to heat waves and a new NbS could alleviate this situation creating green and cool accessible places. Another important issue to consider is that of the marginalities in the city.

Beyond vulnerabilities, there are groups of people living on the margins of society e.g., homeless, drug or gambling addicted. Marginality refers to people who are excluded from the social system to which they should belong e.g., a society where all people have the right to live at home, but some people are homeless [73]. The important issue in this work is to question the usefulness of NbS to bring certain marginal groups back into society or alleviate their poverty status.

Even if NbS are widely recognized as critical to health, well-being, and sustainability [74], most vulnerable and marginal groups of people have less access to green infrastructures [74]. Vulnerabilities and marginalities may be concentrated in certain areas of the city, or they may be transversal among population groups evenly in urban and suburban areas. When vulnerabilities and marginalities are concentrated in certain urban areas, NbS may decrease (or on the other hand increase, also creating gentrification situations) inequalities among areas of the city. Differently, when vulnerabilities and marginalities are transversal to the urban areas, there might be the demand to also investigate in detail the needs of vulnerable social groups and distribute the NbS within the entire urban context. Therefore, the aim of this work is to rebalance the situation in such a way that people with greater needs, vulnerabilities, and marginalities can equally (or widely) access appropriate, useful, and just NbS. This could contribute to improving the individual and the general health, well-being, and quality of life, avoiding situations of gentrification.

6.2 Semi-structured interviews to collect stakeholders' narratives

To investigate the interconnections among inequalities and NbS, in order to support a strategic NbS planning, interviews with the city stakeholders who daily deal with vulnerable and marginal social groups are proposed. The in-depth interview is a methodology that can provide relevant qualitative information for supporting the understanding of the profiles developed in this research and the preferences of citizens and stakeholders. Indeed, every city has its own cultural, social,

- How do actors who are working on (urban) inequalities conceptualize inequalities, vis-a-vis NbS?
- How do actors who are working on inequalities view the role of NbS in solving related urban challenges?

and economic peculiarities, which are not exhaustively interpretable by quantitative analysis. Mixed-methods approaches are recognized as having wider significance of their results. While, a huge amount of data is needed for having a significant quantitative analysis, few in-depth interviews based on strong and recognized interviewer methods provide relevant information for understanding society and cities [75].

This research part aims to get an overview of the main social, economic, and ecological urban inequalities in the CiPeLs that could be addressed by NbS. In particular, the interviews aim to define:

- the urban inequalities and the related challenges in the CiPeLs, which might be answered by the introduction of an NbS or which might be made worse by the introduction of an NbS;
- the conceptualization of NbS in relation to inequalities;
- some insights on how to develop relevant ecological and socioeconomic status and disparities profiles, useful to support an effective and just planning of NbS.

The interviews are schematically analyzed based on the legs of justice proposed by D2.1 (Table 9).

Table 9: Short definitions of the justice legs. For wider discussion, please refer to D2.1 - Conceptual & action framework on Low carbon | High air quality NbS potentials.

Justice legs	Definition
Contributive	It refers to a truly valuable contribution to the common good (e.g., decent work, benefits for all the community) in comparison with what and how the free-market values.
Recognitional	It facilitates the practices related to different cultures (e.g., based on age, nationality, geographical context) through NbS that reflect the needs of the population.
Distributive	It ensures that urban vegetation is evenly distributed among residents, avoiding social and other types of inequalities.
Procedural	It ensures the engagement of all stakeholders in the process of decision-making.
Corrective	It is related to the relation between people according to the concept of equality or fairness. When a person receives losses, there is a duty to restore balance and equality.

Since the focus is on vulnerabilities, marginalities, and inequalities in the urban context, institutions and associations that work daily on these issues (e.g., drug addicts, homeless, youths) were selected for the interviews.

The interview protocol reported in the following paragraphs contains the questions for conducting the interviews to the selected stakeholders. It is designed based on a previous literature review included in D2.1 (Annex 3 - Indicators). The main dimensions considered in this research that from a social science perspective are relevant for understanding the (in-

)justice implications of the introduction of NbS are social cohesion, social exclusion, aesthetics, poverty, vulnerability, quality of relationships, and the risks for gentrification (Annex 3 - Indicators).

Based on the previous dimensions, the following questions have been asked:

(Inequalities and the organization)

1. What is the role/activity of your organization in the city?
2. What do you think are the most visible inequalities in your city?
3. Are they also the most URGENT inequalities?
4. If no to (3), which inequalities do you consider most urgent and for what reasons?
5. How does your organization contribute to solve those inequalities?
6. Are there also environmental inequalities in the city of …?

(Inequalities and NbS)

7. When you think of NbS, what's the first thing that comes to mind?

   (If question is too difficult, a definition of the NbS concept[2] can be provided as support)

8. Do you think that NbS can contribute to reducing, eliminating, or modifying inequalities in your city?
9. If yes to (8), what types of NbS and how?

With the aim of exploring topics from the perspective of the interviewee, the interviewer must be flexible in proposing questions when it is the most appropriate time and with a broad understanding of the perspective (active communication). Furthermore, the interviews must be conducted in full GDPR (or General Data Protection Regulation) compliance. In this research, the interviews are not recorded, no sensitive or personal data will be collected, and the results will be reported and synthetized anonymously. Interviewees will be informed on how their data will be processed and will fill a Consent Form.

[2] The European Commission defines the 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, through locally adapted, resource-efficient and systemic interventions".

This report synthetizes the results of the interviews done in the Bolzano CiPeL, while the interviews for the other six CiPeLs are ongoing.

Example of results - A focus on vulnerabilities and marginalities in Bolzano/Bozen

Three actors were interviewed in the city of Bolzano concerning inequalities, vulnerabilities, and marginalities. Far from believing that three actors are representative of the thinking of associations working daily on vulnerability, marginality, and inequality, an interesting synthesis of perspectives related to the interaction between society and NbS is proposed.

According to the interviews, there are different types of interaction between NbS and social issues related to vulnerabilities, marginalities, and inequalities:

1) The contact with nature through e.g., urban gardens can lead to psychological benefits and new life practices, useful for some particularly vulnerable or marginalized social groups to re-entry into society. NbS, such as urban gardens can sustain the rediscovery of waiting, the seeing a result in a society where work is often included in an assembly line, the satisfaction of having contributed to tending a plant and seeing its fruit. All these aspects can contribute to the psycho-physical well-being of a person.
2) The presence of green spaces is important when it is connected to lived spaces, where people and social relations are observable. The only green infrastructure (without social relationships) can deal to further issues (e.g., no use of the green space, vandalism). At the opposite, it can be an opportunity to put several generations in the same place: "GREEN MUST BE USED. It must be a moment and a space for social interaction, for an ecological perspective" [from interview]. This can be an opportunity to deal with one of the main issues of the Italian society (especially concerning marginal groups of people) of the loneliness. Therefore, even if Bolzano has already a good quantity of certain NbS, these spaces need interventions to promote their livability as spaces for social interactions.
3) During the night, the life of existing green areas changes, making the areas inaccessible to some individuals. This is an issue that needs to be considered.
4) It is important to think, plan, or implement the green space with people using it. This permits to bring the issues of society and justice closer to the people and *vice versa*.
5) Connecting with nature for humans can have educational implications that carry sustainable lifestyles into the next generation and into the future.

Figure 35: A grassy field with trees and a hill in the background. Bolzano surrounded by the nature. Source: J. Balest

6) Decrease inequalities between the urban and rural context in terms of contact with nature and in terms of sustainable practices against e.g., food waste.

7) Decrease inequalities between groups with different vulnerabilities. E.g., a green area can provide fresh places or reduced temperatures during heat waves also to people who have lower income. Improving a person's well-being during heat waves can also bring health and social benefits (e.g., reduced requests for medical assistance). Another type of inequality or 'non-equality' to consider is that relating to different cultural backgrounds or nationalities. People belonging to certain nationalities prefer to experience outdoor spaces (parks, streets, etc.), as opposed to people of Italian nationality who prefer to experience indoor spaces. In any case, people can re-appropriate green spaces to promote coexistence between cultures and nationalities.

8) NbS can be a resource for social-related associations and institutions to reach lower energy consumption for their activities.

Figure 36: A large green field with trees in the background. An urban park around Bolzano/Bozen. Source: J. Balest

9) The presence of NbS can decrease CO_2 emissions, which in some ways (not in-depth described by the interviewees) can be interpreted as an issue of vulnerability and inequality by certain social groups (e.g., young people).

Proposed solutions are:

- At an individual level, cover all possible private and public spaces (e.g., our balconies with bee-friendly plants, bus stops surfaces) with nature and green.
- Remove car parking spaces or make them greener.
- Create urban gardens that are space for relationships between marginal and non-marginal groups and among different social groups (e.g., elderly, and young people).
- Include green spaces in or around buildings that allow associations to reduce their energy consumption and consumption in general.

Figure 37: A path integrated with green elements in Bolzano/Bozen. Source: J.Balest

- Transform or ensure green areas are lived spaces of relationships, engaging people in a just planning process for NbS and promoting events and appropriate spaces.

6.3 Inequalities: a matter of gender

The ecology and socioeconomic status and disparities profiles are supplemented by gender equality profiles of each city. The gender equality profiles were developed based on semi-structured interviews with local gender experts in each city. The aim of the interviews was to understand the state of gender equality in each city and their countries (for more information on the interview structure and questions, see Section 0 - Annex 1). The information collected by these interviews gives aspects to consider in the design of NbS (WP5) as well as in the stakeholder engagement activity of WP4. Background information on the interviews:

- The interviews, which were conducted by two interviewers, were not recorded and were anonymized. While one of the interviewers made the interview, the other one made notes.
- Most of the interviewees were municipal employees, either working on the field of social services or on social equity/gender equality. In case of one city, the interviewees are working for a state-level organization for gender equality.
- Two of the interviews were group interviews, where two gender experts from one city answered together the interview questions, the rest were individual ones.
- Most of the interviews happened online on the platform of Microsoft Teams. One interview happened in a written format because the interviewee felt uncomfortable answering the questions in English.
- Out of the ten interviewees, nine were women and one was man.
- The method has some limitations. One interview per city is not enough to develop a full gender profile, because, in case of single interviews, the subjective factors (interest and personal opinion of the interviewees) become more accented. Nevertheless, because of covered capacity constraints and because it was difficult to find more than one interviewee per city, this limited source of information was considered sufficient.

Example of results - A focus on gender in Bolzano/Bozen

The interviews conducted on the gender topic define the following information (for a wider summary, please refer to Annex 2 - Gender profiles):

- In Bolzano/Bozen, gender-based division of work, gender roles and stereotyping are rooted in the culture and there are few initiatives supporting gender empowerment and discussion about the problems women face in their everyday life. Furthermore, women with migrant background are identified as especially vulnerable social group with whom they have very limited contact, because of the lack of language skills and sometimes education, and because of the patriarchic cultural background of their country of origin. These considerations should be included in the planning and management of NbS.

Considering the interviews about gender, there is the need to:

- Plan new NbS and improve the existing NbS considering dealing, solving, or going beyond the current gender gaps.

7 AN EXAMPLE OF RESULTS FROM THE METHODOLOGY: THE CASE OF BOLZANO

7.1 The profiles

The features used to cluster the Italian census unit of the municipality of Bolzano are:

- For the Air-quality dimension, the 6 levels of risk are identified considering the road classification and urban morphology to identify areas with possible canyoning effects, the levels are reported as % of the census unit within 50m distance from the roads:
  - Very low
  - Low
  - Medium-low
  - Medium-high
  - High
  - Very high
- For the Carbon dimension, the considered layers are:
  - Carbon emission related to building sector [ton $CO2/m^2$]
  - Carbon absorption related to vegetation [kg $CO2/m^2$]
- For Flora, Fauna and Habitat dimension considers:
  - Percentage of census unit area that is protected [%]
- For Spatial dimension include:
  - Accessibility to urban green areas per census unit – 5 minutes walking [%]
  - Walkability Index per census unit
- For Temporal dimension include:
  - Soil sealing difference between 2022 and 2018 [%]
- For Thermal consider the average value of the:
  - Surface Urban Heat Island (SUHI)
- The main sociodemographic elements included in the analysis are:
  - Age index, defined as the ratio between the number of people with an age greater or equal than 65 years old divided by the people with an age smaller or equal than 14 years old ($Age_{index} = P_{>= 65} / P_{<= 14}$)
  - Percentage of foreign population living in the census unit [%]
  - Percentage of families with children [%]
  - Percentage of families without children [%]
  - Percentage of families with one component [%]

The data is scaled and centered using the Robust scaler with a percentile range of 10-90%. Each feature is weighted to consider the different number of features per dimension that compose the data. The data decomposition that produces the best result on the Bolzano data set is Dictionary Learning. For the Municipality of Bolzano, 9 different clusters (from 0 to 8) are selected to describe and identify the main spatial pattern of the municipality's urban context, see Figure 38 and Figure 39. The grey census units are classified as not belonging to any specific cluster, the number of census statistical units with an assigned cluster are 95.5%, only 4.5% of statistical units were unclassified. Some statistical units are blank because the sociodemographic variables were empty (therefore has been excluded by the analyses). The cluster HDBSCAN algorithm has been applied considering the following parameters:

- Minimum cluster size of 15 census units.
- Minimum sample of 5 census units.
- The correlation is used as metrics to evaluate the existing similarity between the census units.

The cluster analysis identified the presence of 9 distinct clusters. In Figure 38, the census statistical units of Bolzano are colored according to their corresponding cluster. Census units colored in grey were not assigned to any cluster and should be evaluated individually.

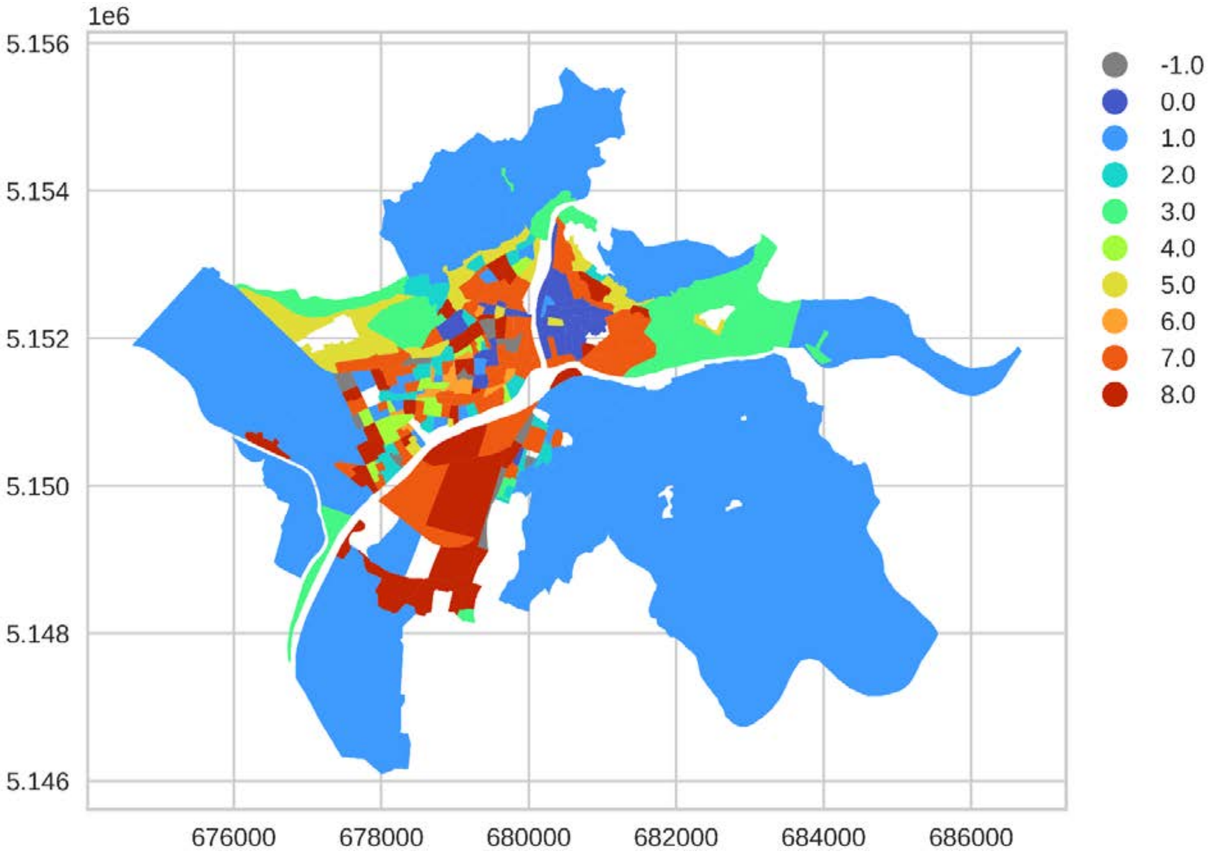


Figure 38: Example of possible clusters in Bolzano based on the selected features.

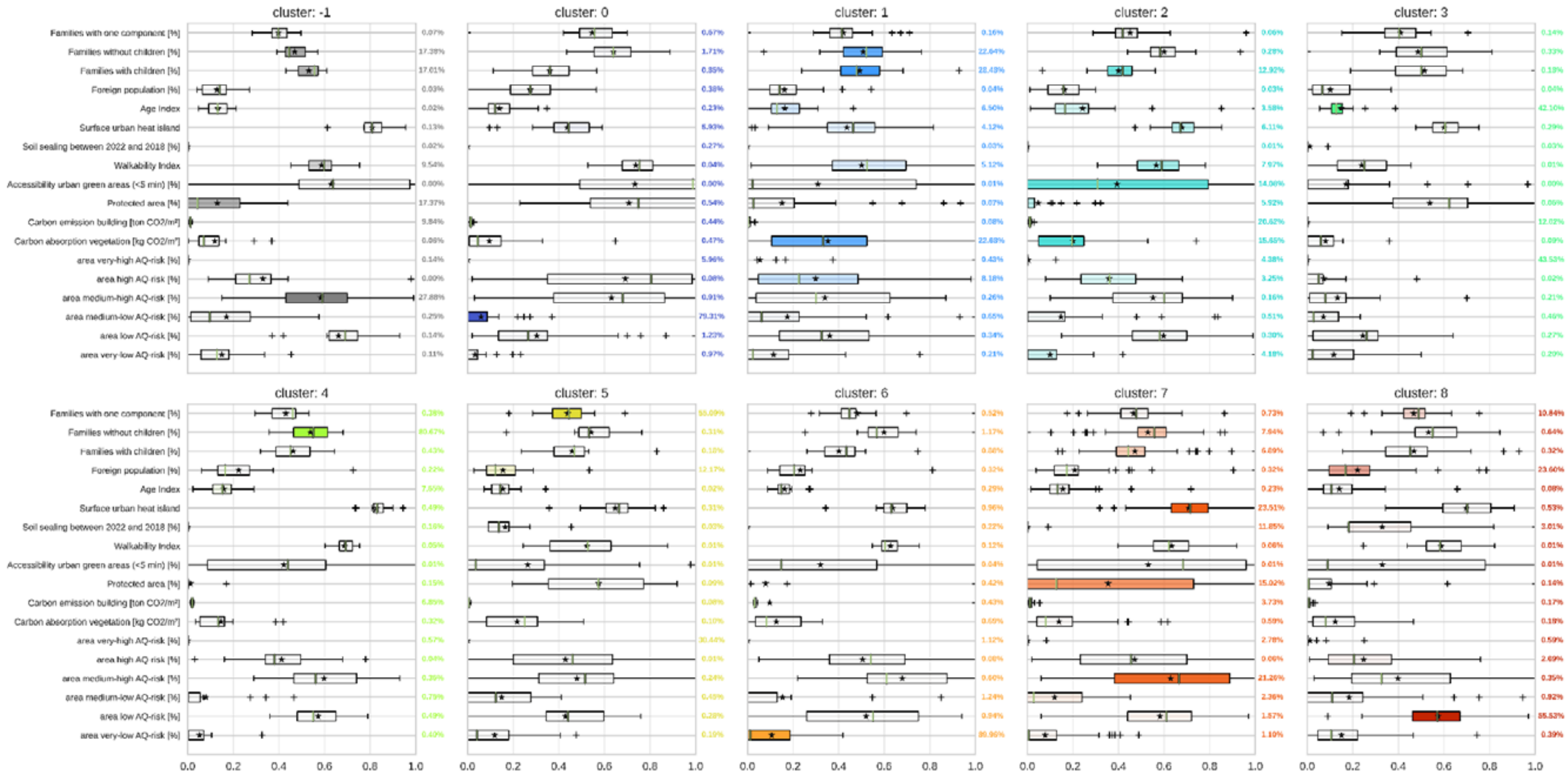


Figure 39: Statistics per variable per cluster. The feature importance for each cluster is reported impacting the transparencies of each boxplot and reported by colour percentage.

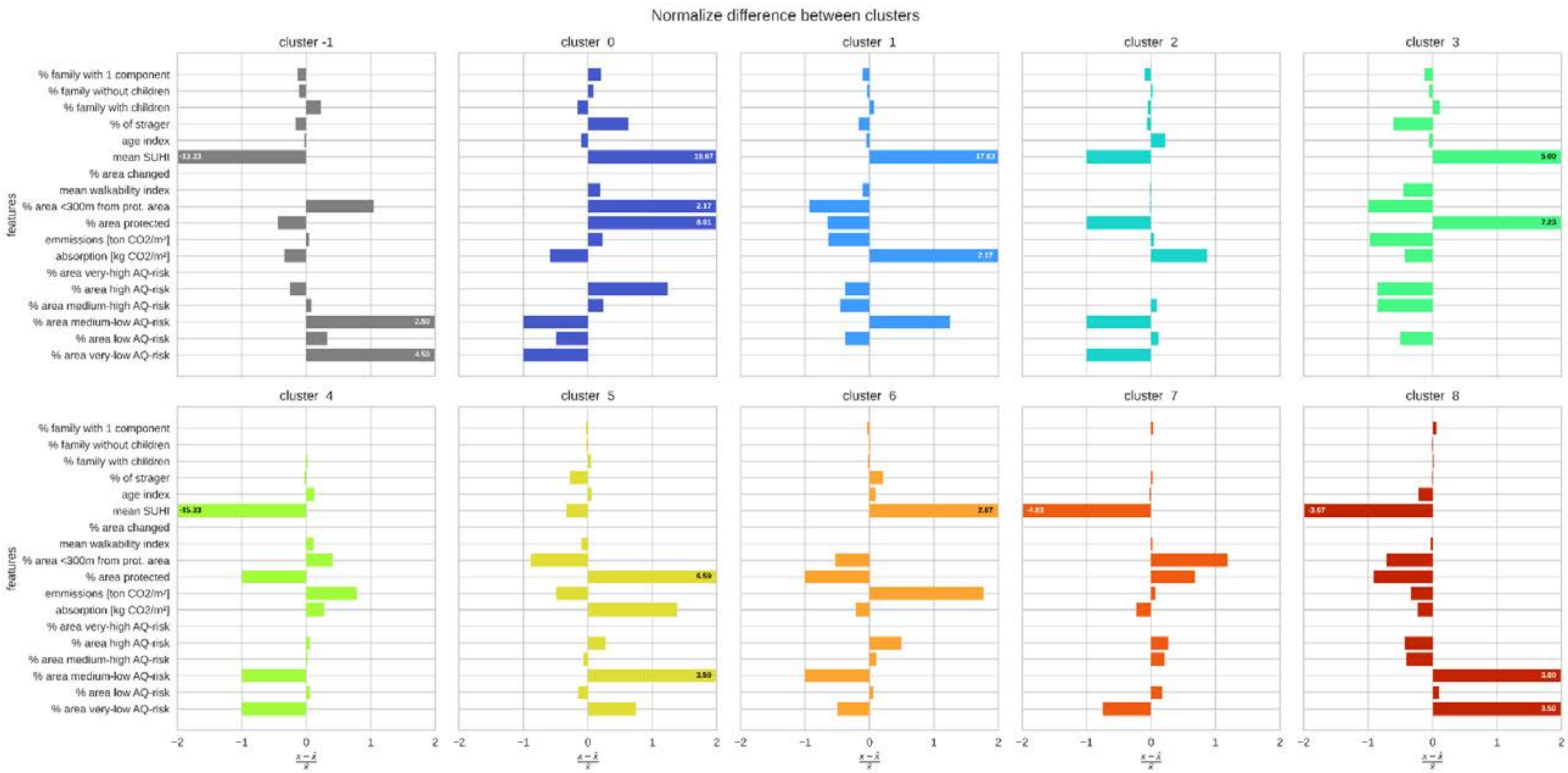


Figure 40: Normalized difference of the median value of the features.

7.2 Cluster characterization

To interpret the results of the cluster analysis, descriptive statistics of the characteristics of the identified clusters are evaluated. In Figure 39, feature value distributions are presented separately for the identified clusters using box-plots. Feature importance (i.e., the relevance of each feature in characterizing a specific cluster) is indicated as percentage on the right side of the plots for each cluster. Moreover, box-plots are colored base on the feature importance, with the most important features represented by vivid colors.

To facilitate the comparison and interpretation of the characteristics of the identified clusters, the median values of each feature are considered. In Figure 40, normalized median differences of the different features are presented using horizontal bar plots separately for each cluster. In Figure 41, instead, normalized median differences are presented using heatmaps where blue indicates values close to the minimum and red indicates values close to the maximum of each feature.

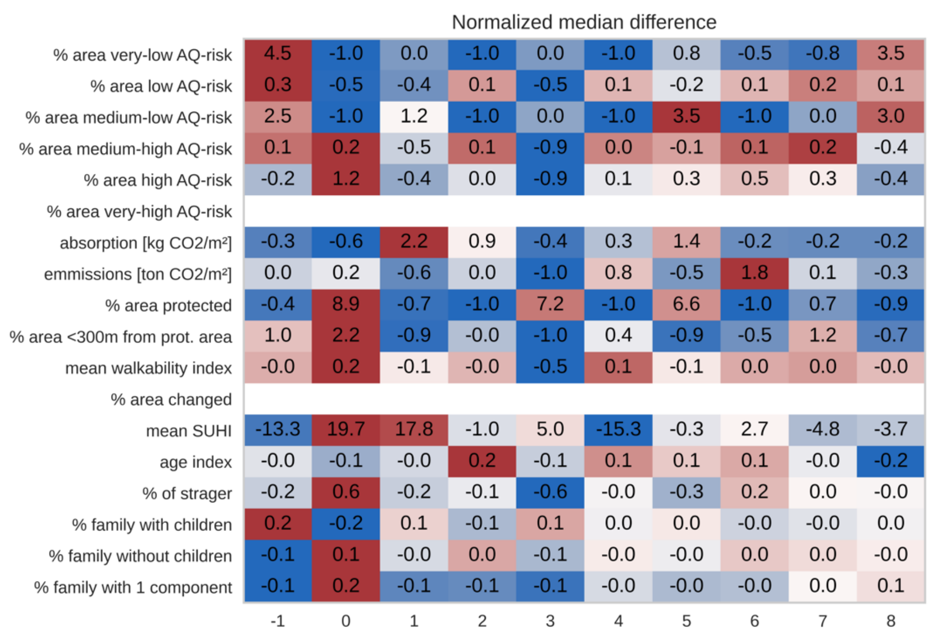


Figure 41: Normalized median difference per cluster, cell with a value close to zero are white, if close to the minimum are blue and red if close to the maximum.

For two features (% area very high risk, % area changed) the median value is 0 and, therefore, it was not possible to compute the normalized median difference. In this case, the mean normalized difference can be used to provide a more qualitative information. In Figure 42, normalized mean differences of each feature are presented using heatmaps. Again, blue indicates values close to the minimum whereas red indicates values close to the maximum of each feature.

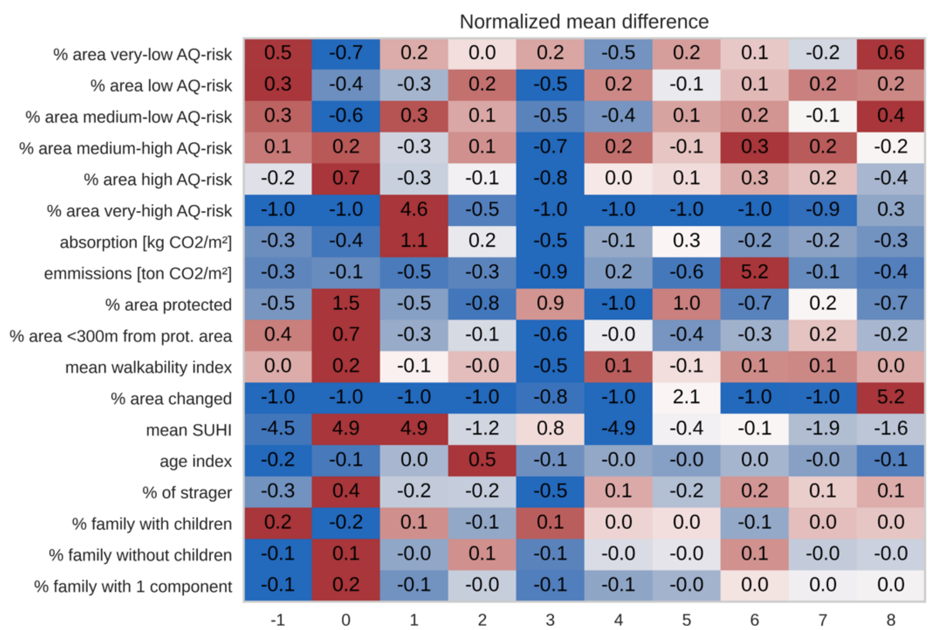


Figure 42: Normalized mean difference per cluster.

In Table 10, a qualitative description of the characteristics of the identified clusters is provided. The cluster with number −1 and colored in gray is not considered as it collects census units that were not assigned to any cluster. These units should be evaluated individually.

Table 10: Qualitative description of the identified clusters through the main variable considered.

Cluster	Air Quality	Carbon	Flora Fauna and Habitat	Spatial	Temporal	Thermal	Socio demographic
0	Medium-high/high	Low absor.	Very high % of prot.area	Very high accessibility / walkability in the average	Very low change	Very high SUHI	Low age index / High % of stranger / low % of family with children / high % of family with 1 component
1	Very-high	Very high absor. / low emiss.	Very low %	Very low accessibility / mean walkability	Very low change	Very high SUHI	High % of family with children, low % of stranger and of family with 1 component
2	Medium-low	High absorp	Very low	Close to the mediian	Very low change	Low SUHI	Very high age index, low %

							of stranger, high % of family without children
3	Low/very-low	Low absorp. / low emiss.	Very high	Very low accessibility and walkability	low change	High SUHI	Low age index / very low % of stranger / high % of family with children
4	Low/very-low	High emiss	Very low	High accessibility and walkability	Very low change	Very low SUHI	% of stranger above the median / % family with 1 component bellow the median
5	Close to the median	High absorp./ low emiss.	Very high	Very low accessibility / mean walkability	High change	Low SUHI	Low % of stranger other values close to the median
6	Close to the median	Very high emiss.	Very low	low accessibility / mean walkability	Very low change	Close to the median	High % of stranger / low family with children / high % family without children
7	Close to the median	Close to the median	Very low	High accessibility / walkability in the average	Very low change	Very low SUHI	% of stranger higher than the median / other values close to the average
8	High percentage of low and very-low risk	Absorp. And emiss. slightly lower than median	Ver low	Low accessibility / walkability in the average	Very high change	Very low SUHI	Low age index / % of stranger higher than median value / other value close to the average

The quantitative analysis highlights some variables that are extremely polarized, like for instance the % area with a very-high risk of air quality that is very high in cluster 1ith all the other clusters that have low values. Similarly, the emissions that are very high for cluster 6 with low or very low value for the other clusters. The % of area changed is very high for cluster 8 and high for cluster 5 with all the other cluster that have very low values. The age index is high for cluster 2, with the other clusters with value in the median or below.

7.3 The profiles according to the stakeholders' narratives

Green areas are spaces or places that today replace old squares and courtyards in terms of interactions. Indeed, the NbS can be supportive of the social cohesion and the related solidarity relationships among community members, belonging to different social groups (e.g., based on age, marginality situations such as drug or gambling addicted or homeless). Furthermore, NbS are recognized as instruments to decrease social exclusion, especially of those groups of people that live on the margins of the society. Finally, NbS can provide resources - e.g., of fresh spaces in the periods of heat waves – also to vulnerable and poor people that do not usually have general possibilities to choose sustainable alternatives and access natural resources and spaces, fundamental for a good health and well-being. In any case, it is important to engage people in vulnerable and marginal situations, which will use the green spaces, in the planning and implementation of NbS.

With the discourses summarized here, it is possible to identify the different dimensions of justice and ask to address them into the strategic planning of NbS. Considering the distributive and corrective means, i.e. promote the access to green areas or sustainable choices to all, also including people in situations of vulnerability and marginality, promoting equality. The recognitional dimension of justice deal with, i.e. the recognition of needs and wants of several social groups, including the most vulnerable and marginal and considering gender inequalities. The contributive dimensions here include the message that the integration of NbS in urban zones is not an exclusive matter of certain actors (e.g., planners, private economic sectors, investors), but NbS are important elements of the city in terms of individual and social well-being and health for all social groups. For all these reasons, it is important to effectively integrate needs and wants of several social groups and engage several social groups into the strategic planning of NbS (procedural dimension of justice), supporting the message that green space should be a living space, of quality, of refreshment from heat waves and of interaction between people.

8 CONCLUSIONS: THE NEED OF A CO-ASSESSMENT OF LOW CARBON | HIGH AIR QUALITY NBS POTENTIALS

One of the key aims of developing ecological and socioeconomic status and disparities profiles is to make spatially explicit the Low carbon | High air quality NbS potentials across a city and in defined neighborhoods. It is based on a methodology that allows an increased level of integration of various indicators to capture various dimensions of ecological (space) justice, building on satellite image data and integrating them with other spatial and socioeconomic information. As previously indicated, the resulting profiles can provide a first knowledge base for strategic decision making, offering a preliminary analysis and suggest where further in-depth scrutiny might be needed, focusing on the identified criticalities.

This kind of profiles mostly provide a 'helicopter' view of where ecological (space) disparities might exist and Low carbon | High air quality NbS potentials can be located. To compensate for the limited in-depth insights such profiles however provide, especially in not only offering an analytical framework for the identification of disparities but to assess existing inequalities, already the additional step of a qualitative investigation was introduced for documenting key social and ecological needs.

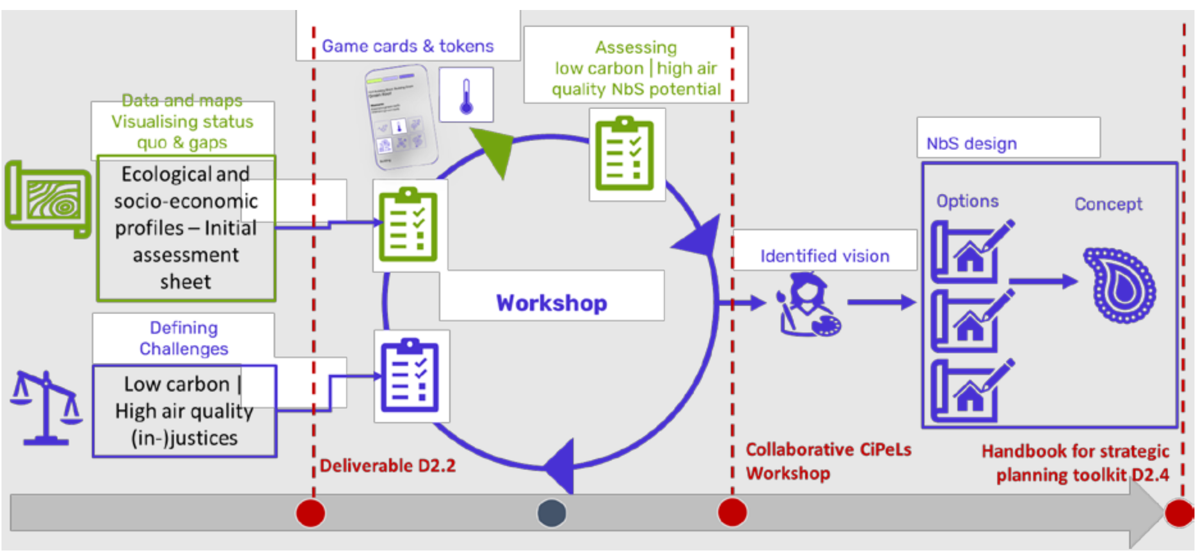


Figure 43: Example of a game card and tokens as part of the ecological (space) justice strategic planning toolkit, based on D2.1 and [76]. Highlighted in green process steps informed by project task 2.2 and D2.2.

The complexity of the topic and the normative nature of questions of justice requires an approach that allows however also to engage different disciplinary and knowledge backgrounds. It also serves as a compass to navigate and prioritise decisions. As iterated in

D2.1, whether a disparity or inequality can be deemed as unjust has to be subject to further scrutiny in practice, to generate actionable knowledge [1]. This means not only relevant for the practice but used by people to transform their city by 'making sense' together. In this regard, the development of an ecological (space) justice strategic planning toolkit was suggested which can be applied in a collaborative planning process. It is expected to include the use of infocards, tokens as well as templates and forms, to be subsequently developed during various activities of the project and to inform the development of an according toolkit (seeFigure 43). How the use of ecological and socioeconomic profiles can be integrated in the ecological (space) justice strategic planning game toolkit is highlighted in green.

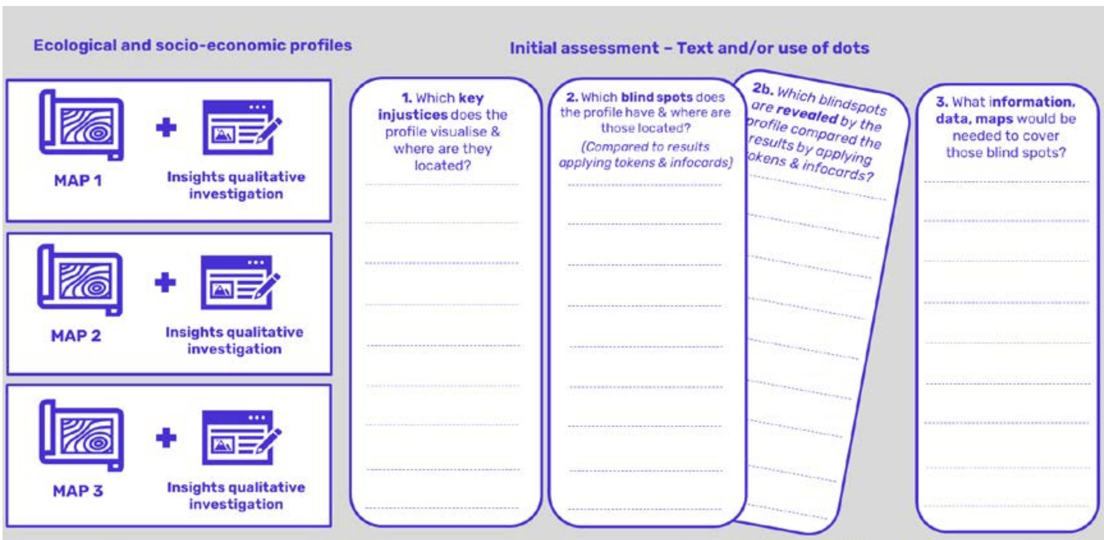


Figure 44: Initial ecological and socioeconomic profiles assessment sheet – Template.

On the one hand, the use of the ecological and socioeconomic profiles is expected to provide an overview of the current status quo in the cities regarding existing disparities. On the other hand, they can be used to assess whether there may be gaps in data and maps to assess the Low carbon | High air quality NbS potentials. Accordingly, it is suggested to use an initial assessment sheet, which as part of the process is used to answer some defined questions for each map presented and used in a workshop setting. This refers to the key injustices that maps and insights from the qualitative investigation help visualise and locate. It also helps discussing any blind spots the presented maps and insights might have, and what information, data and maps would be needed to identify those blind spots. Depending on whether the maps and insights from the qualitative investigation are used separately, for example for strategic discussions with policymakers or entrepreneurs, or whether they are used as part of the workshop exercise using tokens and infocards, additional questions are considered relevant.

This for example includes a reflection upon whether the maps and insights have helped to uncover blind spots that have not been identified by the participants applying the tokens (seeFigure 44). Whereas the ecological and socioeconomic profiles use key integrated indicators to identify first potentials and opportunities, the use of the infocards and tokens allows collecting contextual knowledge by tapping into local expertise. In addition, the various steps of the ecological (space) justice strategic collaborative planning process are envisaged to help reflecting on the various challenges, the role of NbS and weighting as well as prioritising defined decisions, whether in relation to the strategic planning of a city or the NbS design at a selected site.

Following this initial assessment using the maps and insights, an additional step for co-assessing the Low carbon | High air quality NbS potential is foreseen. This step aims to further prioritise Low carbon | High air pollution NbS potentials and also to concretely inform the next steps to be considered. It is suggested to use a simple evaluation matrix, like the initial example provided in Figure 45Figure 45. This matrix can be printed and post-its used to place selected challenges, NbS categories and locations or data blind spots according to what could be worthwhile to further pursue (desirable/less probable), what needs to be kept an eye on (less desirable/less probable), what to pay particular attention to (less desirable/ probable) and the main prize (desirable/probable).

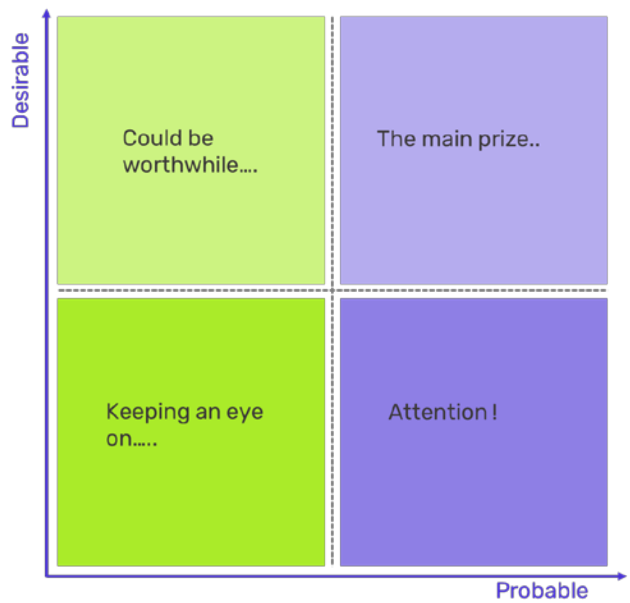


Figure 45: Evaluation matrix – First example. Based on [77]

The further preparation of the collaborative strategic ecological (space) justice planning process represents an opportunity to re-discuss the various integrated maps to be created for the CiPeLs of the project. As much as providing a basis for discussion it is also a matter of further developing the methodology considered for the development of the ecological and socioeconomic profiles, with additional insights to be included regarding considerations of future developments, whether in relation to urban development or evolving climate scenarios.

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ANNEX 1 - GENDER INTERVIEW DESCRIPTION

JUSTNATURE GENDER EXPERT INTERVIEWS[3]

Context, aims and description

Introduction

This document summarizes the background and the aims of gender expert interviews, which will be conducted in the JUSTNature project. First, it introduces the JUSTNature project and its connection to gender issues and provides some key definitions. Secondly, it discusses the aim of the interviews and lists some guiding questions. Thirdly, it provides some technical information about the interviews.

About the JUSTNature project in the context of gender

The JUSTNature project addresses four key challenges:

- Income & wealth inequalities and discriminations as a driver of urban spatial disparities.
- Dispersed & isolated urban elements of high biodiversity value.
- Differently impacted by urban transformation processes.
- Environmental & climate impacts not distributed evenly.

The overall objective of JUSTNature is the activation of NbS[4] by ensuring a just transition to low-carbon cities, based on the principle of the right to ecological space[5]. The solutions will be developed and tested in seven European cities, Bolzano/Merano, Chania, Gzira, Leuven, Munich and Szombathely.

Among other social challenges, the project pays particular attention to addressing gender-based inequalities during the process, for example in terms of distribution of environmental goods and harms, access to decision-making processes and recognition of different abilities and needs. For meaningfully addressing these problems, however, a good understanding of the

[3] This document has been sent out to the potential interviewees during recruiting for the interviews.

[4] 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 (European Commission 2022)

[5] For more information, see the website of the project: https://justnatureproject.eu/

local context, i.e. status of gender inequality in the seven cities, is needed. Therefore, one gender expert was selected in each city for an interview.

Aim of the Interviews

The aim of the interviews is to get an overview on the gender inequality issues in the cities listed above, and in their countries. The interviews primarily focused on women and other vulnerable groups intersecting with gender (for example, migrants, ethnic minorities, etc., depending on the social composition of the cities).

Interview questions focused on general gender inequality problems, and gender inequalities specific to the urban and natural environment, and urban planning processes e.g., unequal access to public space, unequal participation in decision-making. There were also interview questions about how the states and the cities fight against these inequalities, i.e. if there are any gender equality legislations, strategies, policies and initiatives (especially on the city-level, but national-level could be also interesting.) Moreover, the interviews collected information on NGO-s, who are dealing with gender issues in the city, and who can potentially be involved in the JUSTNature project.

Based on the data collected in the interviews, gender inequality profiles of each city were developed.

Key definitions

So that to avoid any misunderstanding, it is important to provide some key definition here. These definitions were introduced in the beginning of the interviews. In the JUSTNature project and during the interviews gender is understood as

> *the characteristics of women, men, girls, and boys that are socially constructed. This includes norms, behaviours and roles associated with being a woman, man, girl or boy, as well as relationships with each other* [78].

By gender identity, it is meant:

> *each person's deeply felt internal and individual experience of gender, which may or may not correspond with the sex assigned at birth, including the personal sense of the body (which may involve, if freely chosen, modification of bodily appearance or function*

by medical, surgical or other means) and other expressions of gender, including dress, speech and mannerisms [79].

Intersectionality is used to describe the phenomenon that certain groups of women are especially vulnerable, not only because they are women but also because of other contributing factors, such as their race, color, language, religion, political or other opinion, national or social origin, association with a national minority, property, birth or other status [80].

Guiding questions

The interview was a semi-structured interview, meaning that only the main, guiding questions are predetermined and the rest of the questions will depend on the direction the discussion takes. This format allows for focusing on some key topics and discover issues specific to the different cities. The guiding questions are as follows:

- How would you describe the state of gender inequality generally in your country and specifically in your city? What are the major problems?
- Can you give some examples about gender inequalities which relate to the city? Think about the following aspects:
    - Distribution of public amenities/spaces, such as parks for men and women.
    - Accessibility and facilities of public amenities/spaces for men and women.
    - Presence and relevance of women participating in decision-making.
    - Risks and discomforts women and girls face in public space.
    - Exposure and vulnerability to environmental hazards of men and women.
- Do some women/men experience further of the above injustices due to their income, age, family status, ethnicity, religion, etc.? Do some women/men experience new injustices?
- How does the federal government/state/city fight against these inequalities? Name the most important tools.
- Can you name some NGOs, who work on gender equality in your city and could be potentially involved in the JUSTNature project?

Interview process

- Length: maximum 60 min
- Format: online interview, on Microsoft Teams platform (or other platform, upon request)

- Language: English
- Interviewer: Rebeka Dóra Balázs, Viktor Bukovszki/Laura Hurtado Verazain (ABUD Ltd.)
- Data protection:
  - the interviews were not recorded, only notes were taken by the interviewers
  - personal data were not collected and recorded

For more information, contact with Rebeka Balázs (balazs.rebeka@abud.hu), senior sustainability consultant at ABUD Ltd.

ANNEX 2 - GENDER PROFILES

This section contains the gender profiles of each city. The data is presented city by city, and each profile begins with a short summary of the country assessment by EIGE (European Institute for Gender Equality) from 2022. This country assessment contains the Gender Equality Index (GEI) of the country, calculated by EIGE[6], the raking of the country among the EU countries based on the Gender Equality Index (GEI), the trend of in(de)creasing gender equality since last year in the country, and the field in which the country performs the best and the worst. The trend of in(de)creasing gender equality is indicated by symbols:

- < 1.0 positive change in GEI: **+**
- > 1.0 and < 2.0 positive change in GEI: **++**
- > 2.0 positive change in GEI: **+++**

This section based on the country assessment by EIGE followed by the processed interview data: the country-level information and the city-level information. Finally, the gender profiles end with some key findings for JUSTNature for each city, i.e. identified risks and identified opportunities based on the interview data.

The main findings of these interviews are:

- The state of gender equality and the attitude toward gender equality is very different in each city, and thus there is no universal strategy to address gender problems. In Gzira, Leuven, Munich and Merano the state of gender equality is quite good in comparison with other European cities. However, it can create a false sense of satisfaction that actual gender equality is reached there. As a result, there is a chance that actual gender-related problems and gender stereotyping remain unaddressed there. On the positive side, Munich, Leuven and Merano have developed gender empowerment strategies, including urban design strategies, which should be considered in the JUSTNature project. At the same time, in Chania, Bolzano and Szombathely, there are fewer initiatives which support gender empowerment, and there is less discussion about the problems women face in their everyday life.

[6] The Gender Equality Index is a tool to measure the progress of gender equality in the EU, developed by EIGE. It considers the domain of work, money, knowledge, time, power and health. For more, see https://eige.europa.eu/gender-equality-index/about.

- Gender-based division of work, gender roles and stereotyping rooted in the culture are common problems everywhere. They are still the women, who are in charge of care work within a family, which could potentially set back the participation of women on the local workshops. Often, this gendered division of work is intertwined with gender-based stereotypes, which are present in every field of life, and could potentially appear on the local workshops.
- In many cities, women with migrant background were identified as especially vulnerable social group with whom they have very limited contact, because of the lack of language skills and sometimes education, and because of the patriarchic cultural background of their country of origin. Such cities could develop a strategy together to engage these women. Other cities mentioned especially vulnerable groups of women, with whom they already have contact with, such as Roma women in Szombathely and lower middle-class women in Bolzano. In these cases, cities should rely on their existing experience of these social groups for their effective engagement.
- Even in the most progressive cities, historical gender inequality still has its impact on women. Many interviewees mentioned the unresolved problem of gender pension gap, i.e. elderly women get less pension than men because of their previous lower salaries and unpaid maternity leave, which result in higher rate of poverty among elderly women in comparison with men. The barriers of their involvement should be considered in the stakeholder engagement strategy.

<table>
<tr><th colspan="3">Chania (Greece)
EIGE country profile</th></tr>
<tr><td rowspan="5">GREECE</td><td>Ranking:</td><td>27th out of 27 countries</td></tr>
<tr><td>Gender Equality Index:</td><td>53.4/100 (EU's score 68.6)</td></tr>
<tr><td>Trends:</td><td>++</td></tr>
<tr><td>Best performance:</td><td>Domain of health, especially access to health</td></tr>
<tr><td>Most room for improvement:</td><td>Domain of power, especially social/economic decision-making</td></tr>
<tr><th colspan="3">Interview data</th></tr>
<tr><td rowspan="2">GREECE</td><td>Gender equality:</td><td>Although in there has been much progress in the recent times, gender inequality is still present in Greece. Women and girls have fewer opportunities in life than men and boys, especially in education, access to power and decision-making, economic participation, and they do not have political representation.
Gender differences are more pronounced in the countryside than in cities and are mostly determined by traditional gender roles. Women are primarily responsible for the housework and are often abused by their husband, leading women to fly away from home and ask for municipal help.
Despite this, in the whole island of Crete, women have a special role in the society, which was described by our interviewee as matriarchate. It means that women (mothers) have the actual power within the household.</td></tr>
<tr><td>Policy&gender:</td><td>▪ Istanbul convention signed and ratified</td></tr>
<tr><td rowspan="4">CHANIA</td><td>Gender equality:</td><td>In Chania, the state of gender equality is similar to the situation in Greece but somewhat better in comparison with the countryside. Women in Chania are strong and willing to voice their strong opinions. In the courts and in the field of culture they are many women. Yet, the majority of municipal council members are men (49 out of 53), and there is a majority of men among municipal leaders (9 out of 10).</td></tr>
<tr><td>Urban design & gender:</td><td>▪ lack of playgrounds, parks, open spaces and public toilets
▪ safety and accessibility are not important issues</td></tr>
<tr><td>Vulnerable groups (intersectionality)</td><td>▪ migrants from East Asia, Syria, Afghanistan, Pakistan, Morocco, Egypt, Albania, Bulgaria, and Romania
▪ Recurring problems: lack of residency permit, unreported employment (construction industry, olive plantations), dropouts from schools, financial problems</td></tr>
<tr><td>Tools for gender equality:</td><td>▪ Gender Equality Committee of the Municipality of Chania: formal meetings in every 3 months
▪ Strategy for integrating women and migrants: education (e.g., Saturday schools), financial support</td></tr>
<tr><th colspan="3">Highlights for JUSTNature</th></tr>
<tr><td colspan="2">Identified risks:</td><td>Potential for gender stereotyping because of cultural reasons
Limited involvement of vulnerable group of women (abused women, women with migrant background)</td></tr>
<tr><td colspan="2">Identified opportunities:</td><td>Involvement of local strong women
Cooperation with Gender Equality Committee</td></tr>
</table>

	Gzira (Malta)	
	EIGE country profile	
MALTA	Ranking:	13th out of 27 countries
MALTA	Gender Equality Index:	65.6/100 (EU's score 68.6)
MALTA	Trends:	+
MALTA	Best performance:	Domain of work, especially participation at work
MALTA	Most room for improvement:	Domain of knowledge, especially segregation in education
	Interview data	
MALTA	Gender equality:	In the recent decades, there has been a progress in economic development of women in Malta. The employment rate is 69.6% for women, while 86.4% for men (in comparison with 67% of EU average.) The gender pay gap is also below the EU average, it is 10% in Malta (in comparison with 13% of EU average). Nevertheless, in sectors with higher salaries the gender pay gap is higher. In retail and ICT sectors, it is more than 20%. At the same time, gender pension gap is highest in the EU. It is because although labour market transformed in the last 15 years, before that, women were working in the household. Decision-making: from 15% to 28% MPs are women (courtesy of legislation) Gender stereotypes are still present; women are more likely to carry out unpaid work and usually the women are the main carers in the family (due to societal pressure).
MALTA	Policies & gender:	▪ free childcare service for women in work and education, after 3 months of age ▪ 5/6 husband pension is inherited by widows ▪ gender corrective mechanism in legislation: increase number of seats for women only, 40% goal. ▪ contributors to better labour market equality: 2014 introduction of childcare, breakfast club, school club 3-16, 3-year phasing out of benefits (for unemployed women returning to the labour market), tax incentives to return, upskilling programs ▪ remote working flexibility for public sector ▪ disability commission overseeing regulations for public building renovations to ensure universal access ▪ free public transport for pensioners: from 1 October, free for all ▪ companies offer work-life balance measures, the NCPE awards the Equality Mark to companies if they do so ▪ long unpaid parental leave is offered in the public sector (5-year career break possible) ▪ 18 weeks of paid maternity leave ▪ partial hours (flexitime) and teleworking for new parents is most popular (public sector employees); few men choose any parental leave, it is not mandatory ▪ Equality bill: to strengthen the remit of the equality body ▪ human rights and equality commission bill: to strengthen sanctioning powers to be given to the commission ▪ the NCPE[7] focuses on Gender mainstreaming checklist and trainings, also one for infrastructural projects and open space development with requirements and examples
GZI.	Gender equality:	Gzira[8] has more foreigners and cultural interactions, centrally located, so it cannot be considered as a particularly conservative region, rather the opposite.

[7] National Commission for the Promotion of Equality

[8] In case of Gzira, JUSTNature researchers could only talk to experts having professional knowledge on the national level. Therefore, information on Gzira is based on the own experience of the interviewees, general information about Malta and about localities similar to Gzira.

	Urban design & gender:	In coastal towns like Gzira there are always "eyes on the street", and thus public space security is generally good. Towns are equipped with playgrounds and public toilets, usually one per centre. Coast is accessible and free for families and children. Generally, pedestrian network in Malta is not universally accessible (wheelchair, elderly, stroller). Heavy traffic in small island means buses usually get congested, 1.5-1.6 cars per person in Malta (off the record, needs to be checked), price freeze on petrol.
	Vulnerable groups (intersectionality)	Generally in Malta: ▪ 20% of the population are foreign nationals ▪ migrant wives rely on husband's residence permit ▪ refugees: mostly from Somalia, Ethiopia, Syria ▪ work visas: Venezuela, Philippines, India, Pakistan ▪ refugee women mostly do not work, those who come to work are usually in caring and cleaning professions ▪ domestic violence in vulnerable groups: capacity building in police is in progress, however, since COVID, domestic violence is on the rise
	Policies & gender:	▪ Responsibilities of localities: o Playgrounds, security, lighting: safety, accessibility, good planning o Gender budgeting: localities have to report their financial decisions impact on women's/men's lives (e.g., assessment of road, public space safety, sports funding) ▪ Buses have been changed for wheelchair accessibility
Highlights for JUSTNature		
Identified risks:		False sense of satisfaction: Since the gender equality situation is relatively good in Malta in comparison with other countries, there is a risk that still existing gender inequality problems or gender stereotyping remain unnoticed Potential barrier-free accessibility problems during the design Unsolved traffic issue which not only strengthens gender inequality but also affects air quality (both are core issues targeted by JUSTNature) Limited involvement of refugee women, women from religious minorities
Identified opportunities:		There are existing gender equality strategies, which can be used: https://riu.gov.mt/gender-equality/ Involvement of NCPE of Malta and RIU[9] of Gzira

[9] Research Innovation Unit of Gzira, https://riu.gov.mt/

	Leuven (Belgium) EIGE country profile	
BELGIUM	Ranking:	8th out of 27 countries
BELGIUM	Gender Equality Index:	74.2/100 (EU's score 68.6)
BELGIUM	Trends:	++
BELGIUM	Best performance:	Domain of money, especially financial resources
BELGIUM	Most room for improvement:	Domain of health, especially access to health
	Interview data	
BELGIUM	Gender equality:	Belgium is doing well compared to other countries. Seemingly, the attitude of men and women towards inclusion and equal opportunities is progressive. Policies in place are favourable in Belgium (gender-equality frameworks, gender mainstreaming), but there are still problems that legislation cannot fix. The gender pay gap between men and women is significant (men tend to earn more). Women are still more likely to be responsible for the household, and most of the not-paid "care" jobs end up on women. Currently, the legislation gives 15 weeks of parental leave for women, while it is 15 days for men. Because of the inequalities of the system, women stay longer away from their jobs when giving birth, and therefore they get less pension, while men do not get the opportunity to spend this same amount of time with their children. Since men tend to do the better paid jobs, the choice is often made that the women take up the unpaid tasks (household, taking care of the children…). According to international research there is a link between the not-paid care jobs and mobility. Women move more often in their neighbourhood on foot, by bicycle or by public transport (this is a general statement, no research or statistics for city of Leuven). There are gender quotas in place in companies and in public institutions. E.g., companies have to ensure women get promoted in their jobs like men, and have to hire equal shares of men and women, but in real life this is not always the case.
BELGIUM	Tools for gender equality:	▪ gender equality frameworks, gender mainstreaming ▪ urban planning: priority given to pedestrians, then cyclists, then public transport and the last priority is to private cars ▪ accessibility ensured to people with disabilities, pedestrians and vulnerable groups in mobility
LEUVEN	Gender equality:	Leuven is a rich city, there are high-level industries and generally people have higher level of education than elsewhere in Belgium. Women also tend to have higher degrees and they get higher positions, which is particular of Leuven. Nevertheless, men still get the higher positions and higher-paying jobs, like engineering, especially in private firms. Furthermore, according to research, more women than men pursue a higher education degree, however, women do not continue their academic career, i.e. they do not advance to a PhD, and mostly men stay in academia and become professors. At the same time, the biggest inequalities are between higher and lower educated people.
LEUVEN	Urban design & gender:	▪ Perceived safety of women: Leuven is a university city, and thus there are lots of students and a lot of party places, that leads women to feel less safe in public spaces ▪ Violence towards women: harassment, sexual violence, aggressions, unsafety ▪ Sport equipment and playgrounds in public spaces: research says that 99% of the public space sports infrastructure are used by boys and men, Men and boys practice often group sports like football or basketball, entering those enclosed sport infrastructure can feel intimidating and therefore less accessible for women and girls. Till the age of 12 girls and boys equally make use of playground (these are general remarks, no research or statistics for city of Leuven).

		▪ Mobility issues, green spaces
	Vulnerable groups (intersectionality)	▪ Ethnic minorities, disabilities, LGBTQ, lower level of education ▪ Women of colour ▪ People with migration backgrounds (these are general remarks, no research or statistics for Leuven): o there are programs to help learn the language, because sometimes people have the necessary education level, but they do not know the language o women with a migration background and poverty suffer more inequalities
	Tools for gender equality:	▪ Supporting victims of violence: center in the university hospital to take care of victims of the aggressions (physically and mentally) or violence cases, in contribution with the police, university, and municipality ▪ Prevention of gender-based violence: awareness campaigns for prevention, education to people in Leuven (what to do if you see this type of aggression, the "Got your Back" campaign); education and information campaign through video-clips about how to act, if you see a woman being harassed ▪ Perceived safety: the city is monitored by the police through CCTVs ▪ Participation in opinion campaigns: they ensure recognition of different groups in the participation process through neighborhood or groups committees to ensure that all voices are heard; participation is high ▪ Gender quota: For decision-making processes, Leuven has a gender quota, so political parties have to ensure the equal participation of women, for example in the city council ▪ They have a tool with useful insights to increase participation for girls that are 12+, to increase their access to playgrounds and public space ▪ Gender-inclusive public spaces: ongoing preparation of a master plan (guidelines) for public space, with focus on accessibility (JN project will also give a good input) ▪ In the public design department, one designer focuses on gender and public space she advises from this perspective design projects and shares her knowledge.
Highlights for JUSTNature		
Identified risks:		False sense of satisfaction: Since the gender equality situation is relatively good in Belgium in comparison with other countries, there is a risk that still existing gender inequality problems or gender stereotyping remain unnoticed Perceived safety issues Limited involvement of migrant women (lack of education and language skills) and less educated women Unequal use of public spaces by different genders
Identified opportunities:		There are already existing tools and frameworks for gender mainstreaming, which should be used in JUSTNature Municipality of Leuven seems to be very conscious about gender empowerment

<table>
<tr><th colspan="3">Merano (Italy)
EIGE country profile</th></tr>
<tr><td rowspan="5">ITALY</td><td>Ranking:</td><td>14th out of 27 countries</td></tr>
<tr><td>Gender Equality Index:</td><td>65.0/100 (EU's score 68.6)</td></tr>
<tr><td>Trends:</td><td>++</td></tr>
<tr><td>Best performance:</td><td>Domain of health, especially access to health</td></tr>
<tr><td>Most room for improvement:</td><td>Domain of knowledge, especially participation in education</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="2">ITALY</td><td>Gender equality:</td><td>Gender inequality is very pronounced in the economic field. One out of every three women does not have their own bank account. There is a serious gender pay gap, and financial gap is very large in case of pensions.</td></tr>
<tr><td>Policies & gender:</td><td>▪ Istanbul convention signed and ratified
▪ Introducing legislation against gender-based violence
▪ Mandatory gender budgeting in each municipality</td></tr>
<tr><td rowspan="2">MERANO</td><td>Gender equality:</td><td>There is a false sense of satisfaction about gender equality, even a lot of women think there are no gender inequality issues. At the same time, one of the most serious gender inequality problems in Merano is gender violence, which takes both the form of domestic and economic violence. The lack of economic autonomy (see national problems section) translates to reduced adaptive capacity for domestic violence survivors, who do not have the resources to start over their life. Another problem is gender stereotyping, which begins at an early age (0-6) and which leads to predetermined development pathways for children in schools, pushing girls towards caretaker roles, and boys to more technical fields. Furthermore, women are not well represented in politics; it is hard to fill up quotas in political positions, because not enough women are elected.</td></tr>
<tr><td>Urban design & gender:</td><td>Public space access:
▪ perceived safety issues after 9:00 pm
▪ lack of eyes-on-the-street
▪ parks and some streets are avoided by women
▪ outskirts of the city have many parks and green areas, but they are mostly used by men
▪ light pollution and perceived safety are conflicting goals
Representation in the city
▪ only 5-8 streets named after women
Differential exposure to environmental hazards:
▪ suburban area of Sinigo: former marshland, low-income people from different cultures, violence hotspot, ground water level can rise after a heavy rain</td></tr>
</table>

	Vulnerable groups (intersectionality)	Indiscriminatory violence ▪ From official statistics of domestic violence, there is no visible difference between social groups ▪ Violence against women appears indiscriminate, happening to rich and poor, migrants and locals alike. People with migratory background ▪ People coming from other cultures (20-30% citizens have migrant background) can be blighted with a religion that discriminates against women. There are cultural conflicts when these people, especially adults engage with gender-neutrality projects. ▪ Men are more integrated, women are isolated, making it difficult to reach them. These women are tough to reach on their own, they are mostly with men. ▪ They are more vulnerable to economic violence. They rarely work, are economically illiterate, and thus harder to reach when diagnosing economic autonomy (the lack thereof). ▪ Discrimination based on colour, country-of-origin, cultural identity symbols is overlapping with gender-based ones. Issues by country of origin ▪ Muslim countries where women's disadvantaged status has a cultural basis: Pakistan, Morocco, India. ▪ Racism due to skin colour, making it harder to find jobs, prone for harassment in school: Senegal, Nigeria, Togo. ▪ Eastern European countries, where there is an impression that women work and men do not: Albania, Kosovo, Romania. ▪ People fleeing from war zones, meaning there is additional trauma that needs to be managed: #no country named specifically
	Policies & gender:	There are many initiatives in Merano to fight against gender inequality, for example, Municipality of Merano was the first one to introduce gender budgeting in the country. At the same time, Merano is a small town, and thus large projects not possible (like real estate, direct financing). Therefore, the focus is mostly on small interventions, soft instruments (like capacity building, engagement). It is a problem that national legislation is not necessarily followed up by providing the instruments to carry out the law, especially HR capacities (e.g., gender budgeting would require an economist). Built environment ▪ Develop criteria for new construction from the perspective of vulnerable social groups, including women. Create a professional discussion and define rules that incorporate these other perspectives – focusing on different needs, different user actions, differing perspectives of security and comfort. ▪ Pink taxi: taking women home, when feeling unsafe, the Municipality supports this project by refunding 5.50 € for every taxi ride, operating from 8:30 until 6:00 the following day. ▪ Commission: introduces more women names in public spaces, and an associated educational program to explain in schools why these women are important. Gender equality strategy ▪ 5-year action plan exists for Merano with small-scale interventions. ▪ Action plan is based on focus group diagnosis of gender inequalities. ▪ Roundtable for public involvement in gender-equality projects. Right now, they are situated in the 2 cities (Bolzano, Merano), and they plan to open more in the remote areas of the province, especially in valley-regions, where gender identity issues are more relevant. Network against gender stereotypes ▪ Eliminate gender stereotypes in kindergartens (0-6 years). Done through workshops, and influences language, interior design (colours),

		stereotype-free toys, books, priming against behavioural stereotypes and predetermined identity traits (like girls pushed away from STEM). Network against gender violence ▪ Preventing violence against women. Through teaching, sensitivity building among citizens. Once a year an annual event focused on violence against women with political involvement. Teaching topic examples: what constitutes violence, avoiding victim blaming, consent, provide instruments to establish healthy relationships. ▪ Supporting violence survivors. Monthly meetings at institutions that encounter gender violence survivor women. Public network provides fresh start capacities, like housing, legal counsel, job finding, financial support for violence survivors. The network monitors violence trends and carries out prevention projects in a targeted way. Instruments for women with a migratory background ▪ Haus Arnika: house for women with migratory background with childcare facilities to allow them to work ▪ Caritas: organizes cooking group and round table (named Knödel-Lasagne-Couscous) that engages only women (open to children), of different cultures ▪ Next project for gender planning: open roundtable to women with migratory background, because at the moment, they are local citizen focused
Highlights for JUSTNature		
Identified risks:		False sense of satisfaction: Since the gender equality situation is relatively good in South Tyrol in comparison with other regions, there is a risk that still existing gender inequality problems or gender stereotyping remain unnoticed Potentially limited involvement of women with migrant background Light pollution and perceived safety are conflicting goals Perceived safety issues
Identified opportunities:		There are many ongoing gender empowerment initiatives in Merano, like gender equality action plan, roundtable, Knödel-Lasagne-Couscous, etc. People familiar with these projects should be involved in JUSTNature.

Munich (Germany)		
EIGE country profile		
GERMANY	Ranking:	11th out of 27 countries
	Gender Equality Index:	68.7/100 (EU's score 68.6)
	Trends:	+
	Best performance:	Domain of health, especially access to health
	Most room for improvement:	Domain of knowledge, especially segregation in education
Interview data		
GERMANY	Gender equality:	▪ Gender quality dominates everyday life. Despite differentiated and binding thematic settings and implementation efforts women In Germany continue to be worse off (decision-making power, distribution of family work, income, single mothers, women with a migration background). ▪ Procedural frustration of gender policies: dodging, delaying, shifting mandates, reallocating capacities to other tasks, generalizing documentation and evaluation, prioritizing other socio-political issues, and avoiding gender questions in intersectional issues. ▪ Nationwide very poor pay in the social and service professions, in which women continue to work for the most part.
	Policies & gender:	The following policies were not mentioned, nor critically assessed in the interview, but are shown here as background information[10]: ▪ German Act on Equal Participation of Women and Men in Leadership Positions in the Private and Public Sectors; associated monitoring and promotion activities focus on glass ceiling symptoms. ▪ Transparency in Wage Structures Act provides the legal basis for equal pay that supports a variety of federal policies for labour market equality. ▪ The Violence Against Women Helpline, the ratification of the Istanbul Convention, the Stärker als Gewalt online support platform, and regulations on prostitution focus on gender violence. ▪ A variety of communication campaigns and channels (e.g., girls/boys day events, No Clichés initiative) focusing on breaking down gender stereotypes.
MUNICH	Gender equality:	One of the biggest problems in Munich is the housing shortage, which is intensified by the strong influx of new residents and the extremely high prices in the housing market. High rents cause hardship for people with low incomes. Single mothers, large families and families with a migration background are particularly affected. Loss of accommodation happens regularly.
	Urban design & gender:	Open space design ▪ The law recognizes equal access to public spaces and facilities, but qualitatively different needs and use patterns of social groups create unqeual access which needs to be better understood and explicitly designed for. The increasing pressure on public spaces in Munich due to high influx of new residents has a high relevance for inequality. ▪ Differential design priorities for women, compared to men: lower perceived safety at night, higher sensitivity to disturbing behaviour, higher importance of sensory impressions, pleasant climate, fresh air, social life. ▪ Differential use patterns for women, compared to men: not counting childcare, walking and strolling is most common use, compared to sports, games, fitness for men.

[10] Source: Federal Ministry for Family Affairs, Senior Citizens, Women, and Youth (2020): Gender Equality Policy in Germany. Retrieved from: https://www.bmfsfj.de/bmfsfj/meta/en/equality/gender-equality-policy

		▪ Cross-gender facility needs: benches, rubbish bins, toilets. However, their quality is more relevant for women: especially for pleasant areas to sit, stand, lie, sanitary facilities, ▪ Women and girls may experience violence and repression, feel unwelcome and/or, are sexually harassed in general services and public spaces. ▪ Lighting is key indicator of perceived safety, night walks are carried out for diagnosis and testing. Lighting design for habitat protection and perceived safety are conflicting, which has proven challenging in the past. In the medium and long term, there will be an improvement in the feeling of safety of women and girls by optimizing the lighting situation in public traffic areas. ▪ Apart from a few pilot projects, the vast majority of constructions in the city have hardly beend developed from a multifocal gender/climate perspective Public facilities, services, and amenities ▪ Both general and target-group specific amenities are present in the city. ▪ Women-(and girl-)specific facilities, services, and amenities are difficult to identify, undersized, insufficiently accessible due to financial, language, physical, mental, emotional barriers. Differential vulnerability to environmental hazards ▪ Understudied area, but differential risks (to comfort) can be deduced from different use patterns (see open space design). ▪ Gender impacts of energy and climate policies are not sufficiently investigated. ▪ Gender norms (in particular the caretaker role) influence climate mitigation: women move fewer times in shorter distances, eat closer to low-carbon diets, and have more holistic attitudes to environmental issues, and have higher residential energy demand. ▪ Disaggregated data collection at all levels is needed. Procedural justice ▪ Women are often not adequately involved in co-creation of spatial planning, especially in climate protective and environmental intervention. In environmental/climate departments, gender expertise is missing. ▪ The topic of gender mainstreaming was not in all cases sufficiently anchored in the various fields of urban development. Positive example (in case you want to include it) In a measure of the EU Charter, the topic was placed at the interface with numerous actors inside and outside the administration with the help of the action space approach, documentation of experiences and findings. The Munich action areas are the particularly dynamic "hotspots" of urban development and have a high interdisciplinary density of projects, planning, and opportunities and challenges orientation. ▪ Planning bodies rarely staffed in a gender-equitable way, and women are not appropriately involved in juries and evaluation of construction and planning contracts with regard to gender equality and gender equality orientation
	Vulnerable groups (intersectionality)	▪ Low income, language and/or technical difficulties, digital divides further limit economic opportunities, uptake of new technologies, and participation in open democracy. ▪ Poverty in old age particularly prevalent among women, Low pensions inhibit housing affordability, exacerbate energy poverty. This often also affects single women in particular.
	Policies & gender:	▪ Signatory of European Charter on Gender Equality ▪ Monitoring of gender mainstreaming progress ▪ Adopted equality-oriented budgeting (gender budgeting) ▪ Action plan to reduce gender-based violence ▪ Information pool of studies and surveys with gender relevance

		▪ Mandatory appointment of equal opportunities officers in district committees ▪ Urban planning performance standards and recommendations for: thematization of gender, perceived safety, playground design, mobility, public space affordances ▪ Guidelines to include in climate and mobility strategies ▪ Flagship project, Prinz Eugen Park: differentiation of open, green space degree of privacy, residential unit variety (in terms of design and business model) tailored to demographic heterogeneity, establishment of a neighborhood cooperative for operation. This is the largest contiguous ecological timber housing estate in Germany. Compact construction, southern orientation and coordinated distances and heights of the buildings create a basis for ecologically responsible and economically justifiable energy use. The neighborhood's energy supply is ensured by district heating from the Munich public utility company, supplemented by solar energy use of the roof surfaces of individual building projects.
Highlights for JUSTNature		
Identified risks:		Many gender-related problems are not addressed because they are not systematically investigated and thematized in public discourse – fuelling a risk of them staying "under the radar" or marginalized as an unimportant topic.
Identified opportunities:		The ongoing flagship projects (E.g., Prinz Eugen Park) can serve as design/planning references. The study on the "patterns of usage in publicly accessible open spaces" is a crucial input for the gender-sensitive design of open space and its affordances that is recommended for the local teams to adopt. Finally, there are several NGOs that could support addressing gender mainstreaming in climate adaptation (e.g., Munich Women's Association, Association of German Women Entrepreneurs, Bündnis München Muss Handeln, Green City e.V., Spiellandschaft Stadt e.V.).

Szombathely (Hungary)

EIGE country profile

HUNGARY	Ranking:	25th out of 27 countries
HUNGARY	Gender Equality Index:	54.2/100 (EU's score 68.6)
HUNGARY	Trends:	+
HUNGARY	Best performance:	Domain of health, especially in health behaviour
HUNGARY	Most room for improvement:	Domain of work, especially segregation at work

Interview data

HUNGARY	Gender equality:	▪ Conservative gender roles relating to starting a family: o In the case of "careerist" woman life path, there is actual emancipation. However, it means that giving birth is postponed until the age of 40, which can have health implications. o To encourage starting a family, it would be necessary to provide: family-friendly workplace, flexible working schedule, no discrimination during the selection process, legally protected workplace. o In the leader – employee dimension there is no gender equality, there is no quota ▪ Usually men leaders, women employees, probably because of the years lost due to childbearing ▪ It can be the cause of the financial disadvantage of women compared to men o Multinational companies pay attention more to the needs of women: flexible working schedule, family-friendly establishments (for example baby dresser, but nursery is less frequent) o There are no protections in the case of child custody or property distribution trials: ▪ For example: crisis shelter, witness program, psychological help ▪ Due to the financial inequalities women are disadvantaged in legal procedures compared to men o Family support cannot follow market pricing, it is troublesome that it is connected to the number of children: women cannot provide housing conditions and mobility in financial terms ▪ In terms of women's emancipation in the political discourse a stronger voice would be needed ▪ More attention is needed to the women-specific health problems
	Policies & gender:	▪ Law 1998/XVI. about the rights of disabled people and equal opportunity: basically does not deal with men-women equality, does not name gender inequalities ▪ There are good practices in the EU regulations, and there is hope that it can be translated: o for example: Horizon Europe principles (mandatory and recommended). It is necessary to adopt gender equality plans in the institution of public administration, together with the action plans. ▪ Women's defence and representation appears in the civil sector
SZOMBATHELY	Gender equality:	▪ Lack of woman leaders o For example: in public administration the non-leader positions are more appealing to women, because it is more reliable, more flexible, provides a guaranteed income. On the contrary, men compete for the leading positions and incomes. o The ratio of women and men leaders in public administration is around 5:20 Rooms for improvement:

		▪ Gender equality in work ▪ Harmonize private and working life ▪ Family-friendly establishments in the workplaces/financed by the workplaces

	Urban design & gender:	▪ Access to public institutions and public services is not equal due to the lack of physical accessibility. They can save money even on new buildings, there is no regulatory protection.
		▪ Deficiencies of the supply system:
		  o the capacity of nurseries is not enough for the city and its metropolitan area
		  o there is not crisis shelter within the city
		  o Improvement is needed for rented flats for families in need, especially multiply disadvantages women
		▪ The capacity of psychological help is not enough
		▪ Screening examinations are unacceptably rare
		▪ Returning to work after giving birth: there is no support for this
		▪ Physical environment:
		  o No-go zones for women, for example: places without proper lighting (Parkerdő, the environment of Csónakázó-lake)
		  o In recreational institutions the pavement is not always sufficient (for example: accessibility with stroller)
		  o Lack of benches, trees providing shadow
		    ▪ Public space/recreational investments: preferring cheap pavement over more expensive, but more efficient and useful one (green area that provides comfortable environment)
		  o Damaging the environment, or equipment, handling vandalism is slow, which reduces the perceived safety
		  o The playgrounds in the suburbs should be further improved/modernised, and it is important to conserve the state of the current equipment – now rather the fitness parks are in focus
		  o Kalandváros is a good practice for a modern, big, and creative playground, but it is not free, and public playgrounds are small and outdated
		▪ There are only 3 public toilets that are free to use – but no in recreational zones
		▪ Traffic safety: there are no detours, deficient ring road system, number of vehicles per unit is higher, than the national average (comfort reasons, commuting between the city and outside it's border, population increase, cheap parking)

	Vulnerable groups (intersectionality)	▪ Discrimination based on colour, origin (especially Roma people): less access to housing ▪ Women with more children: less access to work, public services (lack of time), housing ▪ People with disabilities: no access to work (even though there are incentives, there is still stigma on it) ▪ People from the countryside have difficulties in accessing urban functions (rare public transport) ▪ Due to the generational atomisation multigenerational houses become empty, young people go into debt. Elderly care, placing the elderly is unsolved, there are no places, at-home care is not affordable due to the closeness of the border
	Policies & gender:	▪ Victim help centres ▪ In the social system gender equality appears as an aspect (for example: in terms of rented flats, single woman with children has advantage) ▪ Barrier-free (accessible), stroller-friendly bus fleet ▪ Accessibility in physical terms: for example lowered curb in cases of road improvements ▪ Smart crossing: motion sensor, alert the drivers with flashing

		▪ The municipality prepares a gender equality plan (application requirement): assessing the current situation (employee composition, gender ratio, career path abandonment, family status, ratio of leaders), existing equipment for women-friendly municipality (for example: positive discrimination for the women with children in case of holidays, allowances, flexible working schedule, soft parts), tools for the adoption/implementation of Horizon Europe principles, list of intervention (for example: complaint box, working group for equal opportunities to investigate and remedy injustices, trainings, family-friendly institutions, inviting the equal treatment authority, database of helping organisations, providing information, awareness-raising events, targeted services), monitoring surveys
Highlights for JUSTNature		
Identified risks:		Conservative attitude to the gender roles, typical to the whole society Lack of state-level gender equality principles Lack of women in decision-making Lack of perceived safety in specific areas of the city Problems with accessibility, lack of public toilets Involving Roma women, women with more children, people with disabilities in the planning process
Identified opportunities:		Ongoing municipal strategy to ensure gender equality within the municipality (Horizon Europe principles)

The gender profile for the Bolzano CiPeL is not included here for ethics reasons related to interview protocol, because the interviewee(s) did not formally approve the elaboration of the interview content and thus the elaborated profile.

ANNEX 3 - INDICATORS

Table 11 shows the original set of indicators identified in D2.1 and reported for the drivers of injustices they relate to, the contribution of NbS in relation to such injustices, the justice dimension involved and the level of integration. A re-elaboration of the information included in the table is shown to streamline redundant information and merge similar indicators, select them based on their spatial mapping potential and make a first identification of the data required for their development.

Table 11: List of indicators proposed to measure the components of (in)justice and the data needed.

Indicators	Drivers of (in-) justices	NbS contribution	Justice Dimension	Level of inte-gration	Spatial mapping potential	Data needed
Air quality (in)justice						
Air pollutants removal by vegetation (combination of Leaf Area Index and air pollutants concentrations)	Distribution of urban green spaces	Environmental benefits (air pollution abatement) thanks to trees, hedges, green walls, green roofs	Distributive	++	Strong	Require atmospheric pollutant concentration data from monitoring stations and tree cover data
Distance from air pollution sources (e.g., road, etc.)	Proximity to sources of air pollution	Environmental benefits (air pollution abatement) thanks to trees, hedges, green walls, green roofs	Distributive	++	Strong	Require road networks data from local geodatabase
Street canyons' location (combination of Sky View Factor and traffic volumes)	Air pollutants concentration	Environmental benefits (air pollution abatement) thanks to trees, hedges, green walls, green roofs	Distributive	+	Strong	Require road networks and traffic volumes data from local geodatabase and very high-resolution digital elevation model
Air pollution-induced environmental injustice (combination of Social Deprivation Index and air pollutants concentrations)	Social deprivation (low household income, non-professional job, low education, non-owner occupier)	Societal benefits (reduced inequalities) thanks to trees, hedges, green walls, green roofs	Distributive	++	Strong	Require socioeconomic data at sub-municipal level

Health impact of air pollutants removal (Number of premature deaths/Number of hospital admissions)	Exposure to high levels of air pollutants	Societal benefits (improved health) thanks to trees, hedges, green walls, green roofs	Distributive	+	No	-
Monetary value of air pollutants removal (Damage costs of air pollution)	Pressure on municipal budgets	Economic benefits (savings) thanks to trees, hedges, green walls, green roofs	Distributive	+	No	-
Thermal (in-)justice						
Air temperature at pedestrian level (daytime and night-time)	Urban heat island intensity	Vegetation contributes in decreasing air temperature thanks to evapotranspiration and provision of shading	Distributive	++++	Strong	Require sensor-based data from weather measurement stations
Local environmental parameters: Relative humidity; Solar radiation (shortwave, longwave); Wind speed and direction	In combination with air and surface temperature, contribution to human thermal comfort/discomfort conditions	All types of NbS influence urban microclimate	Distributive	++++	Strong	Require sensor-based data from weather measurement stations
Human thermal comfort indexes: PET; UTCI; SET (MRT)	Heat-related impacts on human body and activities	NbS might contribute in improving human thermal comfort, in particular when applied at street level (trees, urban forests and parks)	Distributive	++++	Strong	Require sensor-based data from weather measurement stations
Land surface temperature (daytime and night-time)	Spatial extent and distribution of surface urban heat island. Contribution to UHI and human thermal comfort/discomfort	NbS contribute in decreasing surface temperatures both at ground level (all types of NbS) and at the building envelope (green roofs)	Distributive	++++	Strong	Retrievable from Multispectral satellite imagery

Urban land use: Land Cover; Share of impervious surface; NDVI; NDBI	Higher shares of impervious surface contribute the most to urban heat; Built structure and vegetation also influence the spatial distribution of thermal conditions	Vegetated land cover usually shows lower surface temperatures	Distributive	++++	Strong	Retrievable from Multispectral satellite imagery
Heat risk/vulnerability indexes UHRI; etc.	Quantification of biophysical factors related to urban heat	Combination of the functionings described in previous lines	Distributive	++	Strong	Retrievable from Multispectral satellite imagery
Housing conditions: Household sizes; Occupancy rates; Insulation level; Presence of air conditioning	Effect of outdoor air temperatures on indoor conditions and heat-related health risks	Building greens contribute directly; other NbS contribute indirectly by mitigating outdoor conditions	Distributive	+	Weak	Require socioeconomic data at sub-municipal level
Carbon (in)justice						
Carbon emissions due to building cooling/heating (tCO2eq/y)	Provide information on location of buildings with higher level of C emissions	Indirect contribution	Distributive	+++	Strong	Require local data on building energy consumption building energy and energy conversion factors to CO2
Carbon emissions from vehicle traffic (t C/y)	Provide information on areas within the city with higher level of C emissions	Indirect contribution	Distributive	+++	Strong	Require fuel consumption data or travel distance data
Household size; Household income	Proxy indicators of emissions related to consumption patterns	Indirect contribution	Distributive	++	Weak	Require socioeconomic data at sub-municipal level
Dwelling ownership	Determines energy saving potentials & avoided emissions	Indirect contribution	Distributive /Procedural	++	Weak	Require socioeconomic data at sub-municipal level
Walkability Index (Proportion of people living near	Determines energy saving potentials &	Key focus on green networks	Distributive	+	Strong	Require transportation links

public transport; Coverage of bicycle lanes …)	avoided emissions through improved connectivity					information and socioeconomic data from local sources
Building age/construction year	Determines energy saving potentials & avoided emissions	Key focus on urban trees, as well as green roofs and walls	Distributive	-	Strong	Require data from housing census retrievable from statistics offices
Population density	Determines energy saving potentials & avoided emissions	Key focus on urban trees	Distributive	-	Strong	Require sociodemographic data at sub-municipal level
Above-ground biomass carbon density (Mg carbon per hectare)	Determines capacity of carbon mitigation based on carbon storage and sequestration	Key focus on urban forests & trees, and to some extent herbaceous & woody vegetation on a city-wide scale	Distributive	+	Strong	Require data on vegetation cover, vegetation structure and characteristics
Below-ground biomass carbon density (Kg per square meter)	Determines capacity of carbon mitigation, also linked to aspects of water retention or nutrient conservation	Key focus on herbaceous & woody vegetation on a city-wide scale	Distributive	+	Strong	Require data on vegetation cover, vegetation structure and characteristics
Soil sealing (%)	Proxy indicator to determine soil climate mitigation potential	Key focus on defined land use/cover classes and degree of pervious surfaces	Distributive	+++	Strong	Retrievable from Multispectral satellite imagery
Urban tree inventory (age, species, stem size)	Determines capacity of carbon mitigation	Urban forest and trees, also to determine low carbon densities	Distributive	++	Strong	Require available urban tree inventory data
Urban tree canopy (carbon density) (kg carbon per square meter canopy cover)	Determines capacity of carbon mitigation based on carbon storage and sequestration + avoided emissions	Key focus on urban forests & trees not only to determine low carbon densities but also avoided emissions	Distributive	++	Strong	Require available urban tree inventory data

Land cover ownership (public/ private/ mixed/other)	Determines capacity of carbon mitigation based on carbon storage and sequestration + avoided emissions	Key focus on the roles of privately owned & managed land versus publicly owned and managed land	Distributive /Procedural	+	Strong	Require socioeconomic data at sub-municipal level
Flora, Fauna and Habitat (non-)inclusiveness						
Number of groups/individuals standing in for nature by proxy	Nonhuman representation	Inclusion in design and planning	Representative, Procedural	++++	No	-
(Local) Natural science experts consulted for NbS design	Provision of a solid foundation of knowledge on ecosystems, biological processes, nonhuman species	Transdisciplinary design and planning	Representative, Capabilities	++++	No	-
Project stage where FFH first included	Target species or habitats are selected at the earliest project stages	FFH-aided design	Procedural	++++	No	-
Criteria used to determine the ecological value and need for protecting certain areas	Socioeconomic & cultural aspects in particular as defining human-nonhuman relationship	Norms, behaviours, values, and needs, and ecological integrity	Recognitional	++	No	-
Population, community, and ecosystem well-being (various units)	Common indicators addressing human and nonhuman communities	Habitat or group size, biodiversity, trophic transfer, interconnectedness of habitats	Distributional	++++	No	-
Structural connectivity of urban green and blue spaces (various units)	Biodiversity benefits	Physical connectivity of NbS elements	Distributive	++	Strong	Require landscape structure information retrievable from detailed Land Cover Maps
Species diversity within a defined area (number)	Biodiversity benefits	Species dicversity	Distributive	++	Weak	Require information on number of individuals for each species

Proportion and size of natural areas within a defined urban zone (% and ha)	Biodiversity benefits	Availability of habitats, aspects of naturalness	Distributive	++	Strong	Retrievable from Multispectral satellite imagery
Proportion and size of protected areas within a defined urban zone (% and ha)	Biodiversity benefits	Availability of habitats, aspects of naturalness	Distributive	++	Strong	Retrievable from local geodatabase
Number of veteran trees per unit area (No per ha)	Links to neighbourhood age		Distributive	+	Strong	Require available urban tree inventory and point data source for each individual veteran tree
Spatial (in-)justice						
Sociodemographic: Education, age, gender, race, cultural diversity index, income, population density	Existence of inequalities based on sociodemographics	Build NbS that reflect the community's characteristics; build NbS that avoid reinforcing existing social and spatial inequalities	Recognitional	++	Strong	Require socioeconomic data at sub-municipal level
Socioeconomic: Job creation	Potential for economic opportunities and green jobs	All NbS measures and categories	Contributive	+	Weak	Require socioeconomic data at sub-municipal level
Social capital: Relation	Offer new meeting places or consolidate existing ones where there is a need	Parks and recreation; allotment and community gardens	Recognitional	-	No	-
Distribution and accessibility to useable NbS	Improve the distribution of NbS	All NbS measures and categories	Distributive	++	Strong	Require detailed information of NbS types and their distribution within the city
Organization, participation, social network	Engage stakeholders during NbS design	All NbS measures and categories	Procedural	+	No	-

Accessibility (walkability index)	Reasonable walking distance or easy to access by public transportation	Urban parks	Distributive	+++	Strong	Require transportation links information and socioeconomic data from local sources
Demolition rate / Construction-demolition balance	Demolitions are a link between neighbourhood's social and biophysical conditions	All NbS measures and categories	Distributive	+	Weak	Require data from municipal cadaster (or real estate registry)
Foreclosure rate	Foreclosures may be seen either as drivers of vegetation change or as driven by vegetation change	All NbS measures and categories	Distributive	-	Weak	Require data from municipal cadaster (or real estate registry)
Housing cost burden, vacant housing units	Housing conditions to investigate spatial disparities	All NbS measures and categories	Distributive	+	Weak	Require socioeconomic data at sub-municipal level and data from housing census
Temporal (in-)justices						
Land use and green spaces configuration and change	Land use changes	na	Distribution / Procedural	++++	Strong	Retrievable from Multispectral satellite imagery
Location of facilities (waste facilities, incinerators, etc)	Land use	na	Distribution / Procedural	++	Strong	Require local data on waste facilities location and historical maps with location of historical or dismissed plants
Proportion of natural areas	Land use change impacts on natural heritage	na	Distributive	++	Strong	Retrievable from Multispectral satellite imagery

Proportion of protected areas	Land use change impacts on natural heritage	na	Distributive	++	Strong	Retrievable from local geodatabase
Neighbourhood age (usually determined by average building age and land use change)	Correlated to the distribution of green spaces and tree canopy	Urban green areas and urban tree canopy	Distributive	+	Strong	Require data on buildings retrievable from statistics offices, land use change information from satellite images
Vulnerable population (e.g., elderly, disable) exposed to risks	Climate change impacts	Green walls and roofs, trees and parks, blues infrastructure; rain gardens, floodplains, bioswales, permeable pavements	Distributive	+++	Weak	Require sociodemographic data at sub-municipal level from local sources
Urban/residential/productive area exposed to flood risks	Climate change impacts	Rain gardens, floodplains, bioswales, permeable pavements	Distributive	+++	Strong	Require land cover maps from remote sensed satellite images; Digital elevation models and demographic data
Buildings and infrastructures exposed to flood risks	Climate change impacts	Rain gardens, floodplains, bioswales, permeable pavements	Distributive	+++	Strong	Require land cover maps from remote sensed satellite images; Digital elevation models and demographic data

By using the table above, the indicators have been selected in line with the criteria described in Section 4. With the aim to capture the multi-dimensional space of ecological (space) justice and the complex interactions between the different justice components, two lists of indicators are identified and reported below.

The first set of indicators shows a list of quantitative and qualitative socioeconomic and sociodemographic indicators which can describe conditions related to the social space and socioeconomic conditions that can be drivers of (in)justice.

The second set of indicators represent those developed in order to map the underlying conditions in relation to the six justice components. Among them, many have been identified in the literature and have been widely used for mapping ecosystem services.

A reference is made to those indicators explicitly adopted in an ESS framework ([14]; [16]).

Socioeconomic and sociodemographic data linked with the justice dimensions

The following table summarizes the list of quantitative and qualitative social, socioeconomic, and sociodemographic indicators, which can be drivers of (in-)justices in the introduction of a NbS. The list of indicators is a re-elaboration of the contents of D2.1 and considers the justice dimensions as conceptualized in the following box.

Table 12: List of sociodemographic and socioeconomic indicators proposed to measure the components of (in)justices.

Indicators	Drivers of (in) justices	NbS contribution (Build a NbS can or should)	Justice Dimension
QUANTITATIVE			
Age (n. of children, n. of elderlies, distribution of age classes)	Existence of inequalities based on sociodemographics	Reflect the community's characteristics Avoid reinforcing existing social and spatial inequalities or that decrease existing inequalities	Recognitional/corrective
Gender	Existence of inequalities based on sociodemographics	Reflect the community's characteristics Avoid reinforcing existing social and spatial inequalities or that decrease existing inequalities	Recognitional
Education	Existence of inequalities based on sociodemographics	Reflect the community's characteristics Avoid reinforcing existing social and spatial inequalities or that decrease existing inequalities	Recognitional
Nationality (ethnicity, number of immigrants)	Cultural diversity index - Existence of inequalities based on sociodemographics	Reflect the community's characteristics Avoid reinforcing existing social and spatial inequalities or that decrease existing inequalities	Recognitional

Socioeconomic status: Income	Socioeconomic status and related inequalities. Socioeconomic status is often measured with a mix of indicators: occupation, income and education (and sometimes wealth)	Reflect the community's characteristics, decrease of poverty due to the revaluation of the price and quality of housing and the neighborhood Avoid reinforcing existing social and spatial inequalities or that decrease existing inequalities	Recognitional/ corrective
Socioeconomic status: Occupation		Contribute to reduce inequalities in terms of socioeconomic status	Recognitional/ corrective
Socioeconomic status: Education			Recognitional/ corrective
Population density	Existence of inequalities based on sociodemographics	Reflect the community's characteristics Avoid reinforcing existing social and spatial inequalities or that decrease existing inequalities	Recognitional/corrective
Job creation	Potential for economic opportunities and green job	Increase the wellbeing of the urban context and its population	Contributive
Crimes	Disparities between people	Improve the quality of the neighborhoods or, at the opposite, provide new spaces for crimes	Contributive
Accessibility and proximity to NbS	Increase accessibility	Improve the quality of life through access to green areas to, for example, cool off-regenerate in very hot summer periods, to interact with other people, etc.	Distributive
Housing cost, vacant housing units	Decrease of vulnerability	Increase the values of the houses and the neighborhood	Contributive/corrective
	Decrease of poverty	Increase the values of the houses and the neighborhood	Contributive/corrective
	Risk of gentrification	Increase housing costs creating gentrification situations	Contributive/corrective
Noise pollution	Inequalities in terms of pollution	Decrease pollution and inequalities between urban areas in terms of pollution	Distributive
Number and type of social, economic, and cultural services	Access to relevant services	Increase the quality of the urban area in terms of access to services	Distributive
QUALITATIVE			
Indicators for social cohesion (e.g., relationships with peers, quality of relationships)	Resource of wellbeing and no-inequalities based on the strength of relationships and the sense of solidarity among members of a community	Increase opportunities to meet and have good relationships with peers and people with different characteristics (in terms of e.g., age, ethnic background)	Contributive
Indicators for social exclusion	Resource of wellbeing and no-inequalities: possibilities to integrate social relationships, reducing exclusion	Increase opportunities to meet and have good relationships with peers (and no-peers), especially for elderlies living alone and minorities	Contributive/recognitional

		Not create exclusive space (for only some minorities or age classes)	Distributive
Indicators of aesthetics of urban context	Decrease inequalities between urban areas, sometimes creating gentrification.	Contribute to increase the aesthetics of the neighborhood, increasing the value (also emotional) of the area. More aesthetic neighborhood can drive the increase of property prices and thus gentrification	Contributive/corrective
Indicators of poverty and vulnerability	Decrease inequalities between urban areas. Where is the need to intervene in the neighborhood to reduce poverty and vulnerability?	New public and green spaces can positively act where inequalities, poverty, and vulnerabilities are higher, promoting social and ecological interventions	Distributive
Engagement of citizens and stakeholders in planning, building, and managing NbS	Including citizens and stakeholders' needs, preferences, and characteristics	Respond to the day-to-day and real needs of the population and key players	Procedural/recognitional
Risks for gentrification	Worsening inequalities within or between neighborhoods	New public and green space can increase inequalities, moving people from the renovated neighborhoods to the low-income or poorest neighborhoods	Distributive/corrective

Justice dimensions:

1) *Contributive* justice refers to a truly valuable **contribution to the common good** in comparison with what and how the free-market values promote. This dimension is closely connected to the SDG 8 on sustained, inclusive, and sustainable economic growth.
2) *Recognitional* justice facilitates the **practices related to different cultures** (e.g., ethnic background, age) through the introduction of NbS, which could reflect the needs of the population.
3) *Distributive justice* refers to the issue that urban vegetation is often distributed unevenly among residents, creating social inequalities. Linking social with biophysical conditions, the availability of NbS should be **evenly distributed in the urban context**.
4) *Corrective justice* is typically a rectifying function that **relates one person to another according to the concept of equality or fairness**. When one has acted in a manner that caused loss to some individual relative to a baseline then there is a duty on the actor to re-establish the original equality.
5) *Procedural justice* is related to the decision-making process in which environmental demands and long-term engagement with individuals and communities are to be achieved.

For a deeper understanding of the dimensions of justice, refer to D2.1.

Selected indicators

The table shows the final list of indicators developed in order to produce thematic maps with the aim to understand and visualize the underlying conditions in relation to the six challenges identified and to be used in the construction of the socio-ecological disparities profiles. The table reports the indicators selected for each justice component, the data required for the computation and the data source.

Table 13: List of indicators actually used to measure the (in)justice components and create the profiles.

(In)justice component	Indicators	Required Data	Data source
Air quality (in-)justice	Air pollution risk of exposure	Digital Surface Model Road network and traffic volumes	Local geodatabase
Thermal (in-)justice	Heat stress zone*	Land Surface Temperature time-series	Multispectral satellite imagery
	Surface urban heat island*	Land Surface Temperature time-series	Multispectral satellite imagery
Carbon (in-)justice	Carbon emissions due to building cooling/heating	Building cooling density Building heating density	Hotmaps database
	Carbon removal by vegetation*	Digital Surface Model Land cover Map	Multispectral satellite imagery /Local geodatabase
FFH inclusiveness	Landscape structure	Land cover map	Multispectral satellite imagery
	Protected areas*	Protected areas	Local geodatabase
Spatial (in-)justice	Accessibility to green areas*	Green urban areas Road network	Local geodatabase
	Accessibility to urban facilities*	Urban facilities Road network	OpenStreetMap/ Locally provided data on urban facilities
	Walkability index	Population density Point of interests Recreational areas Digital Elevation Model Road network	Copernicus Population data OpenStreetMap Local Geodatabase
Temporal (in-)justice	Land surface temperature change	Land surface temperature	Multi-temporal satellite imagery
	Natural environment change	Degree of vegetation	Multi-temporal satellite imagery
	Built-environment change	Degree of imperviousness	Multi-temporal satellite imagery

Note: * Refers to those indicators adopted within an ESS framework

Indicators' development processes

Street canyon risk
SAGA-GIS
Tool Sky View Factor
Input: digital surface model
Number of sectors: 16
Search radius: 100m
Output: sky view factor
ArcGIS
Raster calculator
Expression: Con(sky view factor < 0.56, 3, Con((sky view factor >= 0.56) & (sky view factor < 0.82),2,Con((sky view factor >= 0.82),1)))
Output: sky view factor reclassified
Polyline to Raster
Input: selected streets (from street network)
Output: selected streets raster
Raster Calculator
Expression: (selected streets raster * sky view factor reclassified)
Output: risk matrix
Raster to Polygon
Input: risk matrix
Output: risk matrix vector
Buffer
Input: risk matrix vector
Output: risk matrix vector buffer
Distance: 3m
Intersect
Input: risk matrix vector buffer, selected streets
Output: risk matrix vector buffer intersect
Buffer
Input: street canyon risk 1
Output: street canyon risk 1 buffer
Distance: 50m

Carbon emission
ArcGIS
Int
Input: cooling density float
Output: cooling density integer
Raster to Polygon
Input: cooling density integer
Output: cooling density integer vector
Add Field
Name: Float value
Field Calculator:
Expression: (Value / 10000)
Intersect
Input: cooling density integer vector, census unit
Output: cooling density integer vector intersect
Dissolve
Input: cooling density integer vector intersect
Output: cooling density integer vector intersect dissolve
Dissolve Field: ID census unit
Add Field
Name: electricity
Field Calculator
Expression: (Float value * electricity fraction) / 100
Add Field
Name: electricity emissions
Field Calculator
Expression: (electricity * electricity emissions factor)
Spatial Join
Target: census unit
Join: cooling density integer vector intersect dissolve
Output: cooling density integer vector intersect dissolve spatial join
Int
Input: heating density float
Output: heating density integer
Raster to Polygon
Input: heating density integer
Output: heating density integer vector
Add Field
Name: float value
Field Calculator:
Expression: (Value / 10000)
Intersect
Input: heating density integer vector, census unit
Output: heating density integer vector intersect
Dissolve
Input: heating density integer vector intersect
Output: heating density integer vector intersect dissolve
Dissolve Field: ID census unit
Add Field
Name: diesel
Field Calculator
Expression: (float value * diesel fraction) / 100
Add Field

Name: diesel emissions
Field Calculator
Expression: (diesel * diesel emissions factor)
Add Field
Name: lpg
Field Calculator
Expression: (float value * lpg fraction) / 100
Add Field
Name: lpg emissions
Field Calculator
Expression: (lpg * lpg emissions factor)
Add Field
Name: natural gas
Field Calculator
Expression: (float value * natural gas fraction) / 100
Add Field
Name: natural gas emissions
Field Calculator
Expression: (natural gas * natural gas emissions factor)
Add Field
Name: wood
Field Calculator
Expression: (float value * wood fraction) / 100
Add Field
Name: wood emissions
Field Calculator
Expression: (wood * wood emissions factor)
Name: total
Field Calculator
Expression: (electricity emissions + diesel emissions + lpg emissions + natural gas emissions + wood emissions)
Spatial Join
Target: census unit
Join: heating density integer vector intersect dissolve
Output: heating density integer vector intersect dissolve spatial join
Spatial Join
Target: cooling density integer vector intersect dissolve spatial join
Join: heating density integer vector intersect dissolve spatial join
Output: heating cooling density integer vector intersect dissolve spatial join

Carbon absorption
ArcGIS
Raster Calculator
Expression: digital height model = digital surface model – digital terrain model
Output: digital height model
Resample
Input: digital height model
Output: digital height model 10m
Clip
Input: digital height model 10m
Extent: natural environment (from land cover)
Output: canopy height model
Raster Calculator
Expression: trees = canopy height model > 5m
Output: trees
Raster to Polygon
Input: trees
Output: trees vector
Intersect
Input: trees vector, census unit
Output: trees vector intersect
Dissolve
Input: trees vector intersect
Output: trees vector intersect dissolve
Dissolve Field: ID census unit
Add Field
Name: area
Calculate Geometry
Property: Area
Add Field
Name: c absorption
Field Calculator
Expression: (area / 100) * 15
Spatial Join
Target: census unit
Join: trees vector intersect dissolve
Output: trees vector intersect dissolve spatial join

Accessibility to urban green areas
ArcGIS
Create New File Geodatabase
Name: transportation network
Create Feature Dataset
Import Feature Class: selected streets (from street network)
Create Network Dataset
Intersect
Input: green areas, selected streets (from street network)
Output: green areas points
Network Analysis
Service Area - properties - Analysis Setting:
Impedance: length (meters)
Default Break: 400/800
Input Facilities: green areas points
Output1: green areas points accessibility 400m
Output2: green areas points accessibility 800m

Accessibility to urban facilities
ArcGIS
Create New File Geodatabase
Name: transportation network
Create Feature Dataset
Import Feature Class: selected streets (from street network)
Create Network Dataset
Network Analysis
Service Area - properties - Analysis Setting:
Impedance: length (meters)
Default Break: 400/800
Input Facilities: cultural facilities points
Output1: cultural facilities accessibility 400m
Output2: cultural facilities accessibility 800m
Network Analysis
Service Area - properties - Analysis Setting:
Impedance: length (meters)
Default Break: 400/800
Input Facilities: healthcare facilities points
Output1: healthcare facilities points accessibility 400m
Output2: healthcare facilities points accessibility 800m
Network Analysis
Service Area - properties - Analysis Setting:
Impedance: length (meters)
Default Break: 400/800
Input Facilities social facilities points
Output1: social facilities points accessibility 400m
Output2: social facilities points accessibility 800m
Network Analysis
Service Area - properties - Analysis Setting:
Impedance: length (meters)
Default Break: 400/800
Input Facilities: educational facilities points
Output1: educational facilities points accessibility 400m
Output2: educational facilities points accessibility 800m

Imperviousness change

ArcGIS
Raster Calculator:
Expression: imperviousness change = degree of imperviousness$_{2020}$ – degree of imperviousness$_{2018}$
Output: imperviousness change
Raster to Polygon
Input: imperviousness change
Output: imperviousness change vector
Intersect
Input: imperviousness change vector, census unit
Output: imperviousness change vector intersect
Dissolve
Input: imperviousness change vector intersect
Output: imperviousness change vector intersect dissolve
Dissolve Field: ID census unit
Spatial Join
Target: census unit
Join: imperviousness change vector intersect dissolve
Output: imperviousness change vector intersect dissolve spatial join

Vegetation change
ArcGIS
Raster Calculator:
Expression: vegetation change = degree of vegetation$_{2020}$ – degree of vegetation$_{2018}$
Output: vegetation change
Raster to Polygon
Input: vegetation change
Output: vegetation change vector
Intersect
Input: vegetation change vector, census unit
Output: vegetation change vector intersect
Dissolve
Input: vegetation change vector intersect
Output: vegetation change vector intersect dissolve
Dissolve Field: ID census unit
Spatial Join
Target: census unit
Join: vegetation change vector intersect dissolve
Output: vegetation change vector intersect dissolve spatial join

Soil sealing
ArcGIS
Raster Calculator:
Expression: soil sealing = impermeable surfaces$_{2022}$ (from land cover) – impermeable surfaces$_{2018}$ (from land cover)
Output: soil sealing
Raster to Polygon
Input: soil sealing
Output: soil sealing vector
Intersect
Input: soil sealing vector, census unit
Output: soil sealing vector intersect

Dissolve
Input: soil sealing vector intersect
Output: soil sealing vector intersect dissolve
Dissolve Field: ID census unit
Spatial Join
Target: census unit
Join: soil sealing vector intersect dissolve
Output: soil sealing vector intersect dissolve spatial join