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multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

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Return

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Technical references

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Document history

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1. Introduction

Increasing pressure from climate change, natural resource depletion, and economic and social crises requires the adoption of an innovative approach that combines sustainable development, environmental quality, and inclusiveness. In this scenario, the green transition of urban settlements must be oriented towards regenerative cycles. This approach is aimed at tackling environmental and socioeconomic challenges and adopting sustainable management models to preserve resources and improve quality of life in a sustainable perspective. The green transition requires the ability to achieve balance through integrated policies and long-term strategies for the implementation of adaptation and mitigation design proposals to address risks and increase resilience.

In the framework of WP4 - Mitigation and adaptation for more resilient and livable cities, the work developed in Task 4.3 intends to define conceptual guidelines, planning and design tools, and assessment protocols to monitor and support urban resilience. The activities intend to synthesize interdisciplinary knowledge for the design of inclusive, resilient and livable urban settlements. Through the exploration of RETURN case studies, the intent is to offer replicable and implementable planning and design solutions in line with the New European Bauhaus (NEB) initiative. NEB promotes systemic approach that involves communities, ensuring co-creation, inclusive participation, and design that responds to specific local needs, representing a conceptual framework that combines sustainability, aesthetics and inclusiveness and emphasizing the need for environmentally efficient and culturally stimulating design solutions. In parallel, the integrated resilience approach contributes to define systemic responses to urban vulnerability issues, combining mitigation and adaptation measures that consider multiple risks.

The task aims to synthesize interdisciplinary knowledge and translate it into operational tools, thus outlining a methodological framework to support the transition towards resilient and regenerative eco-districts. Planning and design tools and methods for urban regeneration the integration with three-dimensional urban area planning processes and strategic environmental assessments. In this context, the adoption of monitoring and assessment protocols plays a crucial role both to quantify and improve the adaptation and mitigation capacity of cities and to support strategic planning, strengthening the participation of public and private stakeholders.

To translate global policies into local actions, urban districts are identified as the appropriate scale of intervention for green transition, addressing potential environmental, natural, and anthropogenic risks while facilitating actions to mitigate, adapt, and increase the resilience of urban settlements. The district scale enables dynamic downscaling and upscaling processes to define mutual dependencies among various levels, crucial for contemporary cities' complexity.

Following a ‘transformative’ approach, design proposals are defined through the identification and systematization of multi-scalar and multi-disciplinary factors. Such an approach allows them to be used throughout the design process, supporting the identification of strategies and actions best suited to the specific needs of the local intervention according to hazard and site-specific criteria. Different contexts of application at building, urban and territorial scale have been identified and considered in relation to the effects of intervention in terms of applicability. The relationship with the temporal dimension, as strongly related to the risk management phases in the integrated urban resilience framework, is also considered as a key feature.

Finally, the contribution focuses on the definition of concept guidelines to identify key features, methods and standards for the application in different contexts to support the green transition of urban settlements and increase urban resilience.

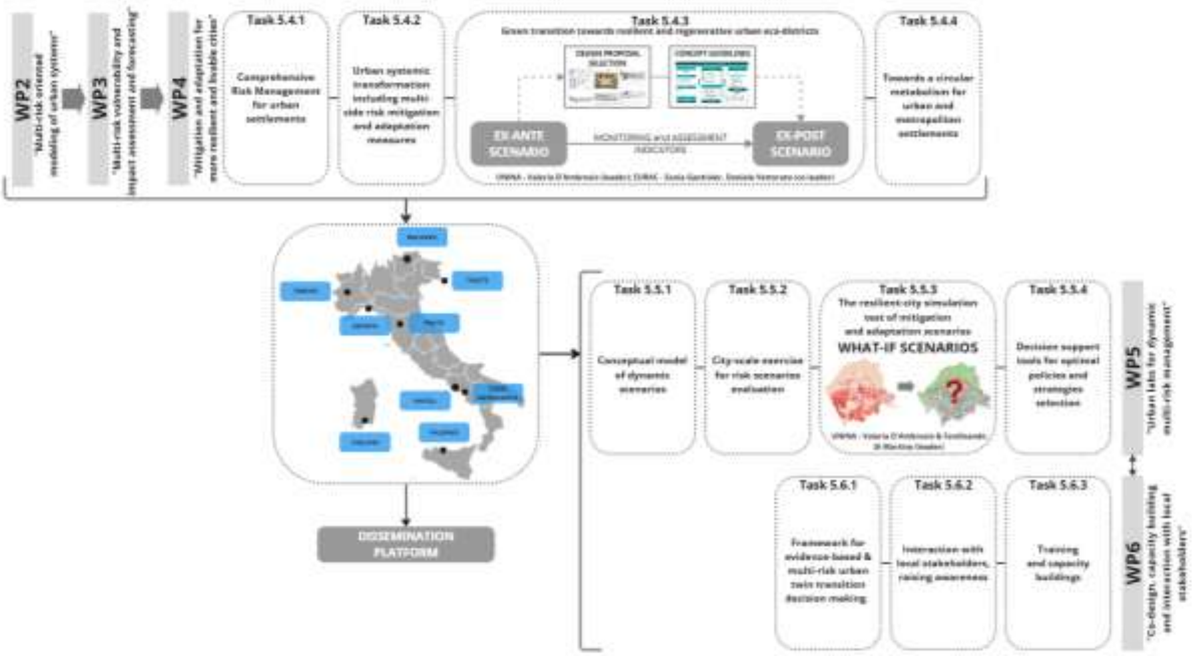


Figure 1. Framework of T5.4.3 interactions as related to TS1 internal structure.

2. Conceptual frameworks and reference scenario

2.1 Green transition for regenerative urban settlements

In today's scenario, characterised by the depletion of non-renewable resources, the effects of global warming, the economic and social crisis and the health emergency, cities must deal with new needs, new actors and plan and design innovations, combining development, innovation and environmental quality (Crupi, 2022).
Such a transition requires development policies that enhance productive, cultural and relational potential, exploiting growing systemic interconnections (Losasso, 2015). The green transition of settlements cannot be based on expansionist models but must be oriented towards regenerative cycles that integrate civic, environmental and productive values. This approach is aimed at tackling environmental and socioeconomic challenges and adopting sustainable management models to preserve resources and improve quality of life.
This necessarily calls for a paradigm shift to bring together different dimensions: environmental, economic, social, institutional, settlement and energy. It also combines regeneration and resilience, promoting new policies and strategies aimed at improving natural cycles, decarbonising the energy system, and using innovative materials and technologies for the environment, transport, welfare and human health (Crupi, 2022). The necessity of objectivizing the intervention strategy through a scientific method is decisive in understanding the city's real functioning and based on this, prefiguring the interventions to be carried out according to an appropriate involvement of the political and entrepreneurial class (Burdett, 2015). Urban regeneration is no longer limited to the physical dimension of urban design but extends to design processes that actively involve socioeconomic components, foster participation and promote local development through the effective use of resources. Strategic planning targets thus become tools for verifying the effectiveness of interventions, ensuring a tangible response to the expectations of citizens, private investors and public administration.
The green transition for regenerative urban settlements requires the ability to achieve balance through integrated policies and long-term strategies for the implementation of adaptation and mitigation design proposals to address risks and increase resilience.

2.1.1 European and national framework for green transition: policy, programs and guidelines

By 2050, two-thirds of the world's population will live in urban areas. Cities globally are responsible for approximately 75% of all carbon dioxide emissions and are particularly vulnerable to natural disasters and the effects of climate change. Nowadays, governments are busy setting targets and improving legislation to keep a strong focus on the green transition when planning cities, neighbourhoods, and buildings.

In Europe, the theme of green transition related to the urban settlements is present in different documents, policies and initiatives, such as:

- European Green Deal;
- Renovation Wave for Europe;
- NextGenerationEU;
- Fitfor55 Package;
- REPowerEU Plan
- Case Green Directive

The *European Green Deal* is a package of strategic initiatives – initiated by the Commission in December 2019 – aimed at setting the EU on the path to a green transition, with the goal of achieving climate neutrality by 2050. The transition to climate neutrality will offer significant opportunities, such as potential economic growth, new business models and markets, new jobs, and technological development (COM, 2019).

It emphasizes the need for a holistic and cross-sectoral approach where all relevant strategic sectors contribute to the ultimate climate goal. The package includes initiatives related to climate, environment, energy, transport, industry, agriculture, and sustainable finance, all of which are strongly interconnected. The measures identified by this document address the theme of the risk of energy poverty, with reference to household renovations to contribute to mitigate environmental impact. In this context, the issue of a clean energy transition also comes into play, with renewable energy sources playing an essential role across different sectors.

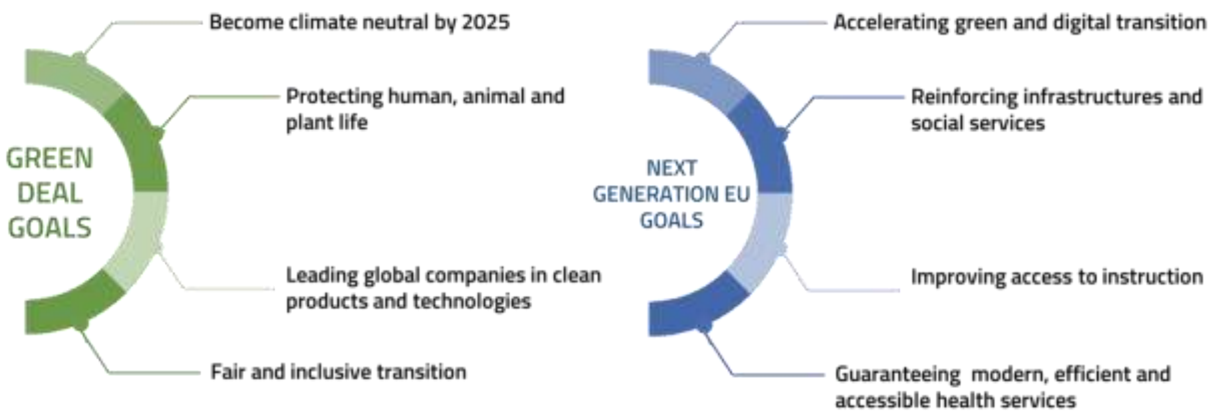


Figure 2. European Green Deal and Next Generation EU programmes main goals based on the European Commission's documents.

The transition to climate neutrality also requires smart infrastructure, increased cross-border cooperation, and a review of the regulatory framework for energy infrastructure to ensure consistency with climate objectives. Moreover, the transition to climate neutrality also requires smart infrastructure, by implementing a regulatory framework that foster the deployment of innovative technologies and infrastructure, such as smart grids, hydrogen networks or carbon capture, storage and utilization, energy storage, also enabling sector integration. Some existing infrastructure and assets will require upgrading to remain fit for purpose and climate resilient.

The private sector will be key to financing the green transition. Long-term signals are needed to direct financial and capital flows to green investment and to avoid stranded assets. At a general level, the EU should use its expertise in "green" regulation to encourage partners to design similar rules that are as ambitious as the EU's rules, thus facilitating trade and enhancing environment protection and climate mitigation in these countries.

Following the pandemic and consequent economic crisis, through the *NextGeneration EU plan*, the Recovery and Resilience Facility (RRF) has been developed. It is a temporary instrument that aims to implement ambitious reforms and investments that make the economies and societies more sustainable, resilient and prepared for the green and digital transitions, in line with the EU's priorities (NextGenerationEU, 2022).

According to these guidelines, the European Commission proposed on 27 May 2020 the *Renovation Wave*, a recovery package featuring a revised Multiannual Financial Framework 2021-2027 and the recovery instrument Next Generation EU (NGEU) of EUR 750 billion available to tackle the economic and social consequences of the COVID-19 crisis and support the twin green and digital transition. Investments and reforms have been provided with high potential to scale up investments in building renovation and leverage public and private financing, with a focus on social and affordable housing. They are particularly relevant to achieve the objectives of the *Recovery and Resilience Facility* (COM, 2025b): green transition (reduction of energy consumption and GHG emissions, creation of jobs and growth stimulus and social resilience) (COM, 2020).

The proposed Just Transition Mechanism (JTM) aims to alleviate the social and economic costs of the green transition to climate neutrality, focusing on the territories, industries and workers who will shoulder the biggest transition challenges.

In line with the European Green Deal Call 5, a specific area is dedicated to measures, demonstration projects and innovative products aimed at enabling a green and just transition in urban settlements. It aims to produce concrete, tangible results within a short time frame, mobilising research and innovation to enable a green and just transition. An area dedicated to "Energy and resource efficient buildings" is included, which explore the design and construction of new buildings and retrofitting of existing ones. The Call also includes an area on "Towards Climate-Neutral and Socially Innovative Cities', that aims at rapidly deploying full-scale, systemic and integrated climate actions at city or district level to reach climate neutrality by 2030, supporting the upcoming 'Climate-Neutral & Smart Cities' Mission. Another area targets demonstration of systemic solutions for the territorial development of circular economy, for which the built environment places a relevant role (COM, 2025a).

In this scenario, climate change and environmental degradation still remain as severe threats both at the European scale and the global one. For this reason, following the European Green Deal and in accordance with its guidelines, other technical regulations have been implemented to support the green transition at the urban scale by:

- Developing climate policy, including advice on climate strategies and action plans, and support for modelling greenhouse gas emissions.
- Supporting land use and forest management, including urban planning, SMART cities and forest accounting and inventory.
- Developing nature-based solutions to address heat waves, drought, flooding and poor air quality in urban areas.
- Supporting the decarbonisation of electricity systems, including the design of renewable-energy-friendly markets and regulatory frameworks.
- Assessing policies for energy-efficient heating and cooling systems.
- Enhancing energy efficiency investments in buildings.
- Defining policies on sustainable transport/mobility and alternative fuels.

In this spirit, the *Fitfor55 package* of proposals aims to deliver the transformational change needed across economy, society and industry to reach the European Green Deal goals and also Europe's commitments to the Paris Agreements. Since all share in the benefits of more space for nature, cleaner air, cooler and greener towns and cities, healthier citizens, lower energy use and bills, as well as new jobs, technologies and industrial opportunities, green transition represent a collective challenge to bring these benefits to all as quickly and as fairly as possible (CISL, 2021).

The Fit for 55 Package represents set of proposals aimed at setting an agenda to work with the rest of the world towards a green transition that addresses existential threats and creates new opportunities for all.

To this end, improving the EU's building stock plays a big part. Since construction, usage, renovation and demolition of buildings account for around 36 per cent of the EU's GHG emissions, retrofitting buildings to improve their energy efficiency, combined with large-scale installation of energy-efficient lighting, heating and cooling systems using renewable electricity, will help save energy, improve living conditions and health, reduce the risk of energy poverty and create local, decent jobs. Buildings have so far been predominantly covered by regulatory measures relating to the operational emissions of new buildings and existing stock. In this context, the most significant revision proposed in the Fit for 55 Package, in relation to the buildings sector, is the plan to establish a new, separate ETS for road transport and buildings. The package proposes an increase of the EU-wide ESR target to 40 per cent and an upward revision of the Member State emissions reduction targets to 10–50 per cent below 2005 levels would extend the responsibility (and rewards) for contributing the overall ESR target to all Member States, including those with the lowest GDP. These proposals would incentivise energy efficiency retrofits, especially in public sector buildings, by extending the renovation obligation from central government buildings (less than 0.5 per cent of the EU's building stock) to all public sector buildings (approximately 10–12 per cent of the EU's building stock. Moreover, the package proposes revisions to the RED designed to incentivise the development of modern district heating and cooling systems to harness local renewable energy and to cost effectively integrate renewable energy supplies in buildings. A specific 2030 target is proposed requiring 49 per cent of energy used in buildings to come from renewables, increasing at a minimum rate of 1.1 percentage points every year.

In this overview of technical regulations for the green transition at the urban and building scale in Europe, it is also useful mentioning the *REPowerEU Plan*. It is a response to the hardships and global energy market disruption caused by Russia's invasion of Ukraine. It develops from the understanding that there is a double urgency to transform Europe's energy system: ending the EU's dependence on Russian fossil fuels and tackling the climate crisis. The measures implemented in the REPowerEU Plan include energy savings, diversification of energy supplies, and accelerated roll-out of renewable energy to replace fossil fuels in homes, industry and power generation.

Most of the experts agreed that the implementation of REPowerEU will lead to the decarbonisation of the building stock in the EU. In this context, this means that the share of renewable energy sources in the building sector would increase. However, they pointed out that the positive effects are more likely in tenant-owned than in rental properties due to a higher likelihood of investment. Additionally, potentials for the building sector to actively contribute to production of

Figure 3. The 4 priorities for the REPowerEU programme (rielaboration from European Commission, 2022).

renewable energy are also likely to be exploited in the context of renovation measures. All experts judged the effect as strongly positive (European Committee of the Regions, 2022).

In the context of green transition and building renovation, the recently approved European Directive *Case Green* is also to be noted. Its main objectives of the Energy Performance of Buildings Directive are a substantial reduction of greenhouse gas emissions and energy consumption in the sector by 2030, with the aim of achieving climate neutrality by 2050 through the retrofitting of the largest number of energy inefficient buildings existing today.

To reduce energy consumption, measures are planned such as the construction of photovoltaic panels, new boilers, the replacement of windows and doors, and the installation of thermal insulation. According to the directive, new buildings will have to be zero-emission from 2030, with the deadline brought forward to 2028 for publicly owned buildings. Houses will have to achieve a 16% reduction in energy consumption by 2030 and 20-22% by 2035. The obligation to install photovoltaic panels will apply to new public buildings from 2026 to 2030. Member countries will have until 2040 to decommission fossil fuel boilers, while from 2025 all subsidies for stand-alone boilers will be abolished. There will also be incentives to encourage a switch to heating and cooling systems powered by renewable energy. To this end each Member State will have to adopt a national plan to gradually reduce the energy consumption of residential buildings; each country will be able to determine which buildings to focus on. Overall, 55 % of the reduction in energy consumption must be achieved by RENOVATING the lowest-performing buildings. By 2030, renovations are to involve 15 per cent of non-residential buildings and, by 2033, 26 per cent of buildings in the lowest energy class. According to the directive's definitions, 43% of the least efficient buildings will have to be upgraded from an energy point of view (NuovaEcologia, 2024).

2.1.2 From urban Districts to regenerative urban Eco-districts

Urban districts as a suitable scale for design interventions at the local level

An urban district typically refers to a specific administrative area that is usually delineated based on population density, land use patterns and other urban characteristics.

In English, the term “District” denotes an area delineated with discernible boundaries and distinguished by its unique characteristics that set it apart from its surrounding areas. It is different from a “Neighborhood” that typically refers to a smaller-scale area, not only as an urban area but also in terms of its inhabitants, more limited in size, and more closely associated with the concept of local community. The two terms have often been used interchangeably since they both refer to a specific scale that is the planning unit of modern cities with a spatially or community-defined geography (EcoDistrict, 2017). However, recent studies have highlighted a difference between the two terms. A “Neighborhood” usually refers to well-defined areas, typically ranging from a few hectares to sizes seldom exceeding 100 hectares, whereas a "District" describes areas identifiable by specific characteristics but with larger dimensions, typically ranging from a few dozens to a few hundred hectares, occasionally reaching sizes of up to 500 hectares depending on the density of construction and habitation (Tucci & Baiani, 2020).

In the new climate regime, linear models of production-consumption-waste necessitate a transition to carbon-neutral societies and green, circular economies. In the pursuit of sustainable urban development, eco-districts have emerged as promising solutions to mitigate environmental impacts while enhancing residents' quality of life.

Urban districts thus establish themselves as the minimum unit of intervention (with a number of 20,000-25,000 inhabitants) and serve as an appropriate scalar dimension for green transition, addressing potential environmental, natural, and anthropogenic risks while facilitating actions to mitigate, adapt, and increase the resilience of urban systems. The district scale enables dynamic downscaling and upscaling processes to define mutual dependencies among various levels, crucial for contemporary cities' complexity. Moreover, urban districts, referring to areas with recognizable settlement features and natural boundaries, represent an intermediate scale between cities and neighbourhoods. Their perimeter considers built environment characteristics, urban infrastructure, and environmental factors to define exposure and vulnerability to hazards.

Urban Ecodistrict definition and characteristics

Within the framework of the green transition, EU regulations emphasise the need for urban regeneration programmes to be structured in the different dimensions of sustainable development: economic, social and environmental. In this context, urban and building renovation processes should determine strategies and actions able to initiate urban regeneration processes identifying some common principles such as (Botti et al., 2014):

- a spatial planning and management that considers cities as unitary and functionally complex organisms;
- an integrated vision of the city that contemplates its different dimensions (metropolitan, peripheral, rural) by adopting a polycentric model aimed at limiting settlement dispersion (sprawl) and land consumption;
- an integration of urban, peri-urban and rural spaces to effectively address issues related to the climate crisis and multi-risk conditions, by implementing both diffuse actions on an urban scale and territorialised actions such as the creation of collective transport infrastructures and the formation of ecodistricts.

In urban regeneration strategies for cities, the theme of ecodistricts is central. Their realisation in fact allows for an effective integration of many aspects characterising urban life. Regeneration processes within urban districts allow for the qualification or construction of not only buildings but also community and neighbourhood services, fostering sustainable living. An ecodistrict can become a catalyst for more extensive regeneration processes of significant parts of the consolidated city, and particularly its suburbs, leading to numerous environmental, economic and social benefits.

The concept of Eco-District signifies a transformation process integrating sustainable development goals and social equity, reducing the ecological footprint of neighbourhoods, areas, or regions with a multi-scalar and multi-disciplinary approach. Usually, the term "Eco District" denotes urban planning processes aiming to integrate sustainable development objectives and reduce ecological footprints, focusing on energy, environment, and social life (Tucci & Baiani, 2020).

In 2011, the Portland Sustainable Institute defined Eco-Districts as neighbourhoods committed to sustainability, featuring empowered people, green buildings, and smart infrastructure. These districts aim to accelerate sustainable development at the neighbourhood scale by integrating building and infrastructure projects with community and individual actions. They offer a significant scale to test and integrate neighbourhood-based solutions urgently needed by cities and bridge the gap between people's needs and how places are designed (Portland Sustainability Institute, 2012).

The experience of the new eco-districts – constructed in the Scandinavian countries and the United Kingdom, as well as in Germany, France and the Netherlands and other European countries - is mostly located in vacant areas or in areas that are abandoned or underutilized (brownfields) as a response to urban sprawl through rational and compact settlements, characterized by diverse typological, functional, and spatial mixes for the growth of contemporary cities through large urban parts. The goal of these design processes is to provide solutions that can represent a model for the future development of urban settlements through urban regeneration strategies and the construction of new city districts, implementing significant innovations in the field of construction processes, urban design, and building technologies (Losasso & D'Ambrosio, 2012).

These interventions reflect the strategic guidelines of the European Union towards neighbourhood-scale redevelopment strategies aimed at adaptation and mitigation, employing innovative technologies, smart infrastructure, and renewable energies to create sustainable, resilient, and inclusive neighbourhoods. This leads to an elevation of standards for sustainable development that, starting from the neighbourhood, can be extended to the entire city (Fitzgerald & Lenhart, 2016). Additionally, decisive responses are provided regarding the issue of the city-centre/periphery relationship, starting from the assumption that the issue of peripheral marginality concerns neither the physical distance from the city centre nor the limited repertoire of morphological and material elements.

The common feature characterizing the Northern European experiences can be found in the intention of public commissions to address the issue of urban growth by correlating the principles of sustainability with the conception of urban parts capable of constituting more credible models for contemporary cities. Eco-districts represent parts of the urban settlements capable of economically and energetically self-sustaining themselves, equipped with services and facilities through which the overcoming of the centre-periphery dichotomy is evident. The proposal of new housing realities has been sought both in terms of functional and strategic aspects and in the hierarchical relations between layouts, urban elements, buildings, infrastructures, and public spaces. The programmatic choice has been made to have functional mixes and building typologies with mixed residential, commercial, and leisure buildings and a constant search for plurality and diversification of the built environment, with a proportion of buildings of experimental value and high-quality architecture. Innovative value is returned both in terms of technical-constructional aspects and based on functional and typological mixity. Examples include the Bo01 district in Malmö or Hammarby Sjöstad in Stockholm.


Figure 4. Hammarby and Bo01 eco-districts. Source image: Wikimedia Commons.

The offer of social housing has been oriented towards common distinctive elements such as morphological and spatial quality, environmental sustainability, energy performance, the conception of 'smart' buildings, cost containment and control, and experimentation linked to technological innovation. In the development of the eco-district, usually, a close relationship is established between the new urban parts and the design of the transport infrastructure network, a strategic field in urban regeneration.

Green spaces and urban parks are, also, distinctive elements of the eco-district design strategies that contribute to improving perceptual, microclimatic, and acoustic comfort conditions, such as Clichy Batignolles in Paris. In the completed district in Europe the identification of forms of aggregation and spatial organization both between dwellings and neighbourhood spaces and between layouts and urban fabrics has constituted a response to the renewed objectives of social housing to be better integrated into new urban realities, favouring mix and social inclusion among new differentiated users.

Building sustainability strategies identify an urban scalability that starts from large systems of spaces, functions, and infrastructures up to solutions implemented at the scale of buildings with environmental branding, use of renewable energy sources, local productivity, water purification and recycling, and waste separation.

To reduce impacts of climate risk – as in HafenCity in Hamburg - principles of environmental design and technological solutions have been implemented aimed at energy performance and meeting well-being conditions through the optimization of openings for natural lighting and ventilation have been adopted. Attention to the small water cycle - through collection systems, filtration and phytodepuration, permeable surfaces, rain gardens, and green facades and roofs - has allowed to counteract the effects of summer overheating. The rational use of water resources has been particularly important in many contexts for environmental rebalancing through local reuse of rainwater, both by recycling it and by channelling it with appropriate technical solutions to collection tanks and water bodies.

Due to the recent energy crisis, the theme of energy performance is, nowadays, increasingly related to energy self-sufficiency and the reduction of consumption. This is also relevant for the share of social housing interventions, in order not to register costs that weigh on users with low economic availability, thus countering the rising fuel poverty throughout

Europe. The theme of almost total coverage of energy needs is related to programs for integrated use of multiple renewable energy sources, with extensive use of biomass, biogas, and geothermal energy.

A common feature of the different experiences of urban eco-districts implemented in Europe is the close relationship between urban regeneration policies and the establishment of new models of economic, social and environmental development at the urban and building scale. For example, the Le Albere project in Trento was born as a response to the closure of the Michelin factory. The objective is to regenerate the urban context on a larger scale than that of the settlement by associating new residences with important cultural services and management activities (Botti et al., 2014).

Eco district planning therefore prioritises strategies, actions and design interventions aimed to minimizing resource consumption, promoting renewable energy use, and fostering community well-being. From the constructed experiences in Europe, it is possible to identify some key defining features, such as, for example:

- the implementation of green infrastructures by integrating into the planning process green spaces like parks, community gardens and green roofs to enhance biodiversity, mitigate the impact of extreme heat phenomena and aid in stormwater management and carbon sequestration; the construction of energy - efficient buildings, incorporating features like high-performance insulation and renewable energy sources to meet the new legislative standards;
- a great care for resource management, including waste reduction programs or water conservation measures also using innovative technologies for greywater recycling;
- a mixed-use development with the integration of residential, commercial, and recreational spaces to encourage active transportation modes and fosters a vibrant urban environment;
- a focus on community engagement so that residents, businesses, and local stakeholders can participate in collaborative decision-making processes to ensure development priorities align with community needs.

In conclusion, eco-districts can represent emerging housing models to face the current multi-risk conditions with a holistic approach to urban development, where environmental, social, and economic objectives converge to create thriving and resilient communities. They can be identified as possible integrated frameworks toward urban regeneration and resilience linked to environmental, social and governance levels (Poli et al, 2022).

In the following section, we provide an analysis of three urban eco-districts in the European context. To better understand the interconnection between the transition towards eco-district and risk mitigation in urban and metropolitan settlement, we choose to provide an analysis of their component through the risk-oriented urban taxonomy developed in Task 2.2 “Integrated physical and socio-ecological exposure to multiple hazards” and further adopted in DV 2.2 “Multi-criteria metrics and methodology for integrated exposure assessment” and DV 3.3 . Such taxonomy (Fig. 3) refers to the physical system of urban settlements, according to the requirements and guidelines of the National Strategy for Adaptation to Climate Change (MASE, 2015) and the National Plan for Adaptation to Climate Change (MASE, 2023), SNAC and PNACC, respectively. The defining aspects, approaches to knowledge and diversity of impacts to which the urban environment is exposed were outlined in the Report on the State of Scientific Knowledge on Impacts, Vulnerability and Adaptation to Climate Change in Italy developed by the Ministry of Environment and Energy Security in 2014 (MATTM, 2014) and subsequently adopted by PNACC. Taking into account the complex interactions between the natural environment and the anthropized systems in urban settlements, the taxonomy aims to provide a tool to support knowledge and climate-proof design through the definition of elements that are potentially receptors for risk reduction interventions as a function of improved behavior in both ecological and systemic terms and coherent with minimizing resource consumption, promoting renewable energy use, and fostering community well-being as eco-district defining features.

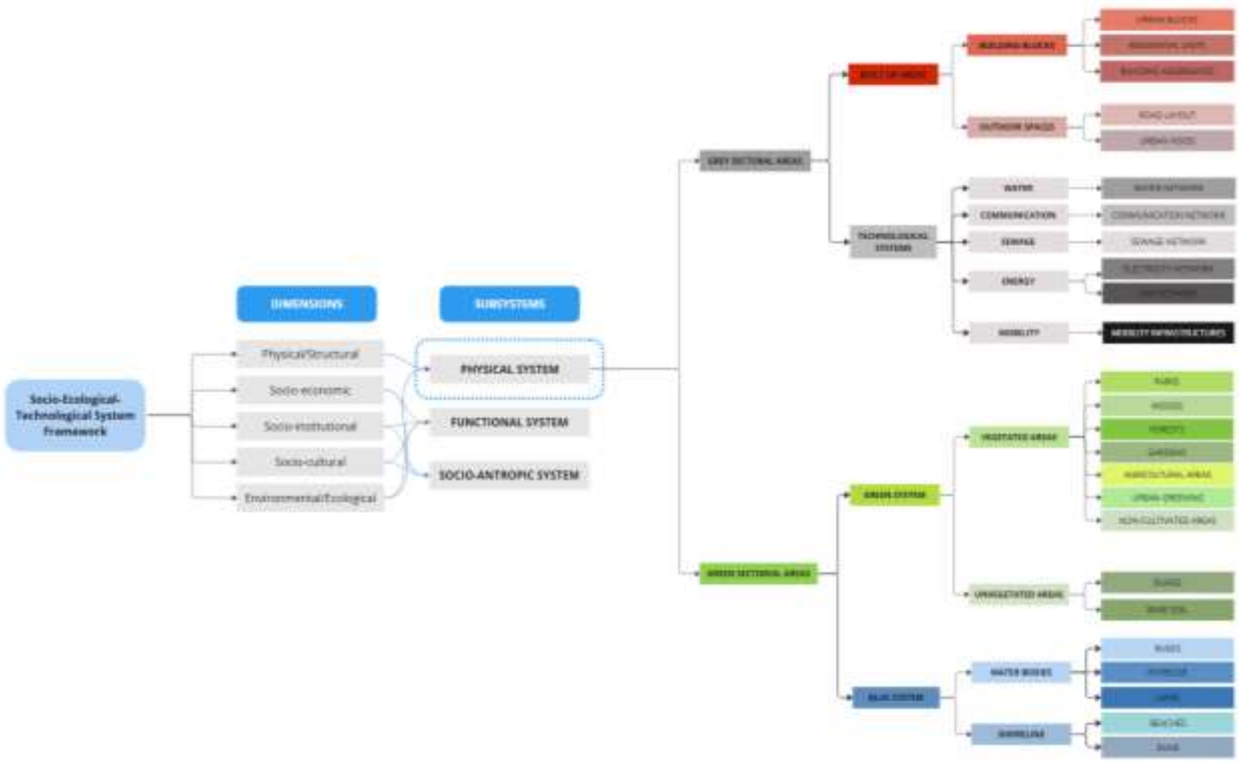


Figure 5. Urban settlements taxonomy regarding physical system as developed in Task 2.2 and further refined in DV5.3.3.

As reported in DV 2.2, the taxonomy incorporates the classification into sectoral domains of the physical system (Grey and Green) proposed by the PNACC. The Grey sectoral domain has been decomposed into the system of built-up areas, which includes building blocks (courtyard blocks, residential units and aggregates) and paved open spaces (squares, urban voids, routes), and technological systems (water, communication, sewage, energy, mobility). The Green sectoral area consists of systems with natural features within the physical system (Green and Blue), capable of contributing to providing an adaptation response to climate change. The Green system consists of Vegetated areas (woods, forests, parks, gardens, agricultural areas, urban greening, non-cultivated areas, green-blue infrastructures) and unvegetated areas (non-cultivated areas and bare soil); the Blue system, of Water bodies (rivers, riverside, lakes) and Shoreline (beaches and dunes). The ecologically active condition of an element was thus assumed to be the discriminating factor between the Grey and Green sectoral domains.

The analysis sheets are structured as follows: an anagraphic of the project (authors, location, year of construction), a brief general description, the analysis through the risk-oriented urban taxonomy and a section devoted to the identification of the main technological solutions for risk mitigation, followed by keywords, references and authors.

Table 2.1 Eco-district 1

CLICHY BATIGNOLLES	
AUTHOR	
François Grether, Jacqueline Osty e OGI (Open General Eng.)	
LOCATION	**YEAR**
Chalon-Sur_Saone, Paris	2001 - 2015
ECO-DISTRICT DESCRIPTION	

The 'Clichy Batignolles' eco-district is developed in the area adjacent to the Batignolles railway line in the north-west of the city of Paris, in the 17th arrondissement, and the area covers approximately 54 hectares.

(a)

(b)

Image: (a) Chichy Batignolles plan, (Gausa & Raveau, 2020); (b) Google Maps view

The urbanisation of Clichy Batignolles neighborhood began in the 19th century with the first railway line in Paris, but underwent a slow decline from the 1970s that led to its abandonment up to the 2000s. In these years the mayor of Paris launched a project to rehabilitate and reconvert the area, in cooperation with the railway transport companies that owned the area.
The regeneration project began with an initial phase tied to the proposal to use the site as the Olympic Village for Paris's attempt to host the 2012 Olympics. Even though the games did not take place there, this was an opportunity to redevelop this area, whose recovery and conversion became an opportunity to create a neighborhood where the goals of climate balance meet those of

social and functional redistribution. Moreover, the District is included in the Paris Climate Plan with the aim of creating a high-density, sustainable settlement with high levels of environmental performance.

The main objectives of the project are: urban structure, as the neighborhood is located straddling two railway lines; the implementation of green areas; functional variety and a plurality of building types; encourage sustainable mobility; energy savings; improve biodiversity; implement water-saving systems and climate impact reduction.
One of the key principles of the project is to reconnect the two areas physically separated by the railway tracks, thus is developed creating a large park as a reconnecting element that would act both as a natural infrastructure supporting biodiversity and as a key element to for the heat island phenomenon reduction. The realization of the park allowed for the development of 27 building plots closely connected to the green system and increased the social and generational mixité.

Source image: Wikimedia commos
Clichy Batignolles, thanks to the Martin Luther King park designed by the landscape architect Osty, is part of a green network consisting of Parc Monceau, Bois de Boulogne and the cemeteries of Montmartre. This constitutes a great resource for the maintenance of biodiversity also implemented through urban greenery and green roofs. In fact, in addition to the 10 hectares of parkland, there will also be 16,000 square meters of green roofs and 6,500 square meters of private green spaces whose species are chosen according to their ecological characteristics and management.

Source image: Wikimedia commos
These adaptation and mitigation strategies and actions also make it possible to reduce impacts due to the risk of saturation of the sewerage system and consequent pollution of the Seine by reducing the amount of rainwater discharged by 50% of which part of the recovered water is used for the maintenance of green spaces at the building scale and of the entire neighborhood. The aims of the project include meeting the requirements of architectural quality, high technological and environmental performance, and ensuring the psycho-physical well-being of the individual and thermo-hygrometric comfort.
According to the Paris Climate Plan, the buildings in Clichy-Batignolles must meet particularly low energy consumption standards. Therefore, high-performance envelopes, passive systems optimizing natural ventilation, and renewable energy sources such as geothermal heating and hot water, and photovoltaic panels for lighting, as well as integrated systems for heat recovery, are used. Those solutions, in conjunction with rainwater harvesting and the promotion of sustainable travel, reduce energy consumption and mitigate the effects of climate change by reducing CO_2 emissions.
Another objective in the Clichy Batignolles project is the discouragement of private car use in favor of sustainable mobility. This includes the insertion of bicycle paths and wide pavements that allow connection to the transversal pedestrian paths in the park, new bicycle rental stations, and only the 2.25% of the total area of the district is allocated to car-parking. In addition, the accessibility of the eco-district is implemented with the extension of the tram network and the extension of metro line 14.

Source image: Wikimedia commos

An example of how technological innovation has been incorporated into the neighbourhood is the Cardinet-Quintessense building by Pèriphèriques Architects. The building, comprising 97 dwellings and 20 social housing flats, is sustainable and zero-emission, with integrated photovoltaic panels and an innovative design that, together with the internal courtyard, reduces heat loss and allows natural light to enter the flats through double exposure.

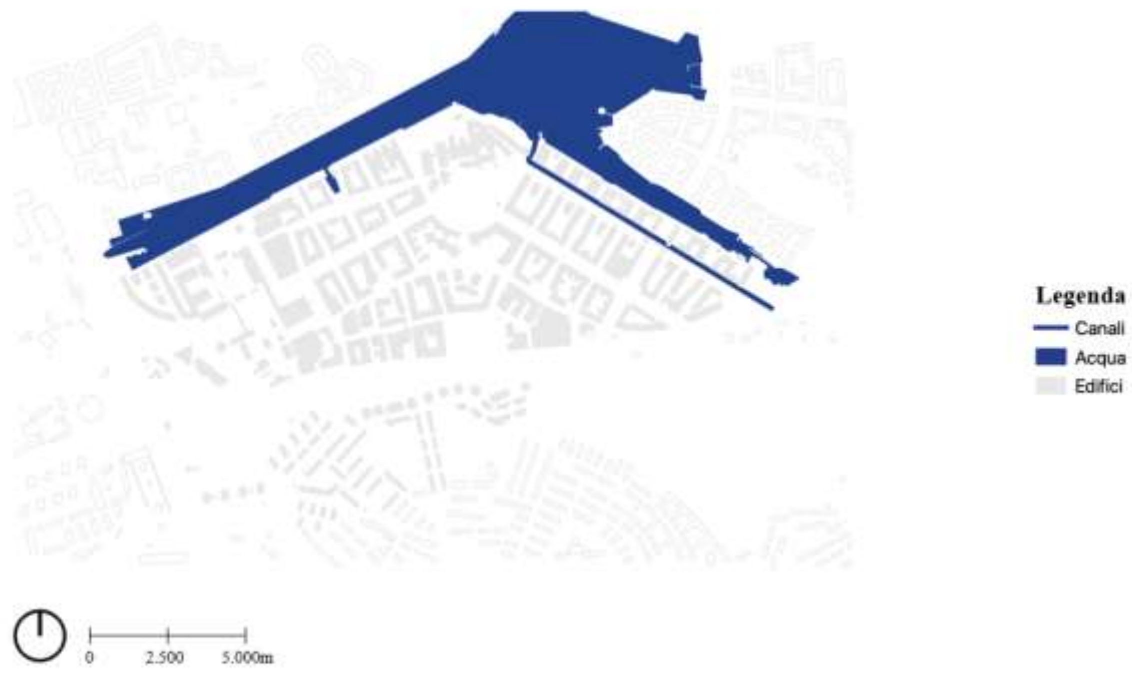
LINK URBAN TAXONOMY

Below: example of first approach for taxonomic reading of the Clichy Batignolle eco-district, Paris, created starting from 2002 by the planner Grether.

1. Settlement system

2. Tracks and infrastructure

3. Water system



4. Green system

7. Synthesis Analysis

TECHNOLOGICAL SOLUTIONS

- Infiltration and Transport-sewer
- Porous pavements
- Rainwater tanks
- Green roofs (extensive)
- Solar water-heat pump
- Artificial urban wetlands
- Reduced paved surfaces
- Use of treated wastewater
- Optimize orientation to wind and sun
- Use of groundwater (aquifer storage and recovery)
- Deep groundwater infiltration
- Use of native species

KEYWORDS
Sustainability, Sustainable mobility, Energy efficiency, Biodiversity, Social integration
REFERENCES
Fabrizio Tucci (2018), Costruire e abitare green. Approcci, Strategie, Sperimentazioni per una Progettazione Tecnologica Ambientale. Gausa, M., & Raveau, F. (2020). Good Vibrations: Clichy Batignolles: Lot E8 & Parc 1. Actar D, Inc.. Antonietta Piemontese (2013), Insediamenti Ecosostenibili Vivibilità e Innovazioni. Cfr: https://www.climateapp.nl/ (accessed December 2024)
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Table 2.2 Eco-district 2

ASPERN	
AUTHOR	
Mischek Systembau GmbH, Tovatt Architects and Planners	
LOCATION	**YEAR**
Vienna	2013 – in progress
ECO-DISTRICT DESCRIPTION	

The ‘Aspern’ eco-district project is located in Vienna's 22nd district, the Donaustadt, about 10 km north-east of Vienna's city centre, covering 240 hectares in an area formerly occupied by Aspern Airport, which was decommissioned in the 1980s and subsequently demolished in the 2000s.

(a)

(b)

Image: (a) Aspern eco-distrcit, (source image: www.aspern-seestadt.at); (b) Google Maps view

After the expansion of the European Union in 2004, the city of Vienna proposed to develop an independent district in the area of the former airport and began a process of collecting ideas and citizen participation. In 2005, an international competition for the design of the new autonomous settlement of 20,000 inhabitants was launched. It was won by the Swedish architectural firm Tovatt Architects & Planners, in collaboration with the German firm N+ Objektmanagement, and finally approved in 2007.
It represents one of the largest urban development projects in Europe and is divided into three phases:

1. the first phase involves the construction of the south-western part;
2. the second phase includes the construction of a junction to Aspern North station;
3. the third phase envisages the completion of the northern part of the district.

The Aspern district is based on technical innovation and climate resilience. Fifty per cent of the total area is devoted to open spaces that are designed with climate change measures in mind. The settlement is structured in such a way as to achieve social and functional mixity, where a neighbourhood social life is recreated, recreating a town-village character.

The district stands on a former airfield and the entire project enters into the logic of the circular economy, where any waste material will be reused and fed back into the production process, e.g. concrete from runways will be reused for road construction. As far as new buildings are concerned, in Aspern, the HoHo Wien, the second tallest wooden building in the world, stands out. The structure is composed of 75 per cent sustainably sourced wood from Austrian forests and the building will house residential and commercial units.

The construction process of the eco-district is subject to the criteria set by the Urban Lab of the Smart City Wien, while the residential construction meets the high Total Quality Building standards. Buildings will be connected with the aim of realising a Smart City based on the use of renewable energy sources. Siemens will play a key role in this endeavour, realising smart buildings that will no longer be seen as passive consumption structures, but as structures that can participate in the energy market, generating and accounting for energy. Thus, the district will have solar panels and heat pumps that convey energy to an electrical and thermal storage system.
The new plan is characterised by the green heart (Grüne Mitte) in which there is a large artificial lake of 50,000 m2, the green will be surrounded by a new Ringstrasse (Sonnenallee - Sun Avenue). The central park and the lake are the most interesting elements and are made possible by the hydrogeological nature of the Danube area, rich in ponds and basins fed by the natural water table.

The urban structure is designed to be completely pedestrian-friendly, subdivided into various district with squares and pedestrian zones, which are clearly outnumbered by streets where cars are allowed to circulate. Car traffic is in fact directed towards the Sonnenallee, the street surrounding the district, so that cars are left outside the district. In addition to the main traffic axis, there are also main axes for pedestrians: the Rote Saite, the shopping street, the Blaue Saite, the street along the lake, and the Grüne Saite, the green corridor.

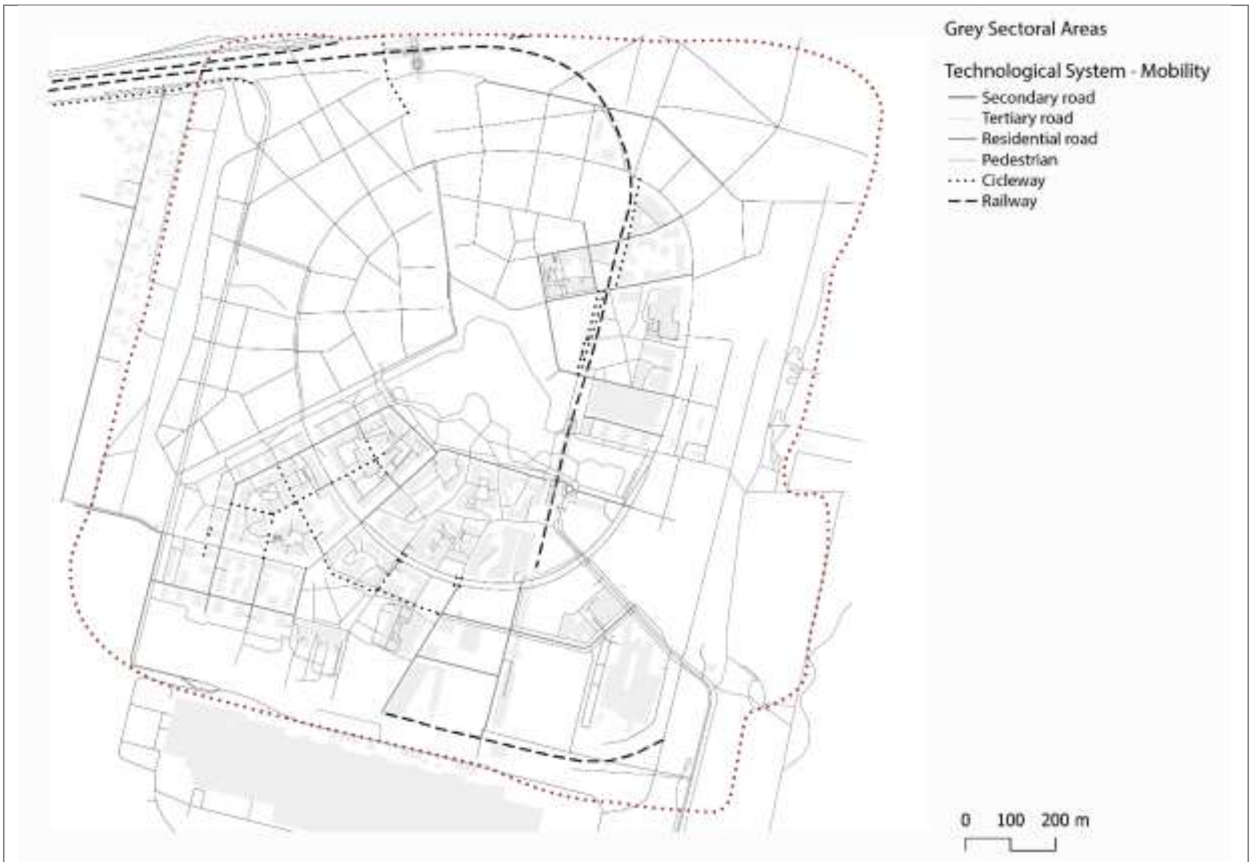
Image 2: aerial view (Eliason, M. (2024)

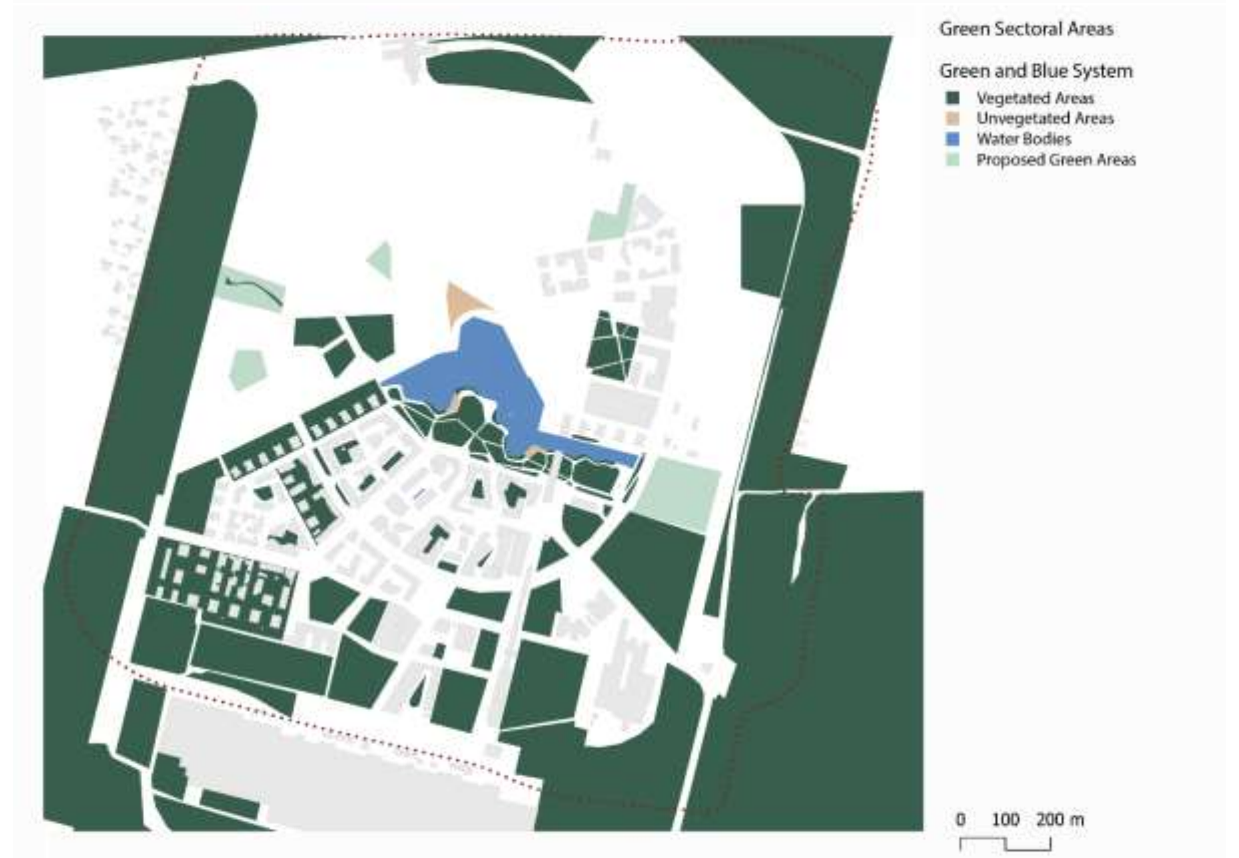
The design of the greenery and public space has changed over time. In fact, the first design included large paved areas that were transformed in 2022 following the design and construction of the pedestrian zone with 1,000 m2 of perennial flower beds, 25 new trees and water features.
Regarding rainwater management, the Viennese ‘Sponge City’ double infiltration model is followed, i.e. a rainwater retention system to irrigate the trees and improve the urban microclimate. In this case, however, the model is extended to an entire district for the first time, covering two thirds of the total area.

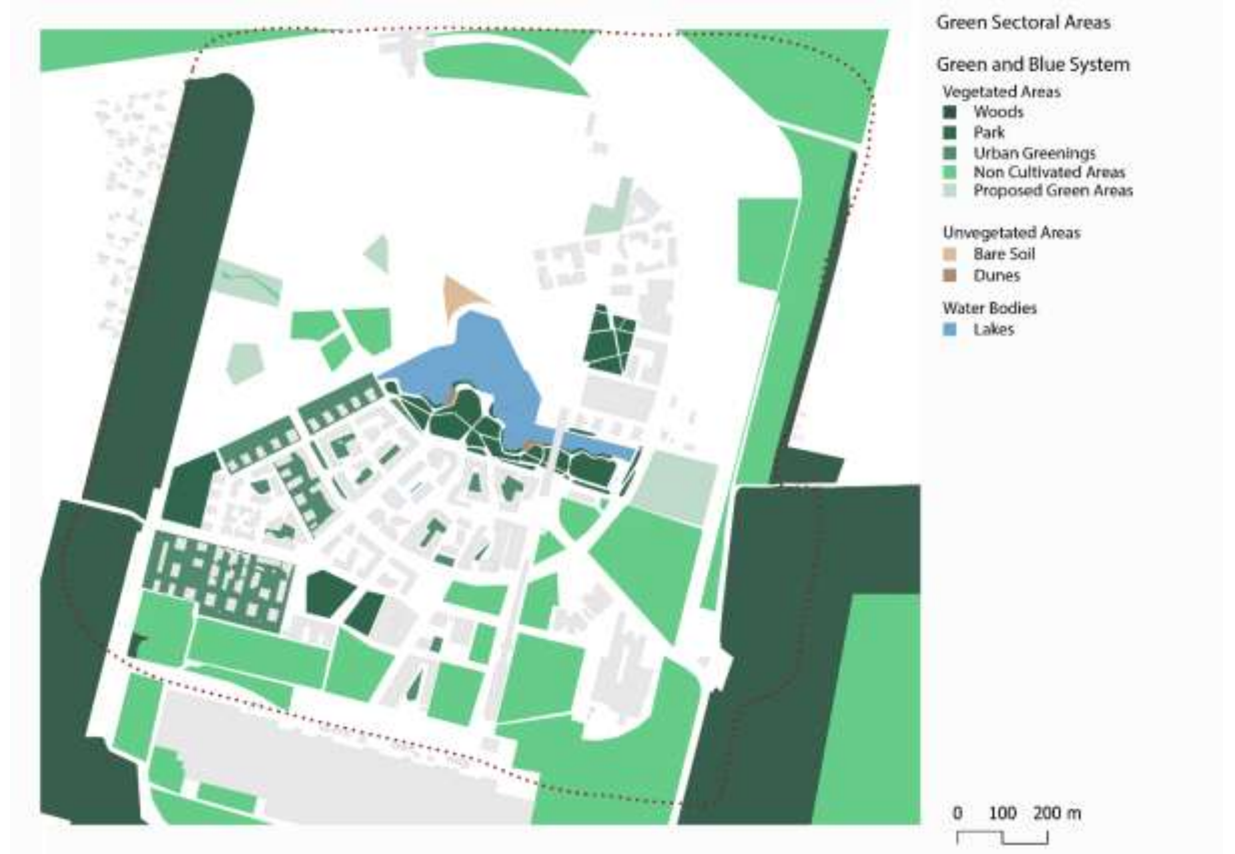
LINK URBAN TAXONOMY

Example of a first approach for taxonomic reading of the Aspern eco-district


0 100 200 m
Grey Sectoral Areas
Built Up Areas
Residential Buildings
Specialistic Buildings
Urban Voids
Proposed Construction Sites
0 100 200 m


Grey Sectoral Areas
Technological System - Mobility
Secondary road
Tertiary road
Residential road
Pedestrian
Cicleway
Railway
0 100 200 m


Green Sectoral Areas
Green and Blue System
Vegetated Areas
Unvegetated Areas
Water Bodies
Proposed Green Areas
0 100 200 m



TECHNOLOGICAL SOLUTIONS

- Optimize orientation to wind and sun
- Infiltration and Transport-sewer
- Porous pavements
- Cooling with water elements (e.g. fountains and ponds)
- Shallow infiltration measures
- Green roofs (extensive)
- Solar water-heat pump
- Artificial urban wetlands
- Reduced paved surfaces

KEYWORDS

Sustainability, Innovation, Resource management, ReSustainability, Innovation, Resource management, Reuse of materials, Climate resilience

REFERENCES

Eliason, M. (2024). Building for people: designing livable, affordable, low-carbon communities. Island Press.
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Antonietta Piemontese (2013), Insediamenti Ecosostenibili Vivibilità e Innovazioni.
Cfr: https://www.climateapp.nl/ (accessed December 2024)

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Table 2.3 Eco-district 3:

VAUBAN	
AUTHOR	
Common Gies	
LOCATION	**YEAR**
Friburgo	1996 - 2006
ECO-DISTRICT DESCRIPTION	

The ‘Vauban’ eco-district is located in a southern suburban area 2 km from the centre of Freiburg, formerly occupied by a military barracks.

Image: Vauban, Google maps view

In the early 1990s, the city of Freiburg underwent a population increase that was unsustainable for the medieval city and thus arose the need to plan a series of satellite settlements around the historic city core, connected to it by a new tram network. Between 1992 and 1996, part of the military barracks was occupied by autonomous communities of young environmentalists who initiated experimental practices of sustainable living, which gave rise to the new Vauban district.
The municipality decided to redevelop this area through a project implemented according to experimental living practices that are declined through an integrated approach involving social, technological and environmental aspects based on four fundamental principles:

1. mobility,
2. energy,
3. green,
4. water resources

The Vauban eco-district is an area characterised by a very dense urban fabric, with a predominance of residential buildings, followed by commercial and specialised facilities, and is characterised by the mixed use of buildings, which house residences, offices, shops and integrated public spaces. This arrangement reduces the need for long journeys, encouraging pedestrian mobility and the use of the public transport network, which increases accessibility and reduces the use of private vehicles, promoting sustainable mobility.
The eco-district is home to about 5,700 residents, most of whom live in low-energy dwellings with a specific heat demand of about 50-60 kWh per square metre per year. In addition, there are about 300 housing units where various experiments of active and passive energy technologies (passive, zero-energy and positive-energy houses) have been implemented that contribute to the achievement of climate adaptation and mitigation goals, as well as emission reduction.
Most of the energy is produced by a high-efficiency cogeneration plant, which is fuelled by 80 per cent wood chips and 20 per cent natural gas. This plant distributes the heat needed to heat the entire air and contributes 30% of the electricity requirements, and is supported by solar panels, also used as solar shading systems, which cover 450 m2 and contribute to the production of hot water.

Source image: Wikimedia commons

From the point of view of the green system, the district is an area characterised by extensive green coverage, both at the block, neighbourhood and forest scale. Green spaces between dwellings contribute to improving the microclimate, providing play areas for children and promoting the well-being of residents. As the project progressed, new public green spaces dedicated to play and recreation were created, designed with the participation of the residents and used as fundamental social and environmental recreational spaces. The care of the green spaces is in fact entrusted to the residents, thus developing responsibility and a sense of community.

Source image: Wikimedia commons

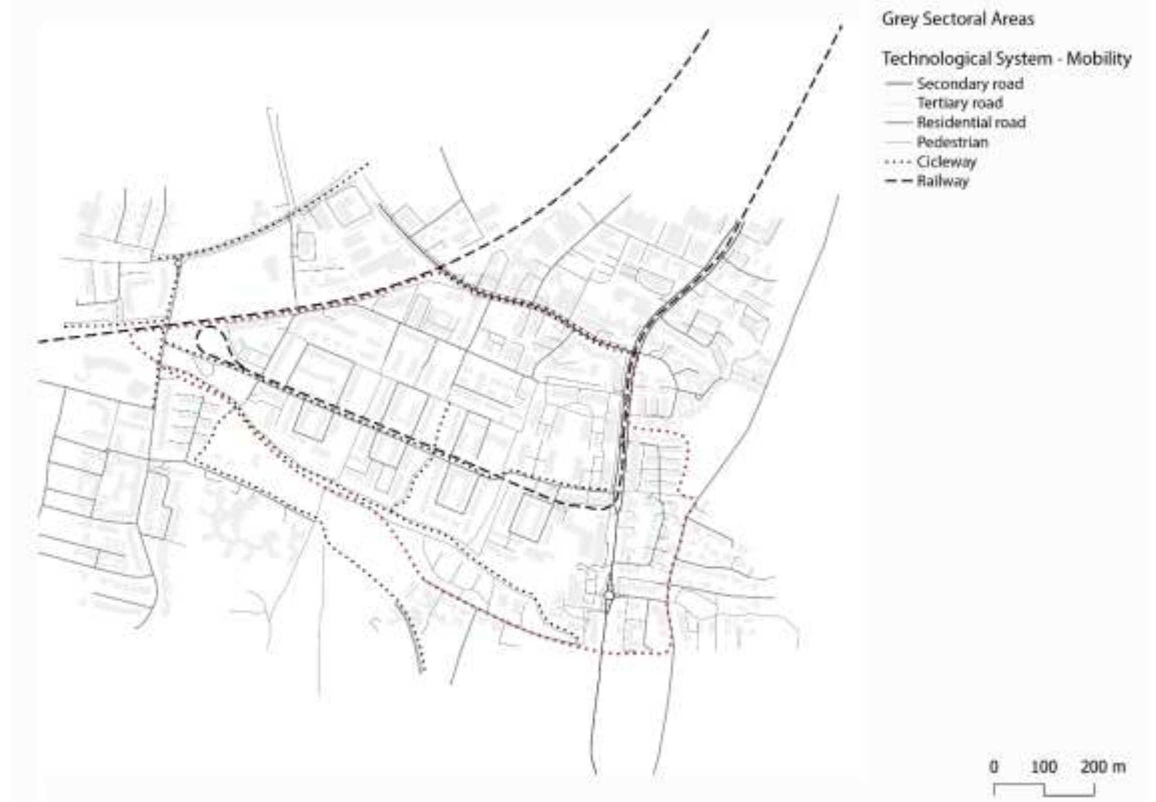
In addition, the increase in permeable surfaces was also achieved through the installation of flat green roofs, built to retain and collect rainwater, thus improving the efficiency of rainfall water management, which is combined with a ground system that allows the recovery and collection of rainwater, reducing the risk of flooding.

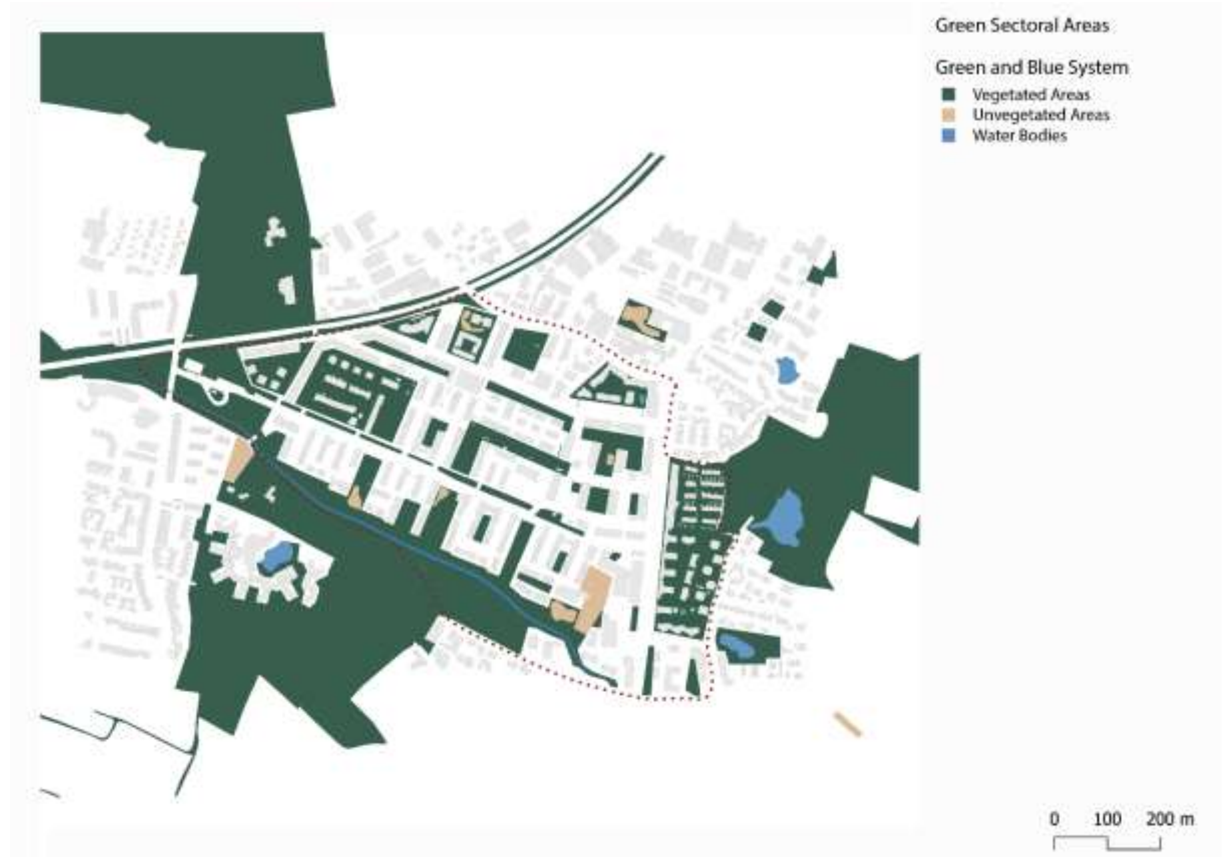
LINK URBAN TAXONOMY

Example of a first approach for taxonomic reading of the Vauban eco-district


Grey Sectoral Areas
Built Up Areas
0 100 200 m


Grey Sectoral Areas
Built Up Areas
Residential Buildings
Specialistic Buildings
Urban Voids
0 100 200 m


Grey Sectoral Areas
Technological System - Mobility
Secondary road
Tertiary road
Residential road
Pedestrian
Cicleway
Railway
0 100 200 m


Green Sectoral Areas
Green and Blue System
Vegetated Areas
Unvegetated Areas
Water Bodies
0 100 200 m

TECHNOLOGICAL SOLUTIONS
- Ditches - Infiltration and Transport-sewer - Porous pavements - Green facades - Rainwater tanks - Green roofs (extensive) - Solar water-heat pump - Artificial urban wetlands - Reduced paved surfaces - Use of treated wastewater - Optimize orientation to wind and sun - Network of waterways - Use of native species
KEYWORDS
Social and environmental sustainability, Participation, Sustainable mobility, Water management, Energy efficiency
REFERENCES
Fabrizio Tucci (2018), Costruire e abitare green. Approcci, Strategie, Sperimentazioni per una Progettazione Tecnologica Ambientale. Antonietta Piemontese (2013), Insediamenti Ecosostenibili Vivibilità e Innovazioni. Cfr: https://www.climateapp.nl/ (accessed December 2024)
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2.2 The New European Bauhaus

The New European Bauhaus (NEB) is a transformative initiative launched in 2020 by the European Commission as part of a broader effort to make the European Green Deal a lived and tangible reality. It introduces a novel and holistic approach to shaping sustainable futures by connecting the Green Deal's climate and environmental ambitions with culture, design, everyday life, and collective imagination (Bilić & Šmit, 2024; Lourenço et al., 2024; Lygnerud et al., 2023). The NEB is not simply a policy instrument, but a cross-sectoral movement—an ecological, economic, and cultural project that brings sustainability closer to people by embedding it in the spaces they inhabit, the products they use, and the experiences they value (Rosado-García et al., 2021).

At the core of the NEB lie three interdependent principles: Sustainability, Aesthetics, and Inclusivity. These principles serve as a framework for reimagining the way we build and live, advocating for a future where climate neutrality and circular economy goals are pursued alongside artistic expression, sensory quality, and social justice. Rather than treating sustainability as a purely technical goal, the NEB encourages its integration with art, design, architecture, and cultural identity, aiming to create environments that are not only efficient but also beautiful, meaningful, and accessible to all.

This initiative introduces a shift in urban development and architectural thinking—away from siloed, top-down planning models and toward participatory, place-based, and regenerative approaches. It envisions built environments that go beyond functionality to foster well-being, creativity, and emotional connection, thereby enhancing the quality of life of residents while contributing to climate resilience and biodiversity.

The NEB places strong emphasis on co-creation and democratic innovation. It promotes the involvement of citizens, scientists, designers, cultural actors, businesses, and institutions in a shared process of imagining and implementing sustainable futures. Through participatory methods such as workshops, design sprints, public consultations, and artistic installations, NEB initiatives strive to empower local communities and reflect the diverse values, identities, and aspirations of people. This inclusive approach helps overcome resistance to change, enhances legitimacy, and supports long-term behavioural and structural transformation (Lygnerud et al., 2023; Lourenço et al., 2024).

A central conceptual anchor of the NEB is the notion of "Living Spaces"—spaces that are physically and symbolically shaped to foster a strong sense of belonging, equity, and ecological balance. These include housing, public spaces, and neighbourhoods, but also infrastructures of care, mobility, learning, and production. Within this perspective, urban environments are not just containers of human activity but dynamic ecosystems that support regeneration, climate adaptation, intergenerational dialogue, and intercultural exchange.

The initiative also encourages experimental and interdisciplinary practices that bridge design thinking with environmental science, urban planning, heritage conservation, and social innovation. It supports pilot projects and demonstrators that exemplify how circular materials, bioclimatic design, and local cultural identity can be woven together into integrated and scalable solutions.

2.2.1 Key concepts

The Key Concepts of the New European Bauhaus are structured around its core values, principles and thematic axes of action.

The NEB is built upon three fundamental and equally important core values: Attractiveness (Beauty), Sustainability, and Inclusivity (Lourenço et al., 2024; Mazzucco et al., 2024; Woźniczka, 2023).

- **Beauty (Beautiful Principle):** This value stresses the quality of the experience and style beyond mere functionality, aiming for spaces that improve people's physical and psychological well-being and are comfortable, meeting users' needs (Mazzucco et al., 2024). It goes beyond traditional aesthetics to include sensory perception of space, tangible and non-tangible elements of context, and the preservation of cultural and natural heritage. The concept of "genius loci" (the spirit of a place) is emphasized, ensuring new developments respect existing urban fabric and preserve heritage value (Lourenço et al., 2024). NEB promotes solutions that go hand-in-hand with EU policies, consciously pursuing beauty as an explicit objective of place-making, planning, or building. This includes addressing:
    - Sensory perception of space: Recognizing that beauty is influenced by a holistic sensory experience, not just visual (Lourenço et al., 2024).

    - Cultural and natural heritage preservation: Enhancing or preserving built heritage, considering the sense of place and characteristics of the natural and cultural landscape. The NEB self-assessment method evaluates efforts in historical fabric preservation and improved preservation of cultural/natural heritage in renovated buildings (Lourenço et al., 2024).
    - Aesthetic perception of buildings and spaces: Assessed through comparison to actual styles and tendencies in art and architecture, considering features that provide a positive visual and aesthetic experience. It specifically focuses on "cognitive experience", which relates to the semantic, symbolic and imaginative aspects of aesthetic experience. The self-assessment tool identifies the most used "style" in a new building project from four contemporary styles: Eco-architecture, Contemporary modernism, Deconstructivism, and Regionalism, evaluating how well the basic features of that style are applied (Lourenço et al., 2024).
- **Sustainability (Sustainable Principle):** This is a broad concept encompassing climate goals, circularity, zero pollution, and biodiversity. It emphasizes (Bilić & Šmit, 2024):
    - Reducing energy consumption and emissions: Focusing on buildings with very low energy demand, maximizing the share of renewables and integrating energy storage systems. The German Climate Protection Plan 2050 describes interim targets for "nearly climate-neutral buildings" (Bilić & Šmit, 2024; Eckart et al., 2022; Lourenço et al., 2024).
    - Circular economy: Promoting the repurposing, reuse, and regeneration of materials and buildings, reducing waste from construction and demolition activities (CDW). This includes prioritizing reconstruction over new construction, brownfield interventions, and extensive application of digital transition. For instance, research suggests that approximately 80% of buildings that will exist by 2050 have already been built, highlighting the importance of renovating existing stock to reduce carbon emissions .
    - Biodiversity protection and green infrastructure: Promoting ecological food, developing urban green corridors, greening cities, and combating urban heat islands (Bilić & Šmit, 2024; Eckart et al., 2022; Lourenço et al., 2024; Mazzucco et al., 2024).
    - Efficient use of scarce and renewable resources: Including sustainable water consumption and management (Lourenço et al., 2024).
- **Inclusivity (Together Principle):** This value fosters diversity, accessibility and affordability within communities (Bilić & Šmit, 2024; Lygnerud et al., 2023; Mazzucco et al., 2024). It aims to:
    - Increase equal access: Ensuring affordable, accessible and non-discriminatory access to suitable buildings and living spaces, upholding adequate services in neighborhoods, and promoting equal opportunities for all residents (Lourenço et al., 2024).
    - Enhance togetherness: Considering and removing potential barriers to access and use of resources and opportunities, and avoiding discrimination based on individual or social group characteristics (Lourenço et al., 2024).
    - Promote democratic participation and co-creation: Actively engaging relevant stakeholders, including citizens, experts, businesses, and institutions, in the collaborative creation of a sustainable, inclusive, and beautiful future (Lourenço et al., 2024; Rosado-García et al., 2021).

Beyond the core values, the NEB also affirms core working principles that guide its implementation:

- **Multi-level approach/engagement**: Emphasizing the need to involve citizens beyond the project scale itself, from local to regional, national, and international levels (Bilić & Šmit, 2024).
- **Interdisciplinary/ Transdisciplinarity approach:** Connecting the European Green Deal with everyday lives by fostering collaboration across science, technology, art and culture. This requires bridging gaps and bringing diverse expertise together (Bilić & Šmit, 2024).
- **Participatory approach:** Encouraging open, collaborative, and participative processes at the deliberation stage, enabling the active engagement of all relevant stakeholders in decision-making (Bilić & Šmit, 2024).

Finally the NEB concept highlights four thematic axes that direct the development of cities:

1. Reconnecting with nature ("Nature in the City"): Focuses on greening the city, developing urban green corridors, studying climate change phenomena in cities, and combating urban heat islands (Bilić & Šmit, 2024).
2. Regaining a sense of belonging to the community ("Connecting People"): Explores possibilities for creating stronger connections among residents and preventing the isolation of individual groups of citizens, aiming for a society without barriers (Bilić & Šmit, 2024).

3. Ensuring accessibility to public services and social facilities ("Affordability and Accessibility"): Examined through concepts like the "15-minute city," which analyzes the placement of public and social facilities to ensure they are within easy reach (Bilić & Šmit, 2024).
4. Long-term renewal of existing urban structures ("Circular Sustainability"): Evaluates topics related to the circular economy, material and building reuse, prioritizing reconstruction over new construction, brownfield interventions, and extensive application of digital transition. This promotes the idea that circular and sustainable design should become the standard (Bilić & Šmit, 2024).

2.3 Resilience of urban settlements in the framework of green transition

The origin of the concept of resilience dates back to the field of ecology and natural sciences, introduced by Holling in 1973. Initially conceived to explain the capacity of ecosystems to return to a state of equilibrium following a disturbance, the concept has subsequently found wide interest and application in various disciplines and sectors, with different approaches.
There are many meanings of the term in the literature, making it a transversal and flexible concept; however, there is no single definition that is valid and applicable in different fields. The lack of a standardised definition reflects the complexity of urban challenges and the need to address them in an integrated manner. Over time, there has been a growing interest in this notion as it takes the form of a 'boundary object' (Meerow et al., 2016) that spans across different spheres and research perspectives, facilitating coherence and collaboration (Baggio et al., 2015; Brand & Jax, 2007), with a view to creating an integrated perspective for urban governance. Cities are constantly exposed to a range of stresses and impacts, whether natural or human-caused, and face new pressures affecting all dimensions daily.

2.3.1 Urban Resilience under multi-risk scenarios

In the relationship between urban systems and climate change, resilience represents the capacity to respond to unforeseen climate impacts in terms of prevention, adaptation, reorganisation and system evolution. This capacity can be measured in terms of response towards minimising the impacts of intense and extreme climatic events, linking to spatial and functional environmental conditions, as well as to processual, governance or technical/constructive aspects, which require the implementation of strategies for prediction and prevention, adaptation to impacts, vulnerability reductions and the planning of mitigation measures.

Indeed, resilience studies focus on reducing system vulnerability as a measure of adaptation to climate change, and addressing climate impacts requires a systemic and integrated approach to urban and building design, necessitating the implementation of innovative processes capable of managing the complexity of urban settlements. Risk reduction cannot, in fact, be limited to the exclusive implementation of climate proof solutions, but the evolution and innovation of the approach becomes a necessity through the combination of ex-ante preventive actions with ex-post interventions (Farinòs-Dasi et al., 2024), referring to different time periods. Thus, the integration of climate adaptation and mitigation actions with respect to the four phases of Disaster Risk Management (DRM) is possible: preparedness, absorption, response/recovery and adaptation.

In particular, the framework of Disaster Risk Management (DRM) and its objectives has undergone a development that can be summarised in three phases:

- **Disaster Management (1990s)**: focuses on Disaster-centred approaches, where special attention is given to measures in the disaster preparedness and response phase.
- **Disaster Risk Management (2000s):** focuses mainly on risk-based approaches where prevention and reduction are considered more relevant phases than response. In particular, it is based on preventing new disaster risks, reducing existing risk and managing residual risk.
- **Resilience Management and Development (years 2010)**: focuses on improving the ability of a system to withstand, absorb, adapt, transform and recover from the effects of a hazard in a timely and efficient manner through the phases of risk management.

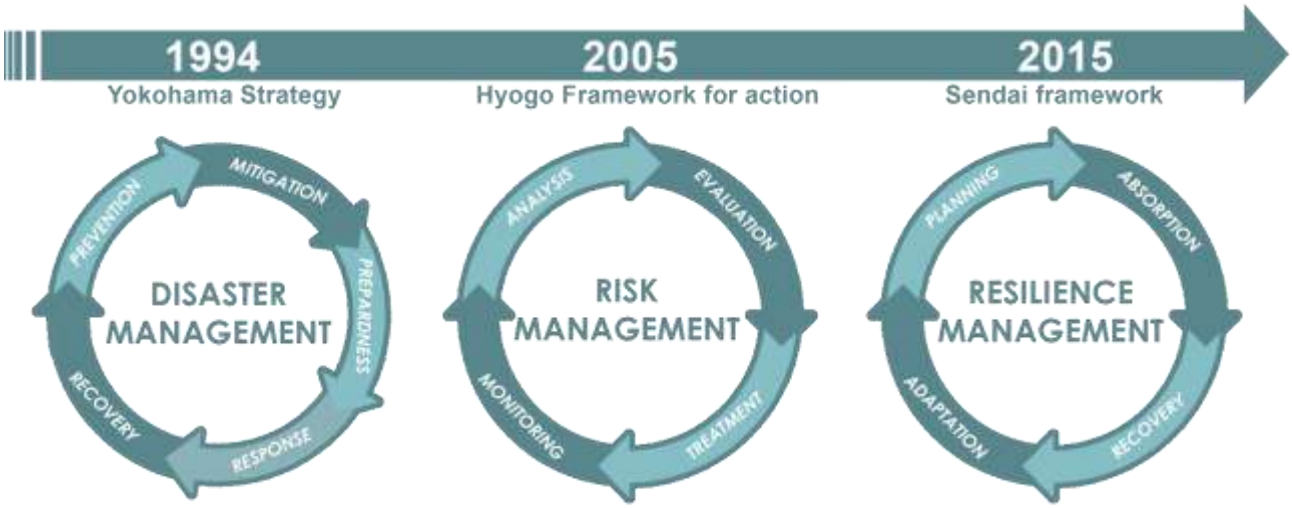

Figure 6. A comparison between disaster management, risk management, and resilience management. Adapted from Wen, J., et al, (2023)

The evolution and innovation of the approach becomes a necessity (Sawalha 2020) both for the contribution of new knowledge to disaster management and for mitigation and adaptation to future events. As a matter of fact the temporal dimension in verifying the effectiveness of design alternatives for the reduction of climate impacts acquires a fundamental role in the design at urban and building scale, in order to identify the most efficient and effective design solutions for the prevention and contrast of impacting phenomena.

Figure 7. The disaster management cycle in a resilient way. Adapted from: Linkov et al, (2014) and Wen, J., et al, (2023)

Where:

- **Time T_0:** before the impacting event occurs (prepare). Prevention and preparation strategies are considered, trying to identify the role of the strategies themselves within a long-term trajectory;
- **Time T_1:** during the disruptive event (absorb). This represents the ability of a system to remain unaffected. In this phase, the consequences of the disaster are identified and it is observed how the system reacts to the impact, whether its performance remains unchanged or an initial collapse phase occurs;
- **Time T_2:** later, after the disruptive event has occurred (recover/respond). This can be understood as the system's ability to recover and respond, which must be rapid and effective with the aim of minimising damage;
- **Time T_3:** later, after the disruptive event has occurred but at a longer time distance (adapt). It is observed whether the system has regained a state of equilibrium through an adaptive capacity to the impacts of the phenomenon.

The design solutions and their verification of effectiveness must necessarily be aimed at defining methodologies, procedures and operational tools to direct interventions on the urban system (Tucci, 2021) towards degrees of adaptation, mitigation and resilience in relation to the climate risk and temporal dimension and requiring continuous downscaling and upscaling actions (Losasso, 2017).
The identification of multi-risk measures and actions (e.g. compatible land use, green and blue infrastructure, envelope retrofits and structural building improvement interventions), need to be incorporated into design practices (D'Alencon, et al., 2020) with the aim of preparing, facilitating the response during the impacting event and then adaptively pursuing after it.

2.3.2 Review of existing protocols for urban resilience assessment and monitoring

The measurement of urban resilience is a very complex and often contentious issue, as defined in Heinzlef and Barroca's 2022 article, which shows that there is no universal definition of the term, but also that its measurement may vary according to context and specific objectives. In fact, the introduction of assessment protocols is crucial to provide an empirical basis for measuring urban resilience against multi-hazard contexts and climate change impacts, some examples are those proposed by various international organisations, governmental entities or research institutes, for example:

- City Resilience Index (CRI): This is a tool developed by the Global Resilience Partnership that provides an assessment of a city's resilience through 52 indicators covering six key dimensions: leadership and strategy, health and well-being, economy and society, infrastructure and environment, institutions and governance, and planning and design.
- Resilience Capacity Index (RCI): This was developed by the Organisation for Economic Cooperation and Development (OECD) and measures a city's ability to cope with and recover from shocks and stresses. It includes indicators on governance, risk management, social cohesion, infrastructure and adaptive capacity.
- Rockefeller Foundation's 100 Resilient Cities (100RC): This programme has developed a resilience assessment framework that helps cities identify their strengths and weaknesses with respect to risks and threats. It includes a set of tools and resources to support cities on their path to resilience.

Each protocol has its own strengths and weaknesses, and the choice of applying one over another depends on specific urban needs and contexts, but in general, what is found in the literature is that at the operational level, one of the challenges of urban resilience is to overcome a 'specific' view in which one adapts to a specific type of shock, to move towards a different concept, that of 'general' resilience by determining the characteristics of the urban system that make it more flexible and adaptable so that it can cope with new challenges in a multi-scalar perspective (Chelleri et al., 2015) and integrated perspective.
The first attempts to define an approach of integration at the urban scale of different sectors, actors and dynamics was carried out in 2007 by Resilience Alliance, which identifies a first framework with which it conceptualises the factors and interactions of urban systems that constitute the fundamental elements of urban resilience, defining generic resilience as the integration of four dimensions

- metabolic flows;
- governance-istitutions
- social dynamics;
- built enviroment.

A further step was taken in 2012 by Chelleri and Olazabal who, instead, see the integrated urban resilience approach as the intersection of disciplines that are distant from each other, but from which interesting formulations emerge. In particular, this concept should not be approached exclusively from a climate perspective, but rather refer to the broad context of sustainable development, where adaptation and transformation of complex systems play a key role (Chelleri et al., 2015).
Over the years, there have been many models introduced to attempt to assess urban resilience, which differ in the approach used and the characteristics of reference; therefore, a compilation of assessment methods and models is necessary in order to be able to analyse the methodology with the aim of introducing a new integrated operational tool.
Measuring urban resilience has become a priority for the development of risk management strategies. However, it is a difficult challenge to measure resilience because it is a complex concept and there are, to date, no fixed rules on how to do so. Experts have defined different methodologies for different purposes, and there is no agreement on how to do it and which is the best way. In fact, many debate which variables to include and how to quantify them without oversimplification. 'Identifying resilience requires planners to identify the variables that trigger disturbances in a city (a community, region, or landscape), the frequency and intensity of these events, and the adaptability-enhancing mechanisms that can be activated to respond to (or avoid) these disturbances' (Heinzlef et al, 2022). The aim, therefore, is to find common ways to assess urban resilience and improve it.

With the aim of collecting and understanding some of the existing assessment tools found in the literature, a summary table was created (Table 2) and the different models collected, show the variety of possible methodological choices to develop an urban resilience assessment model, which differ in several aspects, including the scales of analysis and the number of indicators constructed. This suggests that there is no single established model, but there is still much confusion in the literature, which leaves ample room for work and methodological innovation.

Table 2.4. Comparison of resilient indicator models elaborated starting from Heinzlef et al. (2022), and Barroca e Serre, (2013).

MODEL	REFERENCE	SCALE	CASE STUDY	REMARKS
BRIC (Baseline Resilience Indicators for Communities)	Cutter, S. L., Ash, K. D., & Emrich, C. T. (2014). The geographies of community disaster resilience. Global environmental change, 29, 65-77.	National	USA	Resilience indicators to map the level of resilience across the USA
				Resilience analyzed into **6 indicators:** social, economic, community, institutional, infrastructural and environmental
				Each variable has a positive or negative effect on community resilience
				Possible to locate more or less finely the territorieson which to focus efforts to increase territorial and social resilience
				State-wide analysis
				National data not always adequate for a fine-grained, contextualized analysis of resilience
DS3 Model (spatial decision support system)	Serre, D. (2018). DS3 model testing: assessing critical infrastructure network flood resilience at the neighbourhood scale. Urban Disaster Resilience and Security: Addressing Risks in Societies, 207-220.	Urban	Hamburg	No specific risk identified
				3 resilience capacities: resistance, absorption, recovery
				neighbourhood level analysis
				Identification of interdependent relationships between critical infrastructure
				Identification of potential domino effects in case of disturbance
				Focus on flood risk
				Technical-functional approach to resilience centered around the analysis of the resilience of urban technical networks
Resilience Capacity Index	Foster, K. A. (2012). In search of regional resilience. Urban and regional policy and its effects: Building resilient regions, 4, 24-59.	National	USA	**12 indicators** (regional economic, socio-demographic, and community connectivity attributes
				A broad analysis of the disaster (not only the natural disaster)
				Integration of the notion of stress
				Notion of vulnerability and resilience prior to the disruption
				Visualization of resilience scores
				Metropolitan Analysis Scale
				Attempt to validate or at least discuss the results
				Visualization of results on too large a scale that complicatesdecision making for urban actors
				No specific risk identified

Community Disaster Resilience Index	Peacock, W. G., Brody, S. D., Seitz, W. A., Merrell, W. J., Vedlitz, A., Zahran, S., ... & Stickney, R. (2010). Advancing resilience of coastal localities: Developing, implementing, and sustaining the use of coastal resilience indicators: A final report. Hazard reduction and recovery center, 1-148.	National	USA	**75 indicators** Applied to 144 coastal or near coastal counties across the Gulf Coast Data from 2000 to 2005 Empirical validation (observations) Doesn't work for the probability of fatalities Visualization of results on too large a scale that complicates decision No specific risk identified
Urban resilience index	Suárez, M., Gómez-Baggethun, E., Benayas, J., & Tilbury, D. (2016). Towards an urban resilience index: A case study in 50 Spanish cities. Sustainability, 8(8), 774.	National	Spain	**5 indicators** Quantitative and qualitative indicators Tested in 50 spanish province capital Not a generic approach Very few indicators concentrated on food, land use and business No specific risk identified
Community resilience assessment	Fox-Lent, C., Bates, M. E., & Linkov, I. (2015). A matrix approach to community resilience assessment: an illustrative case at Rockaway Peninsula. Environment Systems and Decisions, 35, 209-218.	Urban	Rockaway Peninsula, NY	**16 indicators** divided according to the temporality of the risk (preparation, absorption, recovery, adaptation) Adapted to a specific risk (flood) Tested with a case study Collaborative approach with stakeholders Support decision-making Possibility to combine this approach with others (model flexibility) Need to develop a collaboration for several indicators (need to develop a long-term approach)
The Peoples Resilience Framework	Fox-Lent, C., Bates, M. E., & Linkov, I. (2015). A matrix approach to community resilience assessment: an illustrative case at Rockaway Peninsula. Environment Systems and Decisions, 35, 209-218.	None	Not known	**7 indicators** Considering the interdependencies between the 7 dimensions Crossing of scales between the individual and spatial scales Qualitative and quantitative indicators Consideration of resilience as a fluctuating variable No identification of risks or specific disturbances No visualization of results No real measure of resilience but more a list of criteriato develop a resilient community
Hybrid method		Urban	Avignon	Inclusive resilience approach

	Heinzlef, C., Becue, V., & Serre, D. (2019). Operationalizing urban resilience to floods in embanked territories–Application in Avignon, Provence Alpes Côte d'azur region. Safety science, 118, 181-193.			**3 indicators:** social, urban and technical resilience
				Administrative limits scale
				Collaborative approach
				Spatial decision support system
				Tool not 100% free access
				No validation of the methodology using a past event
				No long-term study of the impact of new urban projects on overall urban resilience
BB "Behind the Barriers"	Barroca, B., Clemente, M. F., & Yang, Z. (2023). Application of "Behind the Barriers" Model at Neighbourhood Scale to Improve Water management under Multi-Risks Scenarios: A Case Study in Lyon, France. International Journal of Environmental Research and Public Health, 20(3), 2587.	Urban	Lyon	**4 dimension of resilience**: cognitive, functional, correlative, organizational
				Indicators and sub-indicators
				Support decision-making
				local neighbourhood scale
				Adapted to a specific risk (flood)
				basis for planning implementing actions that improve the resilience of water balance

2.3.3 From urban resilience to urban integrated resilience

Urban and metropolitan settlements are characterised by the interdependent, interconnected and hierarchical structure of their component systems, which contribute to their complexity and context-specific socioeconomic and environmental characteristics (Losasso, 2017; Chrysoulakis et al, 2023). The exposure of urban settlements to multiple and increasing stresses of natural, environmental or anthropogenic origin - in terms of intensity, frequency and duration - necessitates the introduction of the concept of resilience in urban management (Barroca, 2013). The theme of resilience is, in fact, today at the centre of European and national technical policies and directives, for example, the European Union's Recovery and Resilience Facility (RRF) measure, within the NextGenerationEU programme, which represents a fundamental tool in the transition of urban settlements into sustainable and resilient realities, or the National Recovery and Resilience Plan (PNRR), which includes among its objectives of innovation and transition, the achievement of greater resilience with a view to adapting to the climate change underway. Resilience has also taken a central role in research and innovation investments, international cooperation initiatives and national plans, strategies and projects.

The concept of resilience is complex and variable both in its meanings, in relation to different fields of knowledge, and in its operational implications, declining in different spheres and research perspectives. In the literature, there are many meanings attached to this term, making resilience a transversal and flexible concept. The lack of a single definition reflects the complexity of the topic and the challenges of its application in urban settings. Against this backdrop, the concept of 'integrated urban resilience' and its characteristics will be explored from an analysis of the scientific and technical literature on the topic of urban resilience.

The concept of resilience originated in the field of ecology and natural sciences, introduced by Holling in 1973, as the ability of ecosystems to return to a state of equilibrium following a disruptive event. The concept has subsequently found wide interest and application in various disciplines and sectors, declining with different approaches in relation to different fields of knowledge.

With the aim of collecting and understanding the multiple definitions identified in the literature starting with the contribution of Datola et al. (2023), a list of the main definitions of urban resilience is proposed (Table 2):

Table 2.5 Urban resilience review. Elaboration starting from an elaboration by Datola (2023).

YEAR	DOCUMENT	SOURCES	DEFINITION OF URBAN RESILIENCE

2003	Article	Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. (Alberti, M. et al, 2003)	Resilience is the degree to which cities tolerate the change before reorganizing around a new set of structures and processes and depends on the ability of cities to maintain their eco-systemic and human functions simultaneously.
2008	Article	The social production of ecosystem services: lessons from urban resilience research. (Ernstson, H., 2008).	Resilience is the ability of a socio-ecological system to sustain a given set of ecosystem services in the face of uncertainty and change for a community.
2010	Article	Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. (Wardekker et al, 2010)	A resilient system is a system that can tolerate disturbances by means of characteristics or measures that limit its impacts, reducing or neutralizing damages and disturbances, and allowing the system to respond, recover and adapt quickly to such disturbances.
2011	Annual report	UNISDR (United Nations Office for Disaster Risk Reduction). (2012). Annual report 2011: UNISDR Secretariat work programme 2010–2011.	Resilience is the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to, and recover from the effects of a hazard promptly and efficiently by preserving and restoring essential basic structures.
2012	Article	From the «Resilient City» to Urban Resilience. A review essay on understanding and integrating the resilience perspective for urban systems. (Chelleri, L., 2012)	Urban resilience usually refers to the ability to maintain functions and structures, it must be framed in the visions of resilience (system persistence), transition (incremental system change), and transformation (system reconfiguration).
2012	Book	Ecological resilience as a foundation for urban design and sustainability. In Resilience in ecology and urban design: Linking theory and practice for sustainable cities. (Wu et al, 2012)	Urban resilience is the ability of a city to persist without qualitative changes in its structure and function, despite the disturbances.
2013	Article	Planning for climate change in urban areas: from theory to practice. (Wamsler, C. et al, 2013)	A city resilient to disasters can be understood as a city that can successfully support measures to strengthen individuals, communities and institutions to: (a) reduce or avoid and future risks; (b) reduce current and future susceptibility to resist risks; (c) establish mechanisms and functional structures for disaster response; and (d) establish functional mechanisms and structures for disaster recovery.
2014	Book	Asprone, D., Cavallaro, M., Latora, V., Manfredi, G., & Nicosia, V. (2014). Urban network resilience analysis in case of earthquakes. In Safety, reliability, risk and life-cycle performance of structures & infrastructures (pp. 4069-4075). Taylor & Francis Group.	City resilience is based on the efficiency of hybrid networks composed by citizens and urban infrastructures.
2014	Report	Index, C. R. (2014). City resilience framework. The Rockefeller Foundation and ARUP, 928.	City resilience describes the capacity of cities to function, so that the people living and working in cities particularly the poor and vulnerable – survive and thrive no matter what stresses or shocks they encounter.
2016	Article	Mehmood, A. (2016). Of resilient places: planning for urban resilience. European planning studies, 24(2), 407-419.	Urban resilience can be defined in evolutionary terms as a proactive vision for planning, policy formulation, and strategic direction in which communities play a vital role in resilient place modelling through their active learning ability, robustness, capacity for innovation and adaptability.
2016	Article	Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. Landscape and urban planning, 147, 38-49.	Urban resilience is the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.
2018	Website	Cities, R. (2018). '100 Resilient Cities Programme'.	The capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience.
2018	Article	Sharifi, A., & Yamagata, Y. (2018). Resilient urban form: A conceptual framework.	Resilience is a property of the urban system that enables it to survive against the uncertainty, the adversity and the change, which requires continuous efforts of the system during all the

		Resilience-oriented urban planning: Theoretical and empirical insights, 167-179.	phases of the change (i.e. mitigation, preparedness, absorption, recovery, response and adaptation).
2019	Article	Urban resilience: A conceptual framework. Sustainable Cities and Society. (Ribeiro, P. J. G. et al, 2019)	Urban resilience is the capacity of a city and its urban systems (social, economic, natural, human, technical, physical) to absorb the first damage, to reduce the impacts (changes, tensions, destruction or uncertainty) from a disturbance (shock, natural disaster, changing weather, disasters, crises or disruptive events), to adapt to change and to systems that limit current or future adaptive capacity.
2020	Technical document	PNR: Programma nazionale per la ricerca 2021-2027. Allegato esteso "Clima, energia, mobilità sostenibile"	Resilienza è la capacità di un sistema sociale, economico o ambientale di far fronte a un evento pericoloso, o anomalie, rispondendo e riorganizzandosi in modo da preservare le sue funzioni essenziali, l'identità e la struttura, e da ritornare alle condizioni iniziali senza subire cambiamenti permanenti.
2020	Article	Heinzlef, C., Robert, B., Hémond, Y., & Serre, D. (2020). Operating urban resilience strategies to face climate change and associated risks: Some advances from theory to application in Canada and France. Cities, 104, 102762.	Urban resilience is the ability of populations, territories and infrastructures to put in place resources, skills and capacities in order to best experience a disruptive event so as to limit its negative impacts. Capacities can be both tangible (urban networks, supply of vital resources, etc.) and intangible (knowledge of risk, economic dynamics, institutional framework, etc.).
2022	Report	World Health Organization. (2022). Review of indicator frameworks supporting urban planning for resilience and health: third report on protecting environments and health by building urban resilience (No. WHO/EURO: 2022-5649-45414-64989). World Health Organization. Regional Office for Europe.	Urban resilience is the measurable ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability.
2023	Website	Resilient Cities Network: https://resilientcitiesnetwork.org/	Urban resilience is the capacity of a city's systems, businesses, institutions, communities, and individuals to survive, adapt, and thrive, no matter what chronic stresses and acute shocks they experience.
2023	Glossary	Wyss R., Luthe T., Pedoth L., Schneiderbauer S., Adler C., Apple M., Erazo Acosta E., Fitzpatrick H., Haider J., Ikizer G., Imperiale AJ, Karanci N., Posch E., Saidmamatov O., Thaler T. (2022). Mountain Resilience: A Systematic Literature Review and Paths to the Future. Mountain Research and Development. 42(2),A23-A36. https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1	In disaster research, the resilience concept bridges theory and practice and emphasizes the importance of community, societal, and governance aspects in reducing the risks and impacts of hazardous processes.

The synthetic-comparative analysis shows that urban resilience

- refers to the capacity for adaptation, resilience and response in relation to potential crises (Desouza & Flanery, 2013)
- refers to the capacity of urban systems and subsystems to maintain, or recover, essential functions following disruptive events, adapting to change and rapidly transforming, integrating or replacing, systems or subsystems that limit the overall adaptive capacity of the system itself (Meerow et al., 2016)
- is understood as a process that involves not only absorption and recovery from the shock, but also includes aspects of transition and transformation and adaptation (Chelleri, 2012; Mehmood, A. 2016; World Health Organization, 2022);
- is understood as a multidimensional process that includes the 5 urban systems: physical, natural, economic, institutional and social (Ribeiro et al., 2019).

Therefore, urban resilience is declined as a complex and 'transformative' approach (Chelleri, 2012; Mehmood, 2016), involving multiple aspects and multiple systems of urban settlements, including social, economic, institutional, infrastructural, ecological and community systems, among others (Ribeiro et al., 2019). Therefore, the need and urgency to investigate the multidimensionality of urban resilience as a transformative approach in urban design and planning is highlighted, in order to make cities adaptive in an integrated, proactive and contextualised intervention perspective.

The complexity of the topic highlights the need to identify a holistic approach that incorporates and integrates different disciplines, sectors, perspectives and expertise (Urquiza et al., 2021).
Following the theoretical frame of reference, the concept of integrated urban resilience of urban settlements in relation to the issue of multi-hazard must refer to:

- the integration of resilience, adaptability and transformability in urban design and planning (Folke et al., 2010; Sharifi, A., et al, 2018);
- the integration of the concept of urban resilience in the framework of Emergency Disaster Management (Manyena et al., 2019) and in urban risk assessment and mitigation processes (Urquiza et al., 2021).
- a systemic approach that encompasses multiple urban systems and sub-systems in an integrated view of settlements (Heinzlef et al., 2022).

The concept of integrated urban resilience can thus be declined as the ability of the entire settlement, or parts of it, to cope with and adapt to stresses, disruptions and changes, ensuring the effectiveness of its core functionalities, safeguarding and promoting the wellbeing of communities, and fostering the integration of resource management, security, risk assessment and integrating active community participation into urban planning design.

3. Planning tools and methods for urban regeneration

3.1 Target definition and reference scenario (cfr. WP2 T2.1, T2.2)

3.1.1 Review of existing planning tools and methods for urban regeneration at national level

Since the 1990s, urban regeneration has increasingly become a key approach to addressing issues related to the marginalization and decline of urban areas. It can be understood as a combination of integrated actions, policies, and initiatives designed to address areas facing socio-economic challenges while also offering opportunities for growth and improvement (Roberts et al., 2016; Gargiulo & Sgambati, 2021). Urban regeneration strategies can encompass various dimensions, including land use planning, the economy, the environment, society, and culture. The goals of regeneration can be achieved through both "hard" and "soft" measures. Hard measures focus on physical interventions such as infrastructure and urban development, while soft measures include governance, citizen participation, and other collaborative actions. Urban regeneration is often seen as an effective means of transforming urban areas to tackle social, environmental, cultural, and economic issues, ultimately enhancing the resilience of the affected communities and territories (Sgambati, 2022).
Urban regeneration represents a central aspect of addressing climate change, sustainability e socio-economic challenges. In Italy, various planning tools and methods have been developed at the national, regional and local levels to meet these targets.

Global and European Frameworks Guiding National Policies
Climate change poses a global challenge that requires joint action by the international community. Since the 1992 United Nations Framework Convention on Climate Change and subsequent agreements like the Kyoto Protocol (1997) and the Paris Agreement (2015), countries have been encouraged to adopt measures for reducing greenhouse gas emissions and enhancing climate adaptation.
In parallel, the United Nations (UN) developed the 2030 Agenda, signed in September 2015 by 193 member states. Through 17 Sustainable Development Goals (SDGs), the Agenda outlines an action plan for people, the planet, and prosperity, integrating the environmental, social, and economic dimensions of sustainable development.
In Europe, policies such as the European Green Deal (2019) focus on creating resilient cities and sustainable urban systems. The European Union has also adopted a Climate Change Adaptation Strategy, updated in 2021, which, although not binding, aims to make Europe more resilient. The initiative is part of the European Green Deal, which promotes a ‘European Climate Act’ with the aim of improving the climate resilience of member states and including adaptation in national strategies.
While the Green Deal promotes resource efficiency, clean energy, and climate neutrality by 2050, the Adaptation Strategy outlines "smarter, systemic, and faster" approaches to resilience. These initiatives have significantly influenced Italian urban regeneration strategies, aligning them with EU priorities.
Europe's contribution to urban adaptation includes financial support and private sector investment incentives through specific programs like LIFE, URBACT, and Interreg. Additionally, it fosters research, studies, and pilot projects via the Climate-Adapt web platform.

Recently, in response to COVID-19 pandemic, the European Union launched the NextGenerationEU (NGEU) financial instrument, allocating €806.9 billion to create a greener, more digital, and resilient community (EC, 2021c).

National Framework for Urban Regeneration

In Italy, the National Strategy for Adaptation to Climate Change (SNAC) is the national reference framework for reducing vulnerability to climate risks. It identifies priority areas such as urban spaces, critical infrastructure, and natural ecosystems, emphasizing the importance of integrating climate adaptation into urban planning (MATTM, 2015).

Subsequently, the National Plan for Adaptation to Climate Change (PNACC) was introduced. Reworked in 2022 and approved in 2023, it provides detailed sectoral actions to enhance resilience which aims to improve the resilience of Italy's socio-economic and natural systems, in line with the objectives of the Paris Agreement. It also includes strategies for retrofitting urban spaces, promoting green infrastructure and improving water and energy efficiency in buildings (MASE, 2023).

At the regional level, some Italian regions have initiated sustainable development strategies to integrate climate adaptation, and metropolitan cities are developing metropolitan agendas that include resilience and sustainability, in line with the 2030 Agenda. The adopted planning tools and methods for urban regeneration follow different approaches that reflect the geographical and socio-economic diversity of the regions and cities. Regions such as Emilia-Romagna and Lombardy have integrated urban resilience into their Regional Sustainable Development Strategies, focusing on green infrastructure, energy efficiency and climate adaptation in urban planning. Cities like Bologna have already implemented climate adaptation plans, such as the Bologna Local Urban Environment Adaptation Plan for a Resilient City (BLUE AP). Other cities, such as Milan and Rome, have developed Metropolitan Agendas in line with the goals of the Agenda 2030, emphasizing smart cities, ecological mobility and inclusive urban environments.

Moreover, in alignment with NextGenerationEU, at the national level Italy's National Recovery and Resilience Plan (PNRR) allocated €222.1 billion, focusing on green projects (37%) and digital initiatives (20%). Investments target areas such as the green revolution and ecological transition (€59.47 billion), digitalization, innovation, competitiveness, and culture (€40.32 billion), education and research (€30.88 billion), sustainable mobility infrastructure (€25.40 billion), social inclusion and cohesion (€19.81 billion), and health (€15.63 billion) (Governo Italiano, 2021).

Table 3.1 – The investments of Italian PNRR (elaboration from Sgambati, 2022).

INVESTMENT	IMPLEMENTING BODIES	RESOURCES (€)
M5C2.2.1 Urban Regeneration to reduce marginalisation and social degradation	Municipalities	3.3
M5C2.2.2 Integrated Urban Plan	Municipalites and Metropolitan Cites	2.49
M5C2.2.2a Integrated Urban Plans overcoming unauthorized settlements	Municipalities	0.2
M5C2.2.2b Integrated Urban Plans Fondo dei Fondi	Private subjects	0.272
M5C2.2.3 Social housing – Piano innovativo per la qualità dell'abitare (PinQua)	Regions, Provinces, Metropolitan Cities, Municipalities	2.8
M5C2.3.1 Sport and social inclusion	Municipalities	0.7
M5C3.1.1.1 National strategies for inner zones	Municipalities	0.725
M5C3.1.2 Valorization of goods confiscated from mafia	Provinces, Metropolitan Cities, Municipalities	0.3

In the NRPP, urban regeneration focuses on promoting sustainable urban development through key components: green transition, green mobility infrastructure and social inclusion. Measures aim to improve the quality of life by improving neighborhood services, rehabilitating buildings and public spaces, and addressing marginalization and socio-economic inequalities. The focus is on creating safer and more inclusive neighborhoods, while ensuring housing support for vulnerable groups, including the elderly, low-income people and people with disabilities, through building renovation and rehabilitation initiatives.

Moreover, in Italy, the bill on urban regeneration is currently under examination in the Senate. The aim of DDL 29/S and abb is to provide a unified text ranging from urban planning to environmental protection via the construction and energy sectors. The basic targets are:

- the rehabilitation of the built heritage to improve its quality;
- promoting energy and water efficiency, as well as seismic safety and technological equipment;
- to promote integrated and sustainable urban policies to pursue social cohesion, environmental and landscape protection and the safeguarding of ecosystem functions.

These targets have been identified in line with the European target of zero soil consumption by 2050 (EC, 2021). To this end, the unified text for urban regeneration also identifies some basic goals to be achieved (Senato della Repubblica, 2024):

- encourage the re-use, renovation or replacement,
    - of already urbanised areas that are no longer environmentally and economically sustainable;
    - of disorganised or unfinished building fabrics;
    - of building complexes and public or private buildings legitimately constructed at least 10 years ago and in a state of decay and abandonment or disused;
    - encouraging their physical, technological and energy redevelopment and the reduction of polluting emissions, aiming at environmental sustainability and the improvement of overall urban and architectural quality;
- improve the permeability of soils in the urban fabric, through
    - the principle of hydraulic invariance;
    - mitigating the effects of climate change in cities;
    - environmental rebalancing, ecological sustainability, green areas and reforestation;
    - implementation of technological, architectural and engineering solutions for seismic safety and energy efficiency;
    - the containment of phenomena such as ‘heat islands’, extreme weather events and hydrogeological instability;
    - the increase of biodiversity in urban areas undergoing urban regeneration;
- building strategic infrastructures for the eco-sustainable development of the territory and for the construction of defense and safety works for the territory and the built heritage located in hydrogeological risk contexts;
- give priority to urban densification and urban compensation interventions for the improvement of public services, also with the aim of pursuing the ‘zero balance’ of soil consumption;
- apply the ‘zero balance’ principle of soil consumption through interventions of
    - non-economic balance of ecosystem services in the municipal territorial context;
    - hydraulic invariance;
    - renaturation;
    - de-impermeabilization;
    - reclamation of already consumed and contaminated soil;
- to improve the quality of life, in historic centres and suburbs, with the functional integration of residences, economic activities, public and commercial services, work activities, technologies and coworking spaces, with a focus on the needs of people with disabilities;
- protecting historical centres in their identity, cultural and landscape peculiarities by encouraging residential functions and related services, and promoting the balanced presence of hospitality-related functions;
- integrating sustainable mobility systems;
- encouraging the construction of social housing interventions;
- promoting the active participation of inhabitants;
- intervene on buildings and neighborhoods constructed under public housing plans, with rehabilitation, energy and seismic upgrading and urban enhancement operations to raise the quality of living standards;
- attracting private investment geared to the public objectives of urban regeneration.

Italy's urban regeneration strategies show a growing commitment to sustainability and resilience. In line with international and European frameworks, the country has made considerable progress in integrating climate adaptation into urban planning. However, addressing the challenges of governance, financing and inclusiveness is key to realizing the full potential of urban regeneration as a tool for sustainable development.

3.1.2 The gap in planning and design in compliance with NEB

The disconnect between current urban planning and design practices and the principles championed by the New European Bauhaus (NEB) reveals a series of structural, cultural, and methodological misalignments. While NEB envisions an integrated approach grounded in sustainability, aesthetics, and inclusion, today's planning systems often remain rooted in siloed disciplines and outdated procedural models.

One of the most pressing challenges lies in the fragmented nature of urban and regional planning. Fields such as engineering, architecture, environmental management, and social policy typically operate independently, without meaningful interdisciplinary collaboration. As a result, core NEB values like beauty and social cohesion are often sidelined, treated as decorative afterthoughts rather than foundational design elements (Bilić & Šmit, 2024). This reflects a fundamental absence of planning frameworks capable of embedding NEB principles holistically from the outset.

Equally problematic is the dominance of top-down, technocratic planning processes. While NEB promotes co-creation and participatory design, public engagement in practice remains limited, often reduced to late-stage consultation or bureaucratic formalities. Many designers and planners still lack the tools, methodologies, or institutional incentives to meaningfully engage communities in the co-design process. Promising examples—such as digitally enabled co-creation in the NEBourhoods initiative—highlight the potential for inclusive participation, but these remain exceptions rather than the norm (Drechsel & Förster, 2023).

The prevailing interpretation of sustainability is another point of divergence. In most planning frameworks, sustainability is equated with compliance—technical standards for emissions, efficiency, and materials. The NEB, by contrast, promotes an experiential and cultural understanding of sustainability, where aesthetics and sensory well-being are essential components. Yet current systems lack appropriate tools and indicators to measure or reward the aesthetic and emotional qualities of space. As a result, the "beauty" pillar of the NEB is often misunderstood, ignored or undervalued in both public procurement and policy evaluations (Semprebon, 2023), (Woźniczka, 2023).

Moreover, planning systems are often constrained by rigid regulatory frameworks that leave little room for innovation. Zoning laws, procurement procedures, and funding models are typically designed to prioritize cost-efficiency over long-term value creation or regenerative design. These constraints inhibit experimentation and prevent the adoption of systemic, NEB-aligned approaches that cut across sectors and disciplines (Woźniczka, 2023).

Finally, while the NEB advocates for place-based, context-sensitive design rooted in local culture, memory, and identity, many planning processes continue to rely on standardized templates and aesthetic homogenization. This leads to the erosion of cultural specificity and weakens the sense of belonging. In contrast, case studies from Venice demonstrate how fostering local craftsmanship and social innovation can strengthen the cultural embeddedness of urban initiatives aligned with the NEB vision (Busacca & Paladini, 2022).

Integrating climate adaptation and sustainability solutions from the earliest stages of building design and urban regeneration is a critical strategy for creating future-ready, resilient, and inclusive environments. This approach allows for a more holistic and anticipatory design process, where energy performance, solar optimisation, climate resilience, and human well-being are considered not as isolated targets but as interrelated drivers of quality in the built environment.

As emphasized in the *IEA SHC Task 63* report (Croce S. et al., 2022), solar energy utilisation and climate-adaptive design should not be retrofitted as technical additions, but embedded in the core architectural and urban design vision. This implies leveraging solar design principles—such as optimal orientation, passive heating and cooling, daylighting strategies, and solar shading—in a way that responds to both current climatic conditions and projected future scenarios. It also means accounting for thermal comfort, glare control, ventilation, and energy load management throughout the entire life cycle of buildings and urban areas.

From a practical standpoint, this requires the use of advanced simulation tools, digital twin models, and dynamic performance assessments capable of integrating diverse datasets—including solar radiation, climate projections, morphology, and material properties—into a unified design environment. These tools enable architects, engineers, and planners to test, compare, and iterate design options that balance energy efficiency with spatial quality, economic viability, and long-term climate robustness.

The integration of adaptation and sustainability at multiple scales—from building façades to open spaces, from block-level interventions to neighbourhood-wide regeneration—ensures that cities can address multiple risks simultaneously, including urban heat island effects, extreme weather events, and energy poverty. Moreover, it supports cross-sectoral policy alignment and contributes directly to high-level goals such as the EU Renovation Wave, the European Green Deal and the vision of the New European Bauhaus, which calls for spaces that are not only sustainable but also beautiful, inclusive, and context-sensitive.

3.1.3 The gap in planning and designing at urban scale

As reported in section 3.1.1, urban regeneration represents a practice for the development of strategies aimed at overcoming some of the criticalities of the contemporary city, in order to achieve lasting progress in economic, physical, social and environmental conditions. Recent experimentation in the national and international field associates urban regeneration with planning and design processes that address socio-economic components, that make use of communication and participation, and that envisage local development in relation to the effective use of resources and strategic planning objectives to verify the effectiveness of the results achieved (Losasso, 2015; Fazia et al., 2023).

Urban regeneration, in this interpretation, is outlined no longer as a set of technical interventions but as a process of technological reconnection between resources, spaces and inhabitants; an opportunity for the inclusive involvement of human and social resources to re-generate the city's physical resources (Vicari Haddock and Moulaert, 2009). Equally worth mentioning is the reference to urban regeneration as part of a project of technological reconnection between resources, spaces and inhabitants that tends to seek levels of resilient balance between objective qualities of the city, which can be measured and parameterised, and subjective qualities of living in the city, expected and experienced by the users, transforming the design experience into a moment of shared commitment and urban quality into the quality of living together (Zaffagnini, 1980).

Therefore, the need to develop regenerative interventions emerges as a priority, not so much through the modification of physical parts as in proposing ‘renewed’ neighbourhoods with smartness, according to the use of decentralised energy sources, eco-building, intelligent mobility, and connection networks. Smart’ logics introduce the theme of “data” and its management in cities, not only as a cognitive element for urban design, but as widespread and accessible information on elements, infrastructures and places in the city itself, marking the transition from a sustainable city to a regenerated city.

Nevertheless, design responses are very often reduced to decontextualized superimpositions of norms, procedures and products that fragment the very idea of urbanity (Angelucci et al., 2015). This condition directs urban regeneration policies towards interventions on single themes (energy, security, climate change, sustainable building, health) or dedicated to specific categories of users and their exclusive areas of competence (the city of children, the elderly, the disabled, tourists).

In this scenario, urban planning and design face several challenges in addressing climate change. These include poor integration between adaptation and mitigation, lack of coherence between sectoral policies and territorial plans, and difficulties in multi-level governance. These issues are further complicated by economic, social, and technological barriers.

Overcoming these obstacles requires an integrated approach. This approach must consider ecosystems, society, and sustainable development as interconnected elements. In this way, urban resilience can be strengthened, fostering a fair and inclusive green transition.

“Gaps” and “barriers” are often discussed as if they were interchangeable, but they represent distinct concepts.

“Gaps” refer to the absence or insufficiency of essential elements, such as knowledge, resources, data, policies, and tools necessary to effectively address climate risks. For instance, a lack of accurate climate data or the absence of adequate policies can undermine both the planning and implementation of mitigation and adaptation measures (Smith et al., 2020; Brown and Jones, 2019). In mitigation, gaps also include the disparity between promised emissions reductions and those required to meet global climate targets, as well as deficiencies in governance and resources.

“Barriers,” on the other hand, are obstacles that, while significant, can be overcome through targeted efforts, creative management, and strategic changes. These may be institutional, financial, social, or technical in nature, such as the lack of coordination among governments or community resistance to new practices (Adger et al., 2009). Unlike gaps, barriers do not imply a structural absence, but rather specific challenges tied to existing conditions. Understanding this distinction is crucial for designing effective climate strategies and overcoming obstacles that hinder action.

One of the key gaps in urban regeneration is its relative recentness, which limits the ability to fully evaluate the outcomes of interventions. Most projects initiated in recent years have yet to produce measurable long-term results, particularly in terms of environmental and social benefits. For instance, solutions such as urban forestry or green infrastructure require extended periods to show tangible effects, making immediate impact assessments challenging.

This lack of consolidated data is further exacerbated by the absence of systematic post-intervention analyses, which are essential to understanding the successes and shortcomings of implemented actions. Benefits that are harder to quantify, such as improved social cohesion or enhanced climate resilience, tend to emerge only over time and require deeper, long-term studies. Additionally, as a relatively new field, urban regeneration is not yet fully integrated into the technical expertise of many professionals, often resulting in experimental interventions lacking well-established methodologies.
While the level of theoretical knowledge is commonly sufficient to provide information for cities, practical know-how in the research community is therefore considerably less comprehensive. The overall level of practical experience and theoretical knowledge is rather low (Kazmierczak et al., 2009).
However, from stakeholders' perspective, public value can be chosen as a common index to compare different projects and scenarios (Rebelo, 2017; Auzins, 2017) that have diverse goals pursued by urban planning actions that can be grouped into the three dimensions of sustainability (UN, 2015; UN, 2017). Urban regeneration planning and design may as well confront challenges due to multi-stakeholder games and conflicts, notably in the profitability-oriented planning practice (Liao&Liu, 2023). Thus, integrated, spatially explicit, collaborative frameworks and multi-methodology interventions require much time and cost (Ferretti, 2021) but may be an effective solution to cope with such conflicts.

3.2 Strategic Environmental Assessment (SEA) and climate change adaptation (CCA)

The objective of this section consists in the definition of a methodological approach for the integration of climate change adaptation (CCA) in the environmental reports (ERs) of the strategic environmental assessments (SEAs) of the territorial plans of local governments that, in the Italian regulatory context, are identified as municipal masterplans (MMPs) (Isola et al., 2023a). It consists, therefore, in the implementation of a downscaling operation to the local level of strategies and plans concerning CCA, in force in the European and national contexts, that is, with reference to MMPs (Frigione & Pezzagno, 2023).
In section 3.2.1, an introduction and a general conceptual layout in relation to the integration of CCA into SEA process is presented and discussed.
In section 3.2.2., the methodology used to carry out the downscaling is described, and the reasons for the choice of the four local contexts in relation to which the methodology is implemented are given, namely the cities of Capoterra, Selargius, Nuoro and Sassari. The ERs of the MMPs of the four cities are based on the declination, in the local spatial contexts, of the principle of sustainable development, in accordance with the provisions of Legislative Decree 152/2006 (Art. 3-quater, and Art. 4, paragraph 4, letter a), in line with the conceptual approach of the Brundtland Report (WCED, 1987). That scientific and technical framework highlights important issues, both theoretical and applicative, with reference to local government spatial planning practices.
In section 3.2.3., the implementation of the downscaling operation is presented, in relation to the reference areas most relevant to this operation. Next, the characteristics that connote them, in terms of the strategic framework and planning actions, are described. The discussion is aimed at highlighting whether, and to what extent, the outcomes associated with the four Sardinian cities are generalizable, with reference to what is found in other similar cases relating to spatial contexts other than the territory of Sardinia. The concluding section highlights the prospects for the development of the research, also in relation to the problematic issues reported in the discussion of the results.
In section 3.2.4, policy implications in relation to the integration of CCA into SEA process are presented.

3.2.1 Introduction and general conceptual layout

The integration of CCA into SEA processes is a widely discussed and analyzed issue in the technical and scientific literature.
During the preparation of Directive No. 42/2001/EC, an analytical research report on the implementation of SEA in the decision-making processes of plans and programs, prepared by the Imperial College for the European Commission (Sheate et al., 2001), emphasizes how the effectiveness of land-use policies at different scales, national, regional and local, is fundamentally linked to the integration of CCA issues, highlighting several profiles of these issues. Of particular relevance, among the many cases analyzed, are the SEA of the land-use plan of the city of Weiz (Austria), in which it is emphasized that "The targets, goals and objectives used in the SEA process are clearly defined, for example, carbon dioxide threshold according to the goals of the 'Climate Alliance'" (Sheate et al., 2001, p. 9), the SEA of the National Environmental Policy Plan 3 of the Netherlands, which places CCA among the reference themes for identifying the structure and framework of administrative and technical competencies of the decision-making process (ibid., p. 85), and

the Regional Economic Strategy of the Yorkshire Regional Development Agency, which explicitly includes climate change among the components of the strategic framework (ibid., p. 153).
A very significant document is the Advisory Note on Environmental Assessment and CCA (ENVIRONET, 2010), which identifies four fundamental moments in the implementation of spatial planning processes that involve the integration of SEA and CCA: (i.) the precise and circumstantial identification of the universe of stakeholders and environmental components that reasonably will be affected, during the plan process, by the impacts of CCAs; (ii.) the implementation of the SEA; (iii) the process of informing and educating local communities, affected by the plan and climate change, in the proactive participation in the definition and implementation of planning policies; and, (iv) the continuous updating of the plan's strategic framework through the ongoing SEA and monitoring. A significant moment in the discussion proposed in the Advisory Note concerns the problematic nature of the conceptual and technical relationships between SEA and CCA. Indeed, it should be acknowledged and kept well in mind how SEA does not so much provide a conceptual and technical framework for the development of scientific research related to the impacts of climate change, but, rather, poses, in problematic terms, the need to fill knowledge gaps (ENVIRONET, 2010), which need to be kept in mind, if not resolved, as SEA is tasked with constructing frameworks and assessing impacts in reasonably plausible terms, which would not be possible if the gaps gave the assessment process a character of dramatic indeterminacy. SEA is effective in monitoring the implementation of plan processes, and, during this, the type and magnitude of climate change and, therefore, related adaptation measures, in relation to, for example, atmospheric precipitation, the genesis and likelihood of extreme weather events, the effects on water quality, and the generation of re-risk conditions, related to the hazard, vulnerability, and exposure associated with the impacts of climate change on natural resources and local societies.
An analytical discussion of this theoretical and technical conceptual vision is proposed by Wende et al. (2012), who examine, in comparative terms, SEA processes which integrate CCA approaches with reference to regional land-use plans from Saxony and East England.
A more comprehensive and general view of the relationship between SEA and CCA is, on the other hand, proposed and discussed by Gonzáles Del Campo et al. (2020) with reference to SEA processes that integrate, in the strategic device of the assessment, specific objectives that refer to Strategic Development Goal No. 13 of Agenda 2030 (Partidário & Verheem, 2019), "Take urgent action to combat climate change and its impacts." The issue of integrating CCA into SEA processes is addressed, specifically, in the European Commission's document "Guidance on Integrating Climate Change and Biodiversity into Strategic Environmental Assessment" (McGuinn et al., 2013), which takes up and develops the contents of ENVIRONET's Advisory Note (2010).
Related to what is presented and discussed in this document, of particular relevance is what is indicated regarding the need to address, in a detailed and specific manner, in environmental reports (ERs), the issue of consistency between the strategic device of the plan and the systems of objectives regarding mitigation and CCA identified in national and local strategies and plans focused on these issues (McGuinn et al., 2013, p. 70). In general, integrating the sustainability paradigm into public policy-making and implementation processes involves a careful assessment of economic and social equity issues in intra- and inter-generational terms (Francini et al., 2021). With regard, in particular, to spatial planning, this integration is not made operational through measures identifiable in deterministic terms, but, rather, through practices that involve an open and continuous dialectic with local societies, based on mediation in relation to the instances and expectations they express, as well as on the contributions of spatial sciences, to be used not only as foundational references of spatial analysis, but, also, as sources of collective learning (Gambino, 2005).
It is within this conceptual framework that the objective of section 3.2. is recognized and placed, which consists in the definition of a methodological approach for the integration of CCA in the ERs of the SEAs of the territorial plans of local governments that, in the Italian regulatory context, are identified as municipal masterplans (MMPs) (Isola et al., 2023a). It consists, therefore, in the implementation of a downscaling operation to the local level of strategies and plans concerning CCA, in force in the European and national contexts, that is, with reference to MMPs (Frigione & Pezzagno, 2023).
The starting point for the development of the downscaling process to municipal urban planning is the National Plan for Adaptation to Climate Change of Italy (NPCCA), whose strategic device declines the European Union Strategy for daptation to Climate Change (EUSCCA)[1] and the National Strategy for Adaptation to Climate Change of Italy (NSCCA)[2].

[1] The two reference documents of the European Commission concerning the EUSCCA are as follows: i) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "An EU Strategy on adaptation to climate change," COM(2013) 216 final; ii) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change," COM(2021) 82 final.
[2] The reference document for the NSCCA is Decree No. 86 of the Director of the Directorate General for Climate and Energy of the Ministry of the Environment and Land and Sea of June 16, 2015, adopting and approving the NSCCA (Art. 1). The NSCAA is contained in the Annex to the Decree and is an integral part of it.

The EUSCCA has had two versions, the first dating back to 2013, the other to 2021 (see footnote 1). The second is a critical restatement of the 2013 EUSCCA following an in-depth evaluative review of its implementation through the national CCA-related strategies and plans adopted and implemented by many EU countries[3]. The EUSCCA promotes, in this regard, the implementation of the conceptual and technical-operational framework of the EU Covenant of Mayors for Climate & Energy initiative[4], for whose local plans and actions the JRC has defined a specific approach in a three-part guideline manual, of which the first proposes a detailed itinerary for the definition of a municipal action plan aimed at CCA and mitigation, and energy savings, the second refers to emission census, and risk and vulnerability assessment, and the third to the identification of best practices and key actions concerning CCA and mitigation, as well as financial issues (JRC, 2018a; 2018b; 2018c). The NSCCA was defined, in 2015, on the basis of the 2013 EUSCCA, and, as far as it concerns the integration of CCA into local plans, it offers some very important pointers, in implementation of the technical device of the EUSCCA.
In particular, the approach of the NSCCA individuates the reference areas for defining the situation of climate dynamics and climate change and, in relation to these, identifies impacts and vulnerabilities, with respect to which the objectives and actions of the NPCCA will be defined. These will form the foundational strategic device for the downscaling operation.

3.2.2 Integration of the strategic framework of the Nation Plan for Adaptation to Climate Change into Municipal Master Plans (MMPs) through SEA

This section is organized as follows. The first part is devoted to the analytical description of the methodology used for the integration of CCA into the ERs of the SEAs of MMPs. The second part presents the reasons for the choice of MMPs, related to four Sardinian cities, taken as a reference for the application of the methodological approach adopted.

Methodology
The NSCCA identifies reference areas for defining the situation of climate dynamics and climate change. In relation to these areas, it identifies impacts and vulnerabilities to which the objectives and actions of the NPCCA have been defined. The current version may, therefore, not be the one that will be approved as a result of any changes made following the completion of the SEA. For the purposes of this study, this version is assumed to be reasonably close to the final draft of the Plan, as its current structure has remained unchanged since the time of its first online publication in 2018. Since then, it also has been subject to the scrutiny of all interested public administrations, at the state, regional and local levels, registering a generalized consensus. The NPCCA is, therefore, the operational extension of the NSCCA, of which it maintains the taxonomy of 18 reference sectors identified. The identification of plan objectives and actions is based on a context analysis, which deepens that of the NSCCA, based, as noted in the fourth chapter of the NSCCA, on the identification of impacts and vulnerabilities associated with each of the 18 reference sectors.
The methodology for the integration of the CCA into the ERs and, therefore, for the construction of the MMPs, consists of three phases, basically geared toward grafting the NPCCA's device of objectives into the systems of objectives of the MMPs. It should be noted that the application of the methodology proposed in this section, which refers to the adopted NPCCA, could be replicated with reference to any future drafts of the NPCCA, whose strategic framework, represented by the system of objectives of the updated version, would need to be incorporated. Among the objectives of the NPCCA, systematized in Annex IV of the NPCCA, called "Database of Actions"[5], the first phase aims to identify those that can be associated with the processes of defining MMPs, having significant implications on land governance. Based on the objectives of CCA, and also taking into consideration the 18 NPCCA Reference Sectors[6] to which they refer, a selection of significant objectives relevant to land-use and urban planning is made, followed by an identification of the actions/measures referring to them. The second stage is the construction of the system of specific objectives of the MMPs to which the ERs refer, that is, the construction of the logical frameworks (LFs) of the ERs of the MMPs, systems that are deduced directly from the ERs of the MMPs.

[3] The evaluation document is the Commission Staff Working Document "Evaluation of the EU Strategy on adaptation to climate change," SWD(2018) 461 final.
[4] An extensive and systematic information dossier on the initiative can be retrieved from the European Union website https://eu-mayors.ec.europa.eu/en/home. Accessed June 16, 2024.
[5] Retrieved from: https://www.mase.gov.it/sites/default/files/archivio/allegati/clima/PNACC_AllegatoIV_database_azioni.ods. Accessed June 16, 2024.
[6] Aquaculture; Agriculture and food production; Desertification, land degradation and drought; Geological, hydrological and hydraulic instability; Ecosystems and biodiversity in inland and transitional waters; Marine environments: Biodiversity, Functioning and Ecosystem Services; Energy; Terrestrial Ecosystems; Forests; Hazardous Industries and Infrastructure; Urban Settlements; Cultural Heritage; Marine Fisheries; Water Resources; Health; Transport; Tourism; Coastal Zones.

Finally, in the third phase, the objectives identified in the first phase are used in the drafting of the ERs for the construction of the MMPs as operational references to redefine the systems of the specific objectives and actions of the MMPs so that these systems integrate the CCA into the overall strategy of the MMPs.
The three phases for the integration of the CCA into the ERs are defined as follows.

- Step 1: Targets of the NPCCA that can be associated with MMPs
  The first phase is aimed at identifying and selecting NPCCA objectives and actions that are relevant to land use and urban planning. All 18 areas of the NPCCA were considered. Out of the 137 Objectives defined in the NPCCA, 74 Objectives were found to be relevant to the analysis of possible effects on spatial governance. Subsequently, by the same process, out of the 360 Adaptation Actions referred to the 137 Goals, 253 Actions were identified as relevant to land-use and urban planning. Table 1 shows, as an example, the identification and selection of Objectives and Actions of the NPCCA with reference to the Sector "Hydrogeological instability." In the example, the actions are identified with reference to the NPCCA goal "Improving emergency management by administrations at all levels and increasing public participation." The table contains a summary description of each action, and an indication of the indicators that the NPCCA associates with the action.
- Step 2: Targets of the NPCCA that can be associated with MMPs
  The second phase consists in the construction of the system of the specific objectives of the MMPs to which the ERs refer, that is, the construction of the LFs of the ERs of the MMPs.
  For the exemplification, which is proposed in the following third phase, reference is made to the Selargius MMP, which is a plan that has completed the process of adaptation to the Regional Landscape Plan (RLP)[7] and the Sectoral Plan for the hydrogeological framework (SPHF), and whose documentation is fully available online in the institutional website of the Municipality of Selargius[8].
  The environmental sustainability objectives, defined in the Selargius MMP as "General Objectives," and the Specific Objectives were extrapolated from the ER of the Selargius MMP, where they are clearly spelled out, while, as far as the plan actions are concerned, the set of actions in the ER was integrated with the actions reported in the Selargius MMP's elaboration No. 37 "Quadro Logico del MMP".
- Step 3: Integration of NPCCA objectives into the LFs of the ERs of the MMPs
  The integration of the NPCCA strategic framework into the LFs of the MMPs is exemplified in Table 2, which shows the structure of the assessment matrix. The matrix has been populated trough the following sub-steps:
  - comparison of all specific objectives of the MMP (column [b]) with all the objectives of the NPCCA relevant to land-use and urban planning (column [a]), selected in the first stage, also in light of the plan actions referred to them. At the end of the series of comparisons, column [c] is populated, which, for each specific objective of the MMP, lists all NPCCA objectives with respect to which it is relevant.
  - For each specific objective of the MMP, assessment of the level of integration of all NPCCA objectives for which relevance was found. Column [d] is thus populated, in which the specific objective is either kept unchanged in case it integrates all relevant NPCCA objectives, or is reformulated, in case the integration with one or more NPCCA objectives is only partial, so as to improve the level of integration.
  - Comparison between the NPCCA objectives relevant to the specific objectives of the MMP and all MMP actions (column [e]) that, in the strategic framework referred to in the second step, are linked to those specific objectives. In this sub-step, column [f] is populated, making explicit the ways in which each action contributes to the achievement of the NPCCA objective to which it is linked through the specific objective, and, where appropriate, indicating any corrections or arrangements needed to raise the level of integration. Non-relevant actions are excluded from the assessment.

  The final result of the assessment conducted through the LF approach is presented through a matrix which features both NPCCA goals relevant to specific objectives of the MMP stated in the ER, and plan actions related to them. Table 3 shows an example related to the Selargius MMP.
  Column [d] in Table 2 shows the new formulation of the specific objectives of the MMP's ER LF, which incorporates the NPCCA strategic framework, thus its regional declination in the CCA, as the specific objectives of the MMP have been reformulated to be consistent with those of the NPCCA. The MMP actions themselves are evaluated in relation to their consistency with the NPCCA Goals (last column of Table 2).

[7] Documents retrieved from: http://www.sardegnaterritorio.it/paesaggio/pianopaesaggistico2006.html. Accessed June 16, 2024.
[8] Retrieved from: https://www.comune.selargius.ca.it/amministrazione_trasparente/index.php?i1=19&i2=60&i3=98. Accessed June 16, 2024.

Table 3.2 Identification and selection of NPCCA Objectives and Actions that are relevant to spatial and urban planning

SECTOR	Hydrogeological instability		
OBJECTIVES	Improving emergency management by administrations at all levels and increasing public participation		
ACTIONS / MEASURES	Improved forecasting systems innovative methods of collecting information	Improved technical support, emergency management, and preparedness and training guidelines for technical design	Improved technical support, emergency management, and preparedness and training-techniques for emergency management
DESCRIPTION	Analysis of innovative information collection and monitoring methods	Development of Guidelines for engineering design in non-stationary environment	Developing emergency management techniques based on interdisciplinary approach
INDICATORS	– Number of early warning systems updated to take into account climate change and adaptation. – Number of registered users of early warning systems and information services. – Increased number of administrations using scientific evidence to support decision and policy making. – Improved catalog of knowledge tools (decision support tools (DST), other tools, technologies, methodologies, etc.) to support adaptation	– Number of projects funded – Number of regions updating their reference standards	– Number of technical reports, publications, and scientific communications relevant to civil protection organization at the local level – Increase in the number of actors/organizations involved in international support networks relevant to adaptation – Increased regional and national coverage of the monitoring carried out

Choice of spatial context

Sardinia, an autonomous region of Italy located in the western Mediterranean area (as shown in Figure 1, panel "A"), covers an area of approximately 24,000 square kilometers and is home to a population of 1,639,591 residents.

The choice of Sardinia as a case study is due to its insular status, which simplifies the investigation of environmental issues at the regional scale.

Additionally, the island's climate exhibits a remarkable consistency, featuring hot and dry Mediterranean summers and mild winters with moderate rainfall (Canu et al., 2015). The landscape is predominantly characterized by hills, with only a few plains, notably the Campidano plain (the prominent greenish area in Figure 1, panel "B"), which is of significance for agricultural purposes. Several small coastal valleys are also present, but their agricultural potential is compromised by coastal urbanization pressures. Sardinia boasts several mountain ranges, none of which exceed 2,000 meters in height, contributing to the island's rugged terrain (Pungetti et al., 2008).

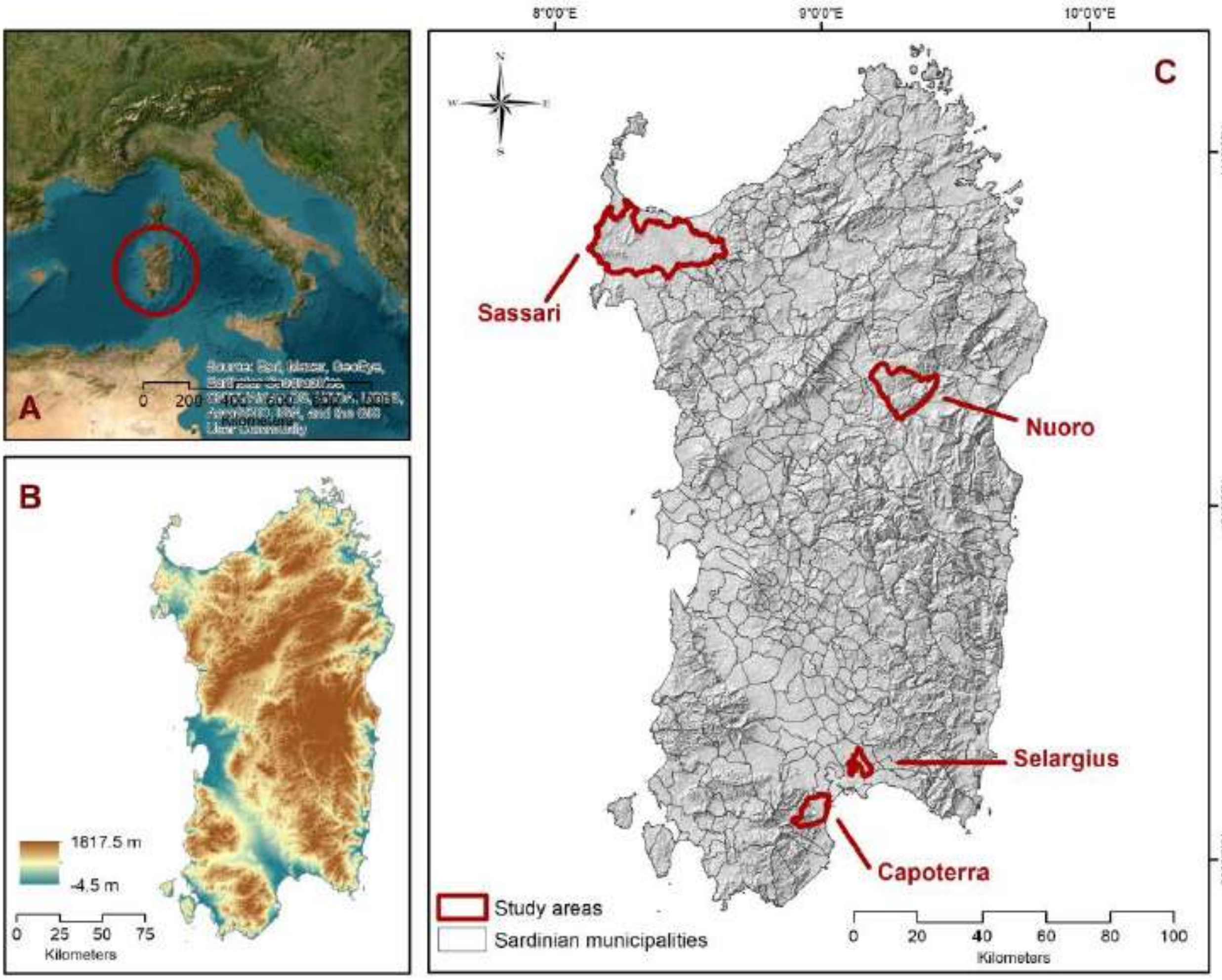

Figure 8. Sardinia within the Mediterranean Basin (A); Topographic map of Sardinia (B). The four municipalities selected as case studies (C).

Regarding land cover, Sardinia is distinguished by its herbaceous vegetation associations, many of which are endemic, as well as by its scrubland, comprising Mediterranean maquis and garrigue (Cardil et al., 2014). Agriculture and pastures, including wooded grasslands resembling Spanish dehesas (Seddaiu et al., 2013), play a significant role.

Table 3.3 - Evaluation matrix for the integration of NPCCA Objectives into the LF of MMPs' ERs.

[a]	[b]	[c]	[d]	[e]	[f]
Objective of the NPCCA	**Specific objectives of the MMP**	**Assessment of relevance between the NPCCA Objective and MMP objectives**	**Reframing the Specific objectives of the MMP in terms of CCA**	**MMP actions related to the specific objectives and consistent with the NPCCA Objective**	**Evaluation of MMP actions in relation to the NPCCA objective**
...	...	...	...	...	...

These multifunctional agro-sylvo-pastoral systems consist of pastures featuring oak and cork oak trees. Urbanized areas constitute less than 3.8% of the region's land, a notably low figure compared to the Italian average, which was recently assessed at 7.6% (Munafò, 2019).

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Table 3.4 - Construction of the LF that integrates NPCCA objectives MMP specific objectives and plan actions – Example referred to the Selargius MMP.

Objective of the NPCCA	Specific objectives of the MMP	Assessment of relevance between the NPCCA Objective and MMP objectives	Reframing the specific objectives of the MMP in terms of CCA	MMP actions related to the specific objectives and consistent with the NPCCA Objective	Evaluation of MMP actions in relation to the NPCCA objective
Encourage and support ecosystem service-based solutions aimed at preventing and mitigating the effects of extreme events attributable to climate change	Protect the qualitative and quantitative status of surface and subsurface water resources	Objectives of the NPCCA relevant to the objective of the MMP (previous column): i) improve land management and maintenance; ii) ensure the functionality of river ecosystems even in lean periods, environmental sustainability of water resource uses, and socioeconomic sustainability of related activities; iii) encourage and support ecosystem service-based solutions aimed at preventing and mitigating the effects of extreme events attributable to climate change; iv) improve the efficiency of the water supply system in periurban areas, suburbs, historic centers, and public spaces; v) increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers and public spaces; vi) promote planning and design for hazard prevention and facilitating monitoring; vii) increase or change the velocity and volume of water runoff; viii) improve the efficiency of water infrastructure; ix) operationally define risk assessment procedures and enhance the resilience of integrated water services; x) implement testing of materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability; xi) secure land in relation to hydrogeological risk.	Protect the qualitative and quantitative status of surface and groundwater resources while ensuring the permanence and functionality of associated ecosystems	Provision of precautionary measures in new residential expansion areas and guidelines for sustainable management of the water cycle: application of the principle of hydraulic invariance in new developments, with the construction of the lamination and rainwater collection tanks in individual lots	Collecting tanks and lamination basins distributed throughout the lots contribute to retention and thus mitigation of the effects of flood events

The ongoing practice of spatial planning in the Region of Sardinia is based on the adaptation of MMPs to the RLP and the SPHF, which involve the implementation of SEA processes within which, in endoprocessual terms, the MMP is produced and, essentially, identified, with the development of the assessment, according to the LF approach, with particular reference to the integration of the CCA in the construction of the system of objectives and plan actions (Table 1 through 3).

The selection of MMPs for testing the methodology for implementing CCA in SEA processes was based on the following criteria:

- cities with approved MMPs in accordance with RLP and SPHF;
- cities with significant population for the Sardinian context;

- availability of plan and SEA documents on cities' institutional websites.

For the first criterion, the monitoring registry of municipal planning instruments freely available on the regional geoportal was used as a data source, which led to the identification of about thirty municipalities with approved MMP compliant with the SPHF and the RLP[9].

The subsequent population relevance criterion, using a threshold of 20,000 inhabitants, narrowed the number of municipalities from about thirty to fewer than ten. Finally, based on the criterion of full availability of plan and SEA documents, the four selected case studies, namely the municipalities of Capoterra, Nuoro, Sassari, and Selargius, were identified from among the ten plans.

Capoterra, with its approximately 24,000 residents and 68 km^2 of land area, and Selargius, with approximately 29,000 residents and 27 km^2 of land area, are two important urban centers in the Metropolitan City of Cagliari, whose municipal territories are adjacent to that of the Regional Capital City to the west and north, respectively.

Nuoro, a provincial capital of Sardinia and the administrative landmark of the region's central mountainous areas, has a resident population of about 34,000 and an area of 192 km^2.

Sassari, the urban center capital of the Metropolitan City of Sassari, recently established under the provisions of the Regional Law No. 2021/7, is located in the northwest of Sardinia, in a predominantly flat territory with periurban belts characterized by an extensive presence of olive groves. Sassari has an area of 547 km^2 and a resident population of about 121,000.

For these four municipalities, whose locations are shown in Figure 2, panel "C", the ERs of the SEAs and the MMPs documents, such as general report and technical implementation rules, are analyzed in order to define the respective LFs that contribute to the overall scheme in Table 3.

3.2.3 Implementation of the methodological approach into the logical frameworks (LFs) of the ERs of four MMP's

The NPCCA reference sectors that stand out as the most significant within the MMPs of the four cities in Sardinia selected for the implementation of the methodology described in section 3.2.2 are hydrogeological instability, which is characterized by 31 specific objectives and 50 plan actions, urban settlements, with 29 specific objectives and 47 plan actions, and transportation, with 40 specific objectives and 62 plan actions. This section is divided into three parts and presents the results for each of these areas in relation to the definition of objectives and operational plan choices that integrate CCA into the LFs, i.e., strategic and implementation arrangements, of the MMPs.

Hydrogeological instability

The full set of actions and measures contained in the LFs of the ERs of the four analyzed MMPs that integrate climate considerations and contribute to addressing hydrogeological instability is provided in Table 4 (third column), together with the objectives from which they descend within each LF (second column), and the NPPCA's goals that are pursued (directly or indirectly, to a larger or lesser extent) through the plans' objectives and action (first column). Three NPCCA's goals have been found to be pursued by the four the LFs of the ERs of the MMPs; two out of three aim at enhancing knowledge, either on areas that are prone to hydrogeological issues within the administrative boundaries, or on the conditions of buildings and infrastructure, while the third goal is action-oriented and paves the way for either revised planning choices or tangible actions.

The first objective, concerning improved knowledge on critical geological and hydraulic issues, is integrated within Sassari's and Selargius' LFs, which both contain an action providing for the identification of areas characterized by hydrogeological hazard and risk. Such action stems from a single objective in Sassari's LF and is connected to three objectives in Selargius LF.

The second objective, concerning improved knowledge on the conditions of buildings and infrastructure with a view to increasing their resilience, is integrated within three LFs of the ERs of the MMPs (Capoterra, Sassari, and Selargius). As for Selargius, a single action, providing for mitigating hydrogeological risks, hence focusing on the resilience part, stems from two LF objectives, while in the two other LFs a one-to-one relation between action and objective can be observed.

[9] The thematic navigator can be retrieved from: https://www.sardegnageoportale.it/webgis2/sardegnamappe/?map=monitoraggio_strumenti_urbanistici. Accessed June 16, 2024. Data extrapolation from the attribute table of the shapefile "Monitoraggio strumenti urbanistici comunali, PUL, PP centri matrice e riperimetrazioni centri matrice" was carried out in December 2021. The shapefile was retrieved from: https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:4c48fe46-1014-4846-ae83-39c3be986b99. Accessed June 16, 2024.

In Capoterra, the action focuses on the coastal areas, where a critical infrastructure, the road connecting the regional capital with Capoterra and the southwestern part of Sardinia, lies over a narrow strip of land, constrained between the coastline and a large wetland.
In Sassari, the action focuses on former mining sites, which also include abandoned buildings forming the old mining hamlets, as knowledge on their status is a precondition for their recovery and reuse for tourism purposes.
Finally, the last objective, concerning improved land management and maintenance, is integrated within all of the four analyzed LFs of the ERs of the MMPs, by means of one action (connected to a single objective) in both Capoterra and Sassari, of three actions (connected to four objectives) in Selargius, and of seven actions (connected to seven objectives) in Nuoro.
The broad goal of enhancing land management and maintenance is variously pursued in the four LFs, whose actions range from studies and analyses, to the identification of rules to be included within the municipal planning implementation code, to tangible interventions aimed at addressing specific problems within the town, as in the case of the conversion of the former railroad and of landscaping actions in Nuoro, or of the recovery and reuse of former mining hamlets in Sassari, or of measures to mitigate hydrogeological hazards in Selargius and to improve the coastal area in Capoterra.

Table 3.5 - Goals related to hydrogeological instability contained in the NPCCA and integrated within the four analyzed logical frameworks (LF) of the MMP's environmental reports, LF's objectives and actions and measures that contribute to pursuing the NPCCA objectives.

NPCCA goals	LF objectives	LF actions
To improve land management and maintenance.	NUORO – To regulate building expansion.	Analysis of the residential and service systems.
	NUORO – To restore areas currently hosting illegal buildings.	
To improve land management and maintenance.	SELARGIUS – To ensure soil conservation and protection.	Restrictive rules for Subareas C3.1 (residential) and G1.4 (services and facilities), classed as areas prone to high and very high geological hazard. Their implementation in terms of urban planning and construction is subject to the execution of hydraulic works of mitigation, regimentation and regularization of the current hydrogeological risk, so as to eliminate constraints arising from the current classification under the SPHF
	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
To improve knowledge on critical geological and hydraulic issues in the area and their associated risks, and to produce updated databases based on land monitoring.	SASSARI – To prevent hydrogeological risks through appropriate land use regulations.	Identification of areas characterized by hydrogeological hazard and risk.
	SELARGIUS – To ensure soil conservation and protection.	
	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
To improve land management and maintenance.	NUORO – To ensure the endowment of public services and facilities.	Allocation of new areas for sports and recreation.
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To improve land management and maintenance.	NUORO – To reclaim areas with illegal buildings.	Preparation of a landscape-oriented redevelopment plan.
	NUORO – To take action on the "Testimonzos" area in accordance with current regulations.	
	SELARGIUS – To ensure soil conservation and protection.	Interventions aimed at mitigating hydrogeological risks.

To improve knowledge of the conditions of the buildings and infrastructure to increase their resilience.	SELARGIUS – To prevent new hydrogeological hazards.	
To improve land management and maintenance.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To improve land management and maintenance.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	Precautionary measures in new residential expansion areas and guidelines for sustainable management of the water cycle: the principle of hydraulic invariance shall be applied in new development, and individual lots will be equipped with lamination and rainwater collection tanks.
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To improve knowledge of the conditions of the buildings and infrastructure to increase their resilience.	SASSARI – To reactivate the Argentiera tourist system.	Functional-architectural recovery and securing of former mining areas
To improve land management and maintenance.	SASSARI – To reactivate the Argentiera tourist system.	
To improve land management and maintenance.	NUORO – To ensure the endowment of public services and facilities.	Conversion of the former railroad into a bicycle and pedestrian pathway.
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To improve land management and maintenance.	NUORO – To contain the built environment within an ideal perimeter.	Redesign of the zoning scheme.
	NUORO – To regulate building expansion.	
	NUORO – To plan and develop a linear park that includes equipment and services of public interest.	
To improve land management and maintenance.	NUORO – To ensure the endowment of public services and facilities.	Redevelopment of the railway station area by maintaining the existing destination while also providing for new volumes for residential, commercial, and office uses, as well as for a new "park and ride" area.
	NUORO – To regulate building expansion.	
To improve knowledge of the conditions of the buildings and infrastructure to increase their resilience.	CAPOTERRA – To protect and maintain environmental, historical and cultural components in order to recover historical memories and preserve landscape areas of particular importance, while also considering safety issues within the municipal areas, so as to promote its sustainable development by mitigating, or even reconsidering, incompatible urban planning expectations.	Improvement of the coastal area, mitigation of current erosion phenomena, conservation of the ecological systems (beach and wetland), environmental recovery of the wetland system for both productive and naturalistic purposes, reorganization of the coastal renaturalized landscape, environmental land rehabilitation for tourism purposes.
To improve land management and maintenance.		
To improve land management and maintenance.	NUORO – To ensure the endowment of public services and facilities.	New green recreation areas and landscaping.
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	

Urban settlements

With reference to urban settlements, Table 5 shows that all four MMPs develop strategies aimed at defining objectives and actions aimed at mitigating climate change negative impacts, and at adapting urban environments.
The NPCCA's objective concerning the improvement of thermal comfort and quality of living involves establishing measures for heat control, storage, and dissipation. The objective is fully implemented into the LFs of the ERs of the four analyzed MMPs through: i. two specific objectives in the LF of the ER of the Capoterra MMP; ii. eight specific objectives in the LF of the ER of the Nuoro MMP; iii. eight specific objectives in the LF of the ER of the Selargius MMP; and, iv. two specific objectives in the LF of the ER of the Sassari MMP. In relation to these objectives, two types of plan actions have been identified to achieve the NPCCA's objective: the first aims at redeveloping and recovering the built characteristics of the urban consolidated fabric, while the second concerns the redevelopment of peripheral, periurban and rural spaces.
This redevelopment pursues the strategic distribution of greenery to mitigate impacts due to solar radiation and the heat island effect (Isola et al., 2023b).
As for Capoterra, four plan actions are of the first type, while three plan actions refer to the second type. Both clusters of actions are associated with the same LF objectives. In the case of Selargius, most of the plan actions are aimed at creating green areas and improving the conditions of existing ones.
The actions are associated with the objective "To pursue an environmental policy aimed at increasing the quantity and quality of green spaces present in the urban and suburban context and to encourage processes of reconfiguration and regeneration of the same through raising the building quality of public spaces and facilities." The actions of the LF of the ER of the Nuoro MMP are, in general, oriented toward the redevelopment of the landscape and built environment, with particular attention to the endowment of urban standards, the enhancement of the built urban fabric and the redevelopment of some of the most important sites of historical and cultural interest.
The LF of the ER of the Sassari MMP, on the other hand, defines a plan strategy that, with reference to the objective of the NPCCA, focuses on the partially unbuilt areas within the urban center, through the inclusion of a share of non-developable areas to make room for an urban network of green areas. These plan actions pursue the objective of reconnecting the most significant urban voids.

Table 3.6 - Goals related to Urban settlements contained in the NPPCA and integrated within the four analyzed logical frameworks (LF) of the MMP's environmental reports, LF's objectives and actions and measures that contribute to pursuing the NPCCA objectives.

NPCCA's goals	LF objectives	LF actions
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To redevelop and re-organize the consolidated Urban Poles (urban center, coastal area, and the settlement of Poggio dei Pini).	Qualification of the main urban settlement: consolidation of the urban fabric, endowment, completion and rationalization of technological and road networks, integration of residential and public services in accordance with territorial safety and specific studies.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To redevelop and re-organize the consolidated urban areas (urban center, coastal area, and the settlement of Poggio dei Pini).	Restoration and completion of the existing urban settlement.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To redevelop and re-organize the consolidated urban areas (urban center, coastal area, and the settlement of Poggio dei Pini).	Recovery of historic public and private buildings.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To promote planning and design for hazard prevention and facilitating monitoring.		

To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To redevelop and re-organize the consolidated urban areas (urban center, coastal area, and the settlement of Poggio dei Pini).	Consolidation of existing public and private buildings and landscape redevelopment in the settlement of Poggio dei Pini.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To redevelop and re-organize the consolidated urban areas (urban center, coastal area, and the settlement of Poggio dei Pini).	Urban, road and environmental requalification of the structure of the coastal urban settlement in line with the landscape characteristics of the context as well as with the new structure that will take on with the construction of new road "SS 195" in order to guarantee adequate coastal accessibility and a rebalancing and compensation of the urban load of coastal settlements; provision of networks, including public and private services, to compensate for the strong existing imbalance between services and housing; enhancement of the connection systems between the different suburban realities.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To redevelop and re-organize the consolidated urban areas (urban center, coastal area, and the settlement of Poggio dei Pini).	Development of Coastal land use-plans allowing for greater qualification and diversification of services.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To protect and maintain environmental, historical, and cultural components to recover historical memories and preserve landscape areas of particular importance, while also considering safety issues within the municipal areas, to promote its sustainable development by mitigating, or even reconsidering, incompatible urban planning expectations.	Improvement of the coastal area, mitigation of current erosion phenomena, conservation of the ecological systems (beach and wetland), environmental recovery of the wetland system for both productive and naturalistic purposes, reorganization of the coastal renaturalized landscape, environmental land rehabilitation for tourism purposes.
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To plan and develop a linear park that includes equipment and services of public interest.	Identification of parking areas.
Improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.	CAPOTERRA – To redevelop and re-organize the consolidated urban areas (urban center, coastal area, and the settlement of Poggio dei Pini).	
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To regulate building expansion.	Analysis of the residential and service systems.
	NUORO – To reclaim areas with illegal buildings.	
	NUORO – To regulate building expansion.	

To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To reclaim areas with illegal buildings.	
To promote planning and design for hazard prevention and facilitating monitoring.	NUORO – To reclaim areas with illegal buildings.	
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To reclaim areas with illegal buildings.	Preparation of a landscape-oriented redevelopment plan.
	NUORO – To take action on the “Testimonzos” area in accordance with current regulations.	
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To reclaim areas with illegal buildings.	
	NUORO – To take action on the “Testimonzos” area in accordance with current regulations.	
To promote planning and design for hazard prevention and facilitating monitoring.	NUORO – To reclaim areas with illegal buildings.	
	NUORO – To act on the “Testimonzos” area in accordance with current regulations.	
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To ensure the endowment of public services and facilities.	Realization of an urban park for sports activities.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To promote planning and design for hazard prevention and facilitating monitoring		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To ensure the endowment of public services and facilities.	Inclusion of new recreational and sports functions.
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To ensure the endowment of public services and facilities.	
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To promote planning and design for hazard prevention and facilitating monitoring.	NUORO – To ensure the endowment of public services and facilities.	
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To ensure the endowment of public services and facilities.	New green recreation areas and landscaping.
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To ensure the endowment of public services and facilities.	
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To promote planning and design for hazard prevention and facilitating monitoring.	NUORO – To ensure the endowment of public services and facilities.	
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To renew buildings within the historic districts.	Architectural restoration and recovery.
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		

To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To promote processes of urban system regeneration.	Definition of interventions and implementation methods that promote the redevelopment of the urban context and the existing built heritage.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To promote processes of urban system regeneration.	Identification of the infrastructural and environmental corridor of the “Road of Parks”.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To promote the recovery of peripheral areas, agricultural, and degraded areas.	Planning of green spaces in building expansion areas.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To redefine the urban fringe and protect green corridors.	Identification of the “Road of Parks” and concentration of areas handed over to the Municipality of Selargius through supplementary agreements pursuant to Law 241/90 within the areas “San Lussorio”, “Paluna” and “Santa Lucia”.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To redefine the urban fringe and protect green corridors.	Provision of compensation mechanisms to ensure continuity of the Riu Nou river corridor.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To increase the quantity and quality of green spaces.	Planning of green areas and public services, dimensioned in relation to estimated housing demand.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To increase the quantity and quality of green spaces.	Concentration of areas for public services acquired for the realization of public parks.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		

To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To strengthen the endowment of green areas and public equipment to serve the urban system.	Acquisition of areas owned by other public entities to be used for services and public green spaces and drafting public agreements according to the 241/90 Law.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To strengthen the endowment of green areas and public equipment to serve the urban system.	
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	Interventions aimed at mitigating hydrogeological risks.
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers and public spaces.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To promote planning and design for hazard prevention and facilitating monitoring.	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SASSARI – To densify the settlement system.	Completion projects of areas within the urban center (type B2 standard).
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SASSARI – To regenerate empty urban spaces.	Urban ecological network construction.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers and public spaces.		
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To plan and develop a linear park that includes equipment and services of public interest.	Redesign of the zoning scheme.

	NUORO – To contain the built environment within an ideal perimeter.	
	NUORO – To regulate building expansion.	
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To plan and develop a linear park that includes equipment and services of public interest.	
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To plan a University center.	Refunctionalization of Artillery Station to change it to Public Services for the University Campus.
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To promote tourism.	Restoration of the Lollove and Ortobene Mount settlemenst .
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	NUORO – To promote tourism.	Maintenance of existing buildings.
To promote planning and design for hazard prevention and facilitating monitoring.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To promote the recovery of peripheral areas, agricultural, and degraded areas	Redevelopment of the Is Corrias areas, the boundary areas with the municipality of Quartucciu, bordering the municipality of Monserrato.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To improve thermal comfort and living quality in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To promote the recovery of peripheral areas, agricultural, and degraded areas	Redevelopment of areas bordering SS 554.
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.		
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To protect the qualitative and quantitative status of surface and groundwater resources.	Precautionary measures in new residential expansion areas and guidelines for sustainable management of the water cycle: the principle of hydraulic invariance shall be applied in new development, and individual lots will be equipped with lamination and rainwater collection tanks.
	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To increase soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To protect the qualitative and quantitative status of surface and groundwater resources.	
	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To promote planning and design for hazard prevention and facilitating monitoring.	SELARGIUS – To protect the qualitative and quantitative status of surface and groundwater resources.	
	SELARGIUS – To prevent new hydrogeological hazards.	

	SELARGIUS – To ensure soil conservation and protection.	
To improve the efficiency of the water distribution system in periurban areas, suburbs, historic centers, and public spaces.	SELARGIUS – To prevent new hydrogeological hazards.	Definition of a planning discipline compliant with the provisions of the SPHF.
	SELARGIUS – To ensure soil conservation and protection.	
To promote planning and design for hazard prevention and facilitating monitoring.	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To promote planning and design for hazard prevention and facilitating monitoring.	SELARGIUS – To prevent new hydrogeological hazards.	Restrictive rules for Subareas C3.1 (residential) and G1.4 (services and facilities), classed as areas prone to high and very high geological hazard. Their implementation in terms of urban planning and construction is subject to the execution of hydraulic works of mitigation, regimentation, and regularization of the current hydrogeological risk, to eliminate constraints arising from the current classification under the SPHF.
	SELARGIUS – To ensure soil conservation and protection.	

Regarding the NPCCA's objective concerning the improvement of the efficiency of the water supply system in periurban areas, suburbs, historic centers and public spaces, it is worth noting that the issue of water resource management is a nationwide problem. Regarding the LFs of the MMPs' ERs, the NPCCA goal is implemented into all of the four plans. In the case of Capoterra, six plan actions stem from a single LF objective alone related to the redevelopment and reorganization of consolidated urban hubs. As for Nuoro, ten plan actions refer to this NPCCA objective, and they derive from as many objectives of the LF of the MMP, largely aimed at enhancing the existing built and cultural heritage and ensuring the provision of new public services. The same aims are pursued in the LF of the Selargius MMP, in which thirteen plan actions implement the NPCCA objective and are associated with a set of specific objectives aimed at protecting the qualitative and quantitative state of water resources, preventing hydraulic and geological risk, and increasing the availability of quality green spaces in the urban, periurban and rural areas. The LF of the ER of the Sassari MMP targets two plan actions that relate to improving the efficiency of the water system; both refer to the need to define an urban ecological network and are linked to two different objectives of the LF.

The third and fourth objectives of the NPCCA aim to promote planning and design for risk prevention and to facilitate monitoring and increasing soil permeability and hydraulic system efficiency in periurban areas, suburbs, historic centers, and public open spaces. Both objectives aim to address these critical issues and are integrated into the LFs of the ERs of the analyzed MMPs.

The third objective is present in three of the LFs of the ERs of the analyzed MMPs, with the exception of Sassari, while the fourth is implemented into all four plans. As far as Capoterra is concerned, six plan actions contribute to the achievement of the NPCCA's third objective, all referring to the same specific objective of the LF of the ER of the MMP, namely the redevelopment and reorganization of the consolidated urban poles, i.e., the urban consolidated fabric, the Poggio dei Pini hamlet and the coastal strip. Also referring to Capoterra, six plan actions are associated with the fourth objective of the NPCCA. Among them, some implement the LF objective focused on the protection and preservation of environmental, historical and cultural components, and the protection of areas of special landscape significance; others pursue the LF objective of spatial and environmental safety.

Transportation network

The LF, reported in Table 6, provides: i. in the first column, the NPPCA's goals directly or indirectly pursued by objectives and actions of the LFs of the ERs of the analyzed MMPs; ii. in the second column, the objectives of the four LFs of the ERs of the MMPs with which the objectives of the NPPCA are associated; and, iii. in the third column, the actions that implement the LFs' objectives, integrate climate considerations, and contribute to addressing transportation network.

Table 3.7 - Goals related to transportation network contained in the NPPCA and integrated within the four analyzed logical frameworks (LF) of the MMP's environmental reports, LF's objectives and actions and measures that contribute to pursuing the NPCCA objectives.

NPCCA goals	LF objectives	LF actions

To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	CAPOTERRA –To regenerate and reorganize the consolidated urban areas (city center, Poggio dei Pini, coastal urban settlement), to be integrated within a unitary, organically articulated functional design.	Urban, road and environmental requalification of the structure of the coastal urban settlement in line with the landscape characteristics of the context as well as with the new structure that will take on with the construction of new road “SS 195” in order to guarantee adequate coastal accessibility and a rebalancing and compensation of the urban load of coastal settlements; provision of networks, including public and private services, to compensate for the strong existing imbalance between services and housing; enhancement of the connection systems between the different suburban realities.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To improve the effectiveness of monitoring, warning and emergency response systems for transport services.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	CAPOTERRA –To regenerate and reorganize the consolidated urban areas (city center, Poggio dei Pini, coastal urban settlement), to be integrated within a unitary, organically articulated functional design.	Development of coastal land-use plans allowing for greater qualification and diversification of services.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To improve the effectiveness of monitoring, warning and emergency response systems for transport services.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To plan and develop a linear park that includes equipment and services of public interest.	Identification of parking areas.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To restore areas currently hosting illegal buildings.	Analysis of the residential and service systems.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To restore areas currently hosting illegal buildings.	Preparation of a landscape-oriented redevelopment plan.
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To take action on the “Testimonzos” area in accordance with current regulations.	Preparation of a landscape-oriented redevelopment plan.
To integrate climate change risks into planning and design process	NUORO – To restore areas currently hosting illegal buildings.	Preparation of a landscape-oriented redevelopment plan.

in order to promote resilience and adaptation.		
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	NUORO – To take action on the “Testimonzos” area in accordance with current regulations.	Preparation of a landscape-oriented redevelopment plan.
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To ensure the endowment of public services and facilities.	Conversion of the former railroad into a bicycle and pedestrian pathway.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	NUORO – To enhance the area of the former powder mill in Prato Sardo.	Conversion of the former railroad into a bicycle and pedestrian pathway.
To make the municipal territory safer in relation to hydrogeological instability.	NUORO – To ensure the endowment of public services and facilities.	Conversion of the former railroad into a bicycle and pedestrian pathway.
To make the municipal territory safer in relation to hydrogeological instability.	NUORO – To enhance the area of the former powder mill in Prato Sardo.	Conversion of the former railroad into a bicycle and pedestrian pathway.
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To ensure the endowment of public services and facilities.	Conversion of existing areas into parking areas.
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	NUORO – To ensure the endowment of public services and facilities.	Conversion of existing areas into parking areas.
	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To improve and reorganize the northern access to the City of Nuoro.	To improve and reorganize the area called “Quadrivio”.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To enhance the historic center as a part of the city to be preserved and handed down to future generations in the most appropriate manner.	Design of the “City of Culture” path.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient	NUORO – To enhance the historic center as a part of the city to be preserved and handed	

to increasing temperatures and rainfall variability.	down to future generations in the most appropriate manner.	Identification of streets, squares and open spaces where the “Soil” Project should be implemented as a priority
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To enhance the historic center as a part of the city to be preserved and handed down to future generations in the most appropriate manner.	Construction of the “Nuoro Littoria” path.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To enhance the historic center as a part of the city to be preserved and handed down to future generations in the most appropriate manner.	Construction of a road to continue the existing one at the height of Via Mughina and construction of a car parking area with a mechanical path “Madonna della Neve” church.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To enhance the historic center as a part of the city to be preserved and handed down to future generations in the most appropriate manner.	Construction of a car park (multilevel and street level) for approximately 600-800 parking spaces.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	NUORO – To build a ring road running all around the existing urban settlement on the east side	Construction of a tunnel - construction of an uncovered section of the road - construction of a viaduct – construction of a cable-stayed bridge – road junction arrangement.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	SELARGIUS – To promote the regeneration of the city's peripheral areas, degraded areas and agricultural areas.	Redevelopment of the Is Corrias areas, the boundary areas with the municipality of Quartucciu, the boundary areas with the municipality of Monserrato.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	SELARGIUS – To protect the qualitative and quantitative status of surface and groundwater resources.	Precautionary measures in new residential expansion areas and guidelines for sustainable management of the water cycle: the principle of hydraulic invariance shall be applied in new development, and individual

To make the municipal territory safer in relation to hydrogeological instability.		lots will be equipped with lamination and rainwater collection tanks.
	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	Interventions aimed at mitigating hydrogeological risks.
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To make the municipal territory safer in relation to hydrogeological instability.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	
	SELARGIUS – To prevent new hydrogeological hazards.	
	SELARGIUS – To ensure soil conservation and protection.	
To experiment with materials, structures, facilities, and technologies that are more resilient to increasing temperatures and rainfall variability.	SASSARI – To define a physical framework of inter-neighborhood relations.	Construction of new inter-neighborhood physical connections.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.		
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	CAPOTERRA –To regenerate and reorganize the consolidated urban areas (city center, Poggio dei Pini, coastal urban settlement), to be integrated within a unitary, organically articulated functional design.	Qualification of the main urban settlement: consolidation of the urban fabric, endowment, completion and rationalization of technological and road networks, integration of residential and public services in accordance with territorial safety and specific studies.
To improve the effectiveness of monitoring, warning and emergency response systems for transport services.		
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	CAPOTERRA –To regenerate and reorganize the consolidated urban areas (city center, Poggio dei Pini, coastal urban settlement), to be integrated within a unitary, organically articulated functional design.	Restoration and completion of the existing urban settlement.
To improve the effectiveness of monitoring, warning and emergency response systems for transport services.		

To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	CAPOTERRA – To regenerate and reorganize the consolidated urban areas (city center, Poggio dei Pini, coastal urban settlement), to be integrated within a unitary, organically articulated functional design.	Recovery of historical features in private and public buildings; identification and requalification of the parts of the consolidated urban fabric, which is of historical and artistic character and of particular environmental or traditional value to be preserved.
To improve the effectiveness of monitoring, warning and emergency response systems for transport services.		
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	CAPOTERRA – To regenerate and reorganize the consolidated urban areas (city center, Poggio dei Pini, coastal urban settlement), to be integrated within a unitary, organically articulated functional design.	Consolidation of residences and services with an urban character, recovery and redevelopment of the landscape favoring maximum integration in the “Poggio dei Pini” area.
To improve the effectiveness of monitoring, warning and emergency response systems for transport services.		
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	NUORO – To identify the university pole.	Functional reconversion of the Artillery Barracks into a university campus (Campus in the Green).
To make the municipal territory safer in relation to hydrogeological instability.		
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	SELARGIUS – To redefine the urban fringe and to preserve green corridors	Identification of the “Road of Parks” and concentration of areas handed over to the Municipality of Selargius through supplementary agreements pursuant to Law 241/90 within the areas “San Lussorio”, “Paluna” and “Santa Lucia”.
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	SELARGIUS – To strengthen and to improve infrastructure networks.	
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	SASSARI – Protection and conservation of Sites of Community Importance.	Identification of transport network nodes along the inland coastline, improvement of services and infrastructure to facilitate mobility and increase the accessibility of the coastline (Special Area of Conservation “Stagno e ginepreto di Platamona”).
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	SASSARI – To encourage sustainable nature-based tourism.	
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	SASSARI – Protection and conservation of Sites of Community Importance.	Measures to reconnect coastal areas by means of tourist-environmental routes (greenways) (Special Area of Conservation “Coste e Isolette a Nord Ovest della Sardegna”).
To integrate climate change risks into planning and design process in order to promote resilience and adaptation.	SASSARI – To encourage sustainable nature-based tourism.	
To make the municipal territory safer in relation to hydrogeological instability.	NUORO – To ensure the endowment of public services and facilities.	New green recreation areas and landscaping.
To make the municipal territory safer in relation to hydrogeological instability.	NUORO – To enhance the area of the former powder mill in Prato Sardo.	
To make the municipal territory safer in relation to hydrogeological instability.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	Definition of a planning discipline compliant with the provisions of the SPHF.

To make the municipal territory safer in relation to hydrogeological instability.	SELARGIUS – To prevent new hydrogeological hazards.	
To make the municipal territory safer in relation to hydrogeological instability.	SELARGIUS – To ensure soil conservation and protection.	
To make the municipal territory safer in relation to hydrogeological instability.	SELARGIUS – To mitigate and reduce current hydrogeological risks in the municipality.	Restrictive rules for Subareas C3.1 (residential) and G1.4 (services and facilities), classed as areas prone to high and very high geological hazard. Their implementation in terms of urban planning and construction is subject to the execution of hydraulic works of mitigation, regimentation and regularization of the current hydrogeological risk, so as to eliminate constraints arising from the current classification under the Regional Plan against hydro-geological risk.
To make the municipal territory safer in relation to hydrogeological instability.	SELARGIUS – To prevent new hydrogeological hazards.	
To make the municipal territory safer in relation to hydrogeological instability.	SELARGIUS – To ensure soil conservation and protection.	

Four NPCCA's goals have been found to be pursued by the four LFs. Two objectives refer to prevention measures, such as promoting the securing of the territory against hydrogeological risk and the integrating climate change risks into planning and design processes. One objective refers to monitoring measures. Finally, the last objective refers to increasing knowledge in relation to materials, structures, plants and technologies that are more resilient to increasing temperatures and rainfall variability.

The first objective, which concerns the testing of materials, structures, plants and technologies more resilient to increasing temperatures and rainfall variability, is implemented into fifteen LF objectives: one from the Capoterra MMP's ER LF, eight from the Nuoro MMP's ER LF, five from the Selargius MMP's ER LF and one from the Sassari MMP's ER LF. With reference to the Capoterra LF, two actions, both connected to the LF objective, contribute to the achievement of the NPCCA objective in terms of transport network.

In reference to the Nuoro LF, twelve actions are connected to the eight LF objectives. With the exception of five LF objectives that are connected to a single action, the objectives "To restore areas currently hosting illegal buildings" and "To ensure the endowment of public services and facilities" are implemented through two actions each, while the objective "To enhance the historic center as a part of the city to be preserved and handed down to future generations in the most appropriate manner" is connected to five actions that contribute to the achievement of the NPCCA objective in relation to the transport network. With reference to the Selargius LF, the five objectives are implemented through a single action that contributes to the achievement of the NPCCA objective in terms of transport network. The action, concerning interventions aimed at mitigating and reducing the hydrogeological risk, is connected to three different LF objectives. The only objective of the Sassari MMP's ER LF is linked to a single action that contributes to the pursuit of the NPCCA objective in relation to the transport network.

The second objective concerning the integration of climate change risks into planning and design is implemented into nineteen objectives: one from the Capoterra MMP's ER LF, nine from the Nuoro MMP's ER LF, three from the Sassari MMP's ER LF, and six from the Selargius MMP's ER LF. With reference to the Capoterra LF, six actions, linked to a single LF objective, contribute to the pursuit of the NPCCA objective in relation to the transport network. In reference to the Nuoro LF, thirteen actions contribute to the achievement of the NPCCA objective. In particular, with the exception of five LF objectives each connected to a single action, the LF objective "To enhance the historic center as a part of the city to be preserved and handed down to future generations in the most appropriate manner" is connected to five actions. The LF objectives "To ensure the endowment of public services and facilities," "To restore areas currently hosting illegal buildings," and "To enhance the area of the former powder mill in Prato Sardo," are each connected to two actions contributing to the achievement of the NPCCA objective.

In addition, three actions ("Preparation of a landscape-oriented redevelopment plan", "Conversion of the former railroad into a bicycle and pedestrian pathway", and "Conversion of existing areas into parking areas") refer each to two different LF objectives. With reference to the Sassari MMP's ER LF, three actions contribute to the pursuit of the NPCCA objective in relation to the transport network.

With the exception of one LF objective, the remaining two LF objectives "To encourage sustainable nature-based tourism" and "Protection and Conservation of Sites of Community Importance" relate to two actions. Furthermore, two out of three actions relate to two different LF objectives. With reference to the Selargius MMP's ER LF, three actions contribute to the achievement of the NPCCA objective. With the exception of one action ("Redevelopment of the Is Corrias areas, the

boundary areas with the municipality of Quartucciu, the boundary areas with the municipality of Monserrato"), which is connected to a single LF objective, the other two actions are connected, respectively, to three LF objectives in the case of the action "Interventions aimed at mitigating hydrogeological risks" and two LF objectives in the case of the action "Identification of the "Road of Parks" and concentration of areas handed over to the Municipality of Selargius through supplementary agreements pursuant to Law 241/90 within the areas "San Lussorio", "Paluna" and "Santa Lucia"".
The third objective concerning the improvement of the effectiveness of monitoring, alerting and emergency intervention systems for transport services is implemented into a single LF objective related to the Capoterra MMP's ER LF. In addition, six actions, linked to the MMP objective, contribute to the achievement of the NPCCA objective.
The fourth objective concerning the securing of the territory in relation to hydrogeological risk is implemented into seven LF objectives: three of the LF of Nuoro, and four of the LF of Selargius. With reference to the Nuoro LF, three actions contribute to the achievement of the NPCCA objective.
Apart from one action ("Functional reconversion of the Artillery Barracks into a university campus (Campus in the Green)") which is connected to a single LF objective, the other two actions are both connected to two LF objectives. With reference to the Selargius MMP's ER LF, four actions contribute to the achievement of the NPCCA objective. Except for one LF objective ("To protect the qualitative and quantitative status of surface and groundwater resources") which is connected to a single action, the remaining three LF objectives are connected to all four LF actions.

3.2.4 Policy implications

Implications concerning planning policies aimed at integrating CCA into local planning processes, based on the LFs of the ERs of the SEAs of the MMPs of the four cities of Sardinia, are related to the plan actions arising from the implementation of the specific objectives. The types of actions are shown in the last column of Tables 4, 5, and 6.
An effective classification of the plan actions, that is, the operational part of the SEAs of the MMPs, which integrate CCA into the LFs, can be adequately represented by three general themes, as follows. First, the establishment or expansion of green areas, parks, outdoor recreation areas, forests, wooded areas and trees. Secondly, the appropriate management of the water resources regime of the municipal spatial contexts. Finally, greening operations referred to existing buildings or new developments.
Parks, forests and urban wooded areas significantly reduce surface temperature (Lai et al., 2020; Lai and Zoppi, 2023; EEA, 2020). According to a study by Armson et al. (2012), the shading and evapotranspiration of wooded areas result in a 5-7 °C drop in temperature, while an article by Bowler et al. (2010) estimates the temperature difference between urban parks and built-up areas at just under one degree. Urban wooded areas, through runoff mitigation, are, in addition, very effective in limiting vulnerability in relation to extreme weather events and, therefore, flooding events, which are particularly severe in urban areas characterized by a significant human presence. For example, Pataki et al. (2011) estimate how built-up areas, whose soils are made impermeable by urbanization, are characterized by runoff that falls within a range of 40-83 percent of rainfall, while in a wooded or forested urban area the phenomenon is about 13 percent.
With regard to planning policies referring to the construction or expansion of parks or wooded areas, the design profile is crucial for generating positive impacts in relation to heat waves, lowering temperatures, and for mitigating negative impacts of flood phenomena, including possible leakage of sewer lines (Berland & Hopton, 2014). There are, moreover, several studies available that estimate the economic impact of implementing these plan actions, although the outcomes are difficult to generalize (among many, Calfapietra 2020; Roy et al., 2012).
The strengthening of ecosystems characterized by the presence of wooded and forested areas is based, in essence, on the protection of primary forests, the recovery of degraded forest systems, the sustainable management of wooded and forested areas, and tree plantings in contexts characterized by the presence of other ecosystems, such as, for example, urbanized areas or those dedicated to agricultural production: here, wooded areas operate effectively in relation to the mitigation of hydraulic and landslide risk, and the negative effects of heat waves.
Planning policies related to urban water resource management consist, fundamentally, of maintenance of riverbanks, and construction of retention basins, retention infrastructure, drainage, and release of water from the increasingly frequent extreme weather events, such as bioswales and rain gardens, and reservoirs (UNaLab, 2019). Bioswales, rain gardens, and urban tree areas are also particularly effective vis-à-vis limiting pollution generated by sewage spills from pipes during extreme weather events (Wild, 2020). Of great importance, as well, are plan actions aimed at re-permeabilizing soils, for example, by removing excess asphalt road covers, cleaning up riverbanks and riverbeds, and restoring culverted streams.
At the broad spatial scale, planning policies related to the relationships between CCA and water resource management generally have the function of regulating flood phenomena and consist of the re-functionalization and restoration of river courses and floodplains (Francini et al., 2021). Floodplains and river belts provide the ecosystem service of mitigating the hardships that occur, in terms of water resource shortages, during periods of drought, as they promote, through drainage and water retention in the subsoil, the formation of water reservoirs, to be used, precisely, in the event of a shortage of the resource. Soil permeability allows, also, to decrease flood flows and the velocity of runoff, and to retain,

at least partially, transported sediments: this function is also put in place by areas used for agricultural production, especially in valley bottoms (Reberski et al., 2017). Surface runoff, water retention, and natural drainage due to permeability, especially during flood events, are, also, facilitated by the effective management of forests and wooded areas, especially in or near river belts (EEA, 2021).
Regarding the management of transportation infrastructure, a relevant issue is the construction of roads, parking lots, pedestrian streets, and playgrounds whose permeable superstructures and pavements decrease runoff, especially during major storm events (Wild, 2020), and allow, as much as possible, its passage into underground aquifers, thereby promoting greater availability of the resource during drought periods, and, at the same time, decreasing the magnitude of flood flows, which often generate significantly negative impacts in urban areas (Du et al., 2019). Porous pavements also enact an important filtering action that improves the quality of water that, through percolation, is stored underground (Depietri & McPhearson, 2017).
As for the interventions on individual buildings that can be traced back to the plan actions arising from the SEAs that integrate CCA-related policies, these are identified with the implementation of green roofs, walls and facades (EEA, 2021). The greening approach to buildings enables the implementation of effective stormwater management. According to a study by Ruangpan et al. (2020), green roofs increase water retention and decrease, and/or delay stormwater runoff during particularly significant events by up to 70 percent and 96 percent, respectively, during peak rainfall. Green roofs, facades and walls are, also, very effective in improving comfort inside residences and decreasing energy demand for building interior air conditioning (Francis & Jensen, 2017). In addition, green surfaces, whether they are outdoors or on the building envelope, have greater reflective power of sunlight than artificial surfaces in the built environment, with a difference that falls, according to an article by Perini and Rosasco (2013), in the range of 15-25%, with a very important impact on the mitigation of the urban heat island phenomenon.
Finally, it should be emphasized that, when defining the plan actions that are identified in the LFs of the ERs of the SEAs of the MMPs, the spillover effects of the implementation of these planning policies, i.e., the positive impacts that go beyond the integration of CCA into the LFs of the SEAs of the MMPs, should also be taken into account. FAO, for example, defines sustainable forest management as an evolving conceptual and technical category that aims to conserve and enhance the economic, social and environmental values of all forest types for the benefit of current and future generations, a category that consists, fundamentally, of making sure that the available productions, with reference to both timber and food, come from production systems that ensure an equitable intergenerational distribution of supply (FAO, 2020).
Forest management is, also, of great importance with reference to the abatement of concentrations of pollutants in water from spills generated by any productive activities, agricultural or industrial, that occur upstream (Mysiak et al., 2019). The increase in the availability of the resource in subsurface water reservoirs, as a result of the substantial in hydraulic and naturalistic engineering works, implemented according to the conceptual references recalled above, constitutes an important positive impact regarding the management of water resources at the large territorial scale.
Natural forest ecosystems are reservoirs of biodiversity and constitute a relevant defense against the negative impacts of climate change (Forest Europe, 2015). The restoration of degraded forest and wooded areas and the planting of new forests are important references for the definition and implementation of effective land policies, including in economic terms, in relation to the balance between costs and benefits, both in the medium and long term (Mansourian et al., 2019).
Plan actions related to the micro-area scale also include those aimed at phytoremediation, such as the establishment of adequate riparian vegetation in river belts, retention and filtration wells, and constructed wetlands: these can be extremely effective in treating effluent before it is discharged into rivers (Wild, 2020). In conclusion, it should be emphasized how a fundamental issue is represented by the inclusion, in prescriptive terms, of the plan actions concerning CCA, generated within the SEA processes, in the implementation codes of the MMPs.
One feasible approach to incorporate a set of rules explicitly linking CCA-related planning policies with the implementation of land-use regulations into the MMPs' statutory code is to establish project worksheets as prescriptive guidelines integrated within the planning code. These worksheets should provide detailed instructions on how to implement each identified plan action to address the specific objectives outlined in the MMPs' LFs. The use of such project worksheets is a well-established method, widely adopted in the planning regulations of various Italian cities, and extensively discussed in scientific and technical literature.
A notable example demonstrating the application of these project worksheets can be found in the Trieste Master Plan (Regione Autonoma Friuli-Venezia Giulia-Comune di Trieste, 2018). In this Master Plan, the project worksheet approach is used on a large spatial scale, particularly in areas earmarked for significant spatial transformations, urban regeneration zones, areas slated for urban renewal, and the creation of a new garden city. According to the Trieste Master Plan, project worksheets pertain to areas and subareas identified through the delineation of the relevant urban zones. Unless specified otherwise (with such specifications included in the worksheets), graphic elements are not prescriptive. However, the key

project elements, quantitative parameters, implementation procedures, and land-use regulations are legally binding (ibid., p. 3).
These "key project elements" encompass quantitative parameters, urbanization efforts, and ecological criteria related to urban planning. These criteria are identified by factors such as permeability rates, tree and shrub densities, and should be integrated with the public service framework across different urban sectors, considering their endowments and planned interventions on existing settlements and expansion. The mandatory nature of these project worksheets concerning plan actions, as dictated by the Trieste Master Plan, necessitates a high level of technical detail to ensure the binding nature of the project rules, thereby ensuring the effective execution of these plans.
Nevertheless, the planning approach centred on project worksheets, which can be seamlessly integrated into standard spatial planning practices without the need for additional legislation, requires expertise not only in CCA-related technologies but also, perhaps most importantly, in financial aspects, project timelines, and the trained personnel essential for managing the operational phases of project implementation.

3.3 A proposal of planning tools integration through the PoC for the transition of urban district in urban eco-districts

Cities face new and multiple challenges at various levels. Currently more than half of the world's population lives in cities and this proportion is expected to continue to rise. In this context, the transition to eco-districts represents a complex challenge that requires an integrated and innovative approach to urban planning. The complexity, quantity and heterogeneity of the phenomena involved in urban and metropolitan settlements require innovative, systemic and multidisciplinary cognitive approaches (Losasso, 2013). To this end, a multidisciplinary, a-scalar and intersectoral method allows optimising all aspects of the different areas of transformative intervention and in the process, project and product dimensions, combining traditional and innovative methodologies in an integrated way.

Wolfram et al. emphasize that, to address the challenges of sustainable urban development, research must register the spatial institutional complexity of urban transformation processes and transition to multi-systemic approaches. In an interdisciplinary and transdisciplinary collaborative approach with the city administrations, the use of the Proof of Concept (PoC) would allow for concrete and measurable testing of the effectiveness of different contributions of tools, from environmental and socioeconomic modelling to active citizen participation and the use of digital technologies.

In the new climate regime, linear production-consumption-discount models impose a transition to a zero-carbon society and a green circular economy (UN Habitat, 2011; IPCC, 2022). Urban regeneration processes focused on "parts of the city" identify the urban district as the "minimum size of interventions", allowing economies of scale and supporting significant investments to qualify buildings, district services and sustainable housing (AUDIS, GBG Italia & Legambiente, 2011). The scale of urban district is thus appropriate for addressing environmental, natural and anthropogenic risks, promoting mitigation, adaptation and resilience actions.

In the application field, the Proof of Concept (PoC) concept represents a cyclic method of observation, knowledge, evaluation and design, aimed at testing an idea to prove its feasibility before its full realisation. The PoC approach thus tends to develop a methodology to obtain a product at a middle stage of its development and prior to its realisation. The objective is not to reach the final product, but to test an idea in order to demonstrate its feasibility, offering the possibility of re-orienting decisions in its development cycle. This aspect is linked to a TRL - Technological Readiness Level - of average value and therefore comparable with the degrees of the idea definition, modulated in comparison with the needs of the stakeholders, as well the needs referable to the urban system in its complexity, resources, environment, etc.

PoC approaches (Goldenberg, 2023) are not to date incorporated into existing design development methodologies. This approach, focused on assessing the feasibility of design concepts using pilots, demonstrators and test beds, would allow for the development of a methodology that incorporates specific requirements, measurements, objectives and results in the design at the urban and building scale, enabling the assessment the impact of different policies, urban interventions and design proposals on reducing the impacts of hazards, improving quality of life and creating more resilient communities, and to help identify gaps and synergies between different instruments, enabling the refinement of long-term planning strategies. The PoC contribution is not limited to experimentation but prefigures the development of planning tools for the transition of urban districts into eco-districts. It also highlights strategies to reduce vulnerabilities and increase resilience by addressing causes of environmental and anthropogenic risks with appropriate mitigation measures. The PoC can therefore play a key role in the context of urban reorganisation and regeneration of urban settlements. It can be a useful tool in the implementation of interventions in areas characterised by a higher concentration of risks and in the planning phases of the necessary adaptation and mitigation interventions.

To further support the use of PoC methodology, we propose a methodological approach based on the integration with the methods and tools provided by the NCAPP.

Within the framework of green transition of urban district into eco-district, a set of actions derived from the Nation Climate Change Adaptation Plan (NCCAP) is defined for the climate risk-oriented design at the district scale, assessing their climate adaptation efficiency through a set of indicators proposed by NCAPP (MATTM, 2023). Setting up a monitoring system of climate change impacts through such set of indicators could therefore provide a knowledge base useful to test and monitor over time the effectiveness of adaptation actions. Moreover, the contribution intends to propose a preliminary methodology through which to address the existing gap between the definition of large-scale strategies by the PNACC and the lack of useful tools for the implementation and verification of actions at the local scale. To this end, a performance indicator and a progress indicator were assigned to each action to assess their effects over time.

Figure 9. Proof of concept approach applied to the design proposal application.

According to the output of DV2.1 and following a taxonomic approach, Grey and Green components (respectively, built-up areas and technological systems for the Grey sectoral domain; green and blue systems for the Green one) were analyzed in relation to climate risks for the study area and to the environmental features highlighting criticalities and strengths to be addressed in the design phase. In accordance with the PoC methodology, the possibility of monitoring the progress of each action in terms of both implementation and results achieved represents a crucial feature of such an approach in the framework of green transition towards urban eco-district. In this sense, the contribution of design proposals in terms of improved environmental conditions in the climate change scenario can be adapted and reset according to indicators and thus contextual needs, simplifying decision support processes through the introduction of a step-by-step toolbox of measurable actions. The definition of requirements, objectives, strategies and actions will therefore be necessary to determine the conditions for the feasibility of the proposal and to apply metrics to evaluate effectiveness of scenarios and outcomes.

After the definition of the strategy, ex-ante and ex-post-performance indices and indicators are checked to measure the effectiveness of the planned actions and their compliance with the requirements set by the project. The proposed methodology can allow the achievement of integrated urban resilience objectives regarding building-block and district scale, acting on both short to long-term solutions monitoring system, as well as on the effectiveness of such strategies and solutions in quantitative terms.
The proposed methodological approach was tested in the urban district of Soccavo in Naples and is further described in section 5.3.1.

4. Monitoring and assessment systems through indicators and protocols for urban integrated resilience in the framework of green transition

4.1 Indicators and protocols to monitor and assess urban systems

The concept of eco-districts represents an emerging housing model, designed to address current multi-risk conditions through a holistic approach to urban development. This concept can create an integrated framework to promote urban regeneration and resilience, linking environmental, social and governance levels.

In this context, it is important to select indicators that effectively measure the resilience of a selected area, particularly with regard to implementing green transition strategies and resource management initiatives such as waste reduction programs, water conservation measures, and innovative technologies for greywater recycling. The final goal is to shape more sustainable and resilient cities.

This study focuses on resilience and ecological transition within urban environments, aiming to develop a simplified and standardized model for territorial analysis. Starting form an extensive literature review on urban resilience—aimed at capturing the complex conceptual and operational aspects related to its measurement—the study led to developing a resilience indicators catalogue. The literature reviewed includes articles from SCOPUS database, recently published (2014-2024), based on specific search strings and keywords. As a result of this process, an extensive catalogue of indicators was compiled (for further details, see DV 4.1).

From this catalogue, 30 indicators were selected for their relevance within the framework of ecological transition (table 4.1). For each selected indicator, detailed information—including definitions, sources, and potential applications—was collected and is presented in Table 4.2 in a concise form. It is important to note that some of these indicators were added in a later phase, sourced from additional studies, institutional reports, planning tools, and other grey literature deemed relevant to the study's objectives but missing from the SCOPUS literature.

The use of indicators is a controversial topic as a single formula may not fully capture all the aspects of a given issue. Many indicators identified in the literature provide generic and discrete values (in the mathematic use of the term discrete) for different territories, but they do not effectively describe the resilience capacity of an urban settlement. Furthermore, this study seeks indicators able to represent specific aspects of a territory through spatial representation, supported by Geographical Information Systems (GIS). Therefore, the selection process was aimed to identify easily representable indicators supported by complete databases with verified information. In many cases, the data required to apply the set of indicators to a concrete case study is not available in current open-source web databases, although it may be found in non-public datasets. While an indicator may be effective for descriptive purposes, it is not useful for this research if it cannot be spatially represented, particularly at the sub-municipal or district scale. For this reason, when testing these indicators in the Turin case study (specifically in the northeastern districts of the municipal territory), finally only 18 of the 30 selected indicators listed in Table 4.1 were applied. In the following pages, each applied indicator is presented with its basic information organised in a table, alongside its spatial mapping.

As established in another study (developed in DV 4.1), when examining methods to measure the capacity to respond and adapt to climate change and track progress toward ecological transition, it is essential to adopt an integrated approach to urban planning. To avoid mere theoretical premises, the complexity of processes related to urban settlements and related development strategies must be captured through both qualitative and quantitative methods. While many studies focus on risk reduction and the implementation of climate-proof solutions, the concept of urban resilience requires a multidimensional approach with the combination of both ex-ante preventive actions and ex-post interventions.

Table 4.1. Indicators selected for their relevance within the framework of ecological transition

ID	Resilience indicator	Topic	Definition	References
1	Energy performance of buildings	Buildings	Energy efficiency of the existing building stock	Chen et al., 2023
2	Energy efficiency interventions or renovation of public buildings	Buildings	Energy efficiency of the existing building stock	Energy Efficiency Directive (EU/2023/1791), 2023
3	Brownfield sites	Buildings	Proportion of brownfield land within a selected area	Smollin and Lubitow, 2019
4	Energy consumption	Resources / Resources consumption	Total consumption of natural gas and electricity from distribution networks in a selected area	Chen et al., 2023 (B); Fu and Wang, 2018; Lin et al., 2022
5	Renewable energy	Resources / Resources consumption	Percentage of energy derived from renewable sources as part of the total gross energy consumption in a selected area	Fu and Wang, 2018; Oliveira and Fath, 2023
6	Reused water	Resources / Resources consumption	Percentage of reused water as part of the total gross water consumption in a selected area	Maffettone and Gawlik, 2022

7	Water consumption	Resources / Resources consumption	Total amount of water consumed by both the resident population and non-residents in a selected area during a year	Chen et al., 2023 (B); Fu and Wang, 2018; Lin et al., 2022; Suárez et al. 2016; Wang et al., 2023
8	Local Agricultural Production Area	Resources / Resources consumption	Proportion of land used for food production within a selected area	Chen et al., 2023 (B); Fu et al., 2021; Wu et al., 2023; Yang and Wang, 2024
9	Carbon Storage and Sequestration	Ecosystem services	Amount of carbon stored in a landscape and amount of carbon sequestered over time	Bayulken, 2021; Mitrović et al., 2023; Wang and Foley, 2021
10	Urban Cooling	Ecosystem services	Index of heat mitigation based on shade, evapotranspiration, and albedo, as well as distance from cooling islands. The index is used to estimate a temperature reduction by vegetation	Bertesaghi et al., 2018; Zawadzka et al., 2021
11	NDVI	Natural/green spaces	Normalized Difference Vegetation Index	Wang et al., 2023; Liu et al., 2024; Sebestyén et al., 2024
12	Protected areas	Natural/green spaces	Proportion of protected areas over the total area	Chen et al., 2023 (B)
13	Public urban trees	Natural/green spaces	Number of publicly managed urban trees	Salazar-Llano et al., 2019
14	Forest cover	Natural/green spaces	Proportion of forest coverage over the total area	Lin et al., 2022 (A)
15	Imperviousness	Natural/green spaces	Proportion of permeable surface over the total area	Fu and Wang, 2018; Mitrović et al., 2023; Oliveira and Fath, 2023; Wang and Foley, 2021.
16	Tree cover density	Natural/green spaces	Extent of land area covered by the canopy of trees	Bayulken, 2021; Chen et al 2023(A)
17	Green urban spaces	Natural/green spaces	Lot area occupied by green urban spaces (public and private) compared to the resident population	Chen et al. 2023(A); Delgado-Ramos and Guibruner, 2017; Gaber et al., 2022, Lin et al., 2022 (A), Lin et al., 2022 (B); Oliveira and Fath, 2023
18	Natural and seminatural areas	Natural/green spaces	Proportion of Land use/Land cover classes related to natural and seminatural areas (Artificial, non-agricultural vegetated areas, Agricultural areas, Forest and semi-natural areas, Wetlands, Water bodies)	Chen et al., 2023 (B)
19	Ecological network	Natural/green spaces	Areas with High and Moderate Ecological Functionality, according to ecological network analysis obtained with ENEA methodology	Minciardi et al., 2019
20	Elements of the ecological network	Natural/green spaces	Areas of ecological value, according to ecological network analysis obtained with ARPA Piemonte methodology (DGR n. 52-1979 del 31/7/2015)	Regione Piemonte, 2015
21	Land Capability	Land use	The land-use capability makes it possible to differentiate soils according to their productive potential in the agro-silvopastoral sphere	Upadhyay et al., 2006
22	Accessibility to green urban spaces	services	Percentage of population with access to a green public area less than 300m away	Chen et al., 2023 (B); Suárez et al. 2016

23	Cycling infrastructure	Infrastructures and network	The proportion of the census section area covered by a 300 m buffer from a bicycle lane	Chen et al., 2023 (B)
24	Public transport	Infrastructures and network	Concentration of bus and tram stops within a 300-meter radius, reflecting the accessibility and coverage of the local transportation network	Chen et al 2023(A); Jiao et al., 2023; Mu et al. (2022); Wang et al., 2023; Zhang et al., 2020; Zhano et al. 2022
25	Walkability index	Infrastructures and network	Mobility and accessibility for pedestrians	Sebestyén et al., 2024; Shaker et al. 2020; Tumini et al., 2017
26	Public water fountains	Infrastructures and network	Density of public water fountains within a 300-meter radius, representing the accessibility of free, potable water in a given area	Salazar-Llano et al., 2019
27	Air pollution	Pollution	Number of days with concentrations above the local norm or standard for key criteria pollutants (NH_3, NOx, PM 2.5, PM 10, SO_x) in a selected area	Chen et al., 2023 (B); Lin et al., 2022 (A); Zhano et al. 2022
28	Water pollution	Pollution	Number of days exceeding Enviromental Quality Standards (water) in a selected area	Gaber et al., 2022
29	Land take	Land use	Proportion of land take over the total area	Fu et al., 2021; Sharma et al., 2023
30	Land use diverisity	Land use	Variety and mixture of difference types of land uses	Fu et al., 2021; Sharma et al., 2023

Table 4.2. Exemplary data sheet illustrating the information collected for each selected indicator

Name	Name of the indicator
ID	Reference number
Dimension	The dimensions of resilience addressed by the indicator. These include environmental, built environment, social, economic and institutional dimensions. A single indicator can cover one or more dimensions.
Topic	Thematic categories including buildings, cooperation, demography, ecosystem services, emergency, heritage, income, infrastructure and networks, land use, landscape, natural/green spaces, planning and programming, pollution, resources/resource consumption, and services.
Definition	Short explanation of the indicator
Direction	Whether the indicator has a positive or negative effect on resilience. n addition, the direction can be expressed as "not defined" when the effect varies depending on the specific context and requires further interpretation.
Formula	The mathematical representation, when possible, of the indicator
Unit of measure	The unit in which the indicator is measured
Data source	The dataset, institutional repository or platform that supplies the information used to build the indicator
Territorial scale	The geographic resolution of the dataset used for the indicator
Timescale	This is the year or time frame that the dataset used to calculate the indicator covers.

Table 4.3 Brownfields Sites

Name	**Brownfields Sites**
ID	**3**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☒Institutional
Topic	Buildings
Definition	Surface and location of unused, abandoned, or underutilized areas, typically previously used for industrial or commercial purposes, which may have potential for redevelopment
Direction	☐positive ☐negative ☒not defined
Formula	$$N = \frac{A_b}{A}$$ N= Brownfield sites A_b= Global surface of the brownfield site(s) A= surface of the selected area
Unit of measure	% (m2/m2)
Data source	Carta Tecnica Comunale (Comune di Torino), 2024; Piano Regolatore Generale (Comune di Torino), update 2024; Torino Atlas (Urban Lab), 2017
Territorial scale	Sub-district
Timescale	2017

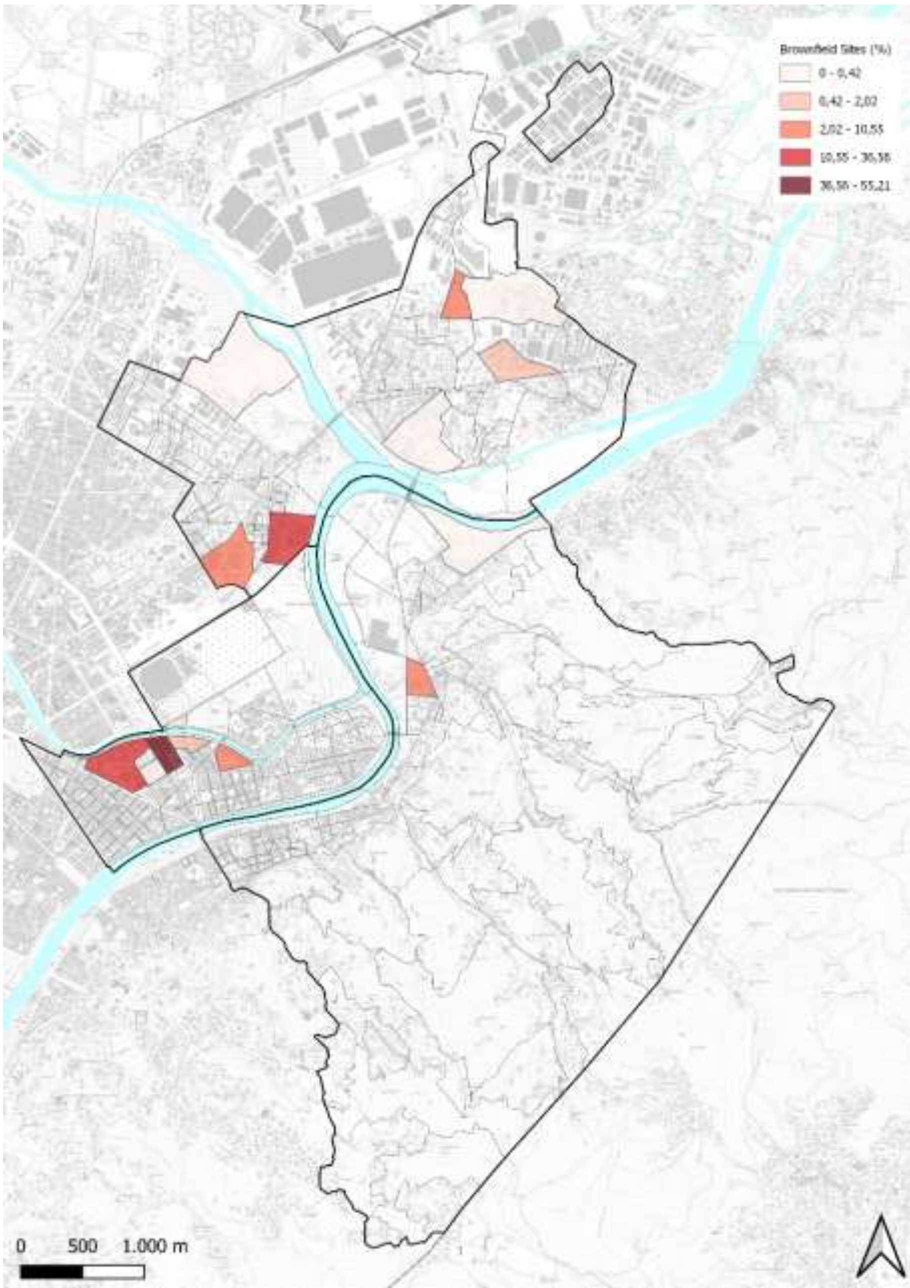

Figure 10. Brownfields Sites indicator (output map).

Table 4.4 Carbon Storage and Sequestration

Name	**Carbon Storage and Sequestration**
ID	**9**
Dimension	☒Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Ecosystem services
Definition	Amount of carbon stored in a landscape and amount of carbon sequestered over time
Direction	☒positive ☐negative ☐not defined
Formula	N= Carbon Storage and Sequestration* * Based on the chosen evaluation model
Unit of measure	t/pixel
Data source	Città metropolitana di Torino, Simulsoil, 2018
Territorial scale	Sub-district
Timescale	2018

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Figure 11. Carbon Storage and Sequestration indicator (output map).

Table 4.5 Normalized Difference Vegetation Index

Name	**NDVI**
ID	**11**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	natural/green spaces
Definition	Normalized Difference Vegetation Index
Direction	☐positive ☐negative ☒not defined
Formula	N= Normalized Difference Vegetation Index where Red and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively
Unit of measure	adimensional
Data source	Land Cover Piemonte (Regione Piemonte), 2023
Territorial scale	Sub-district
Timescale	2023

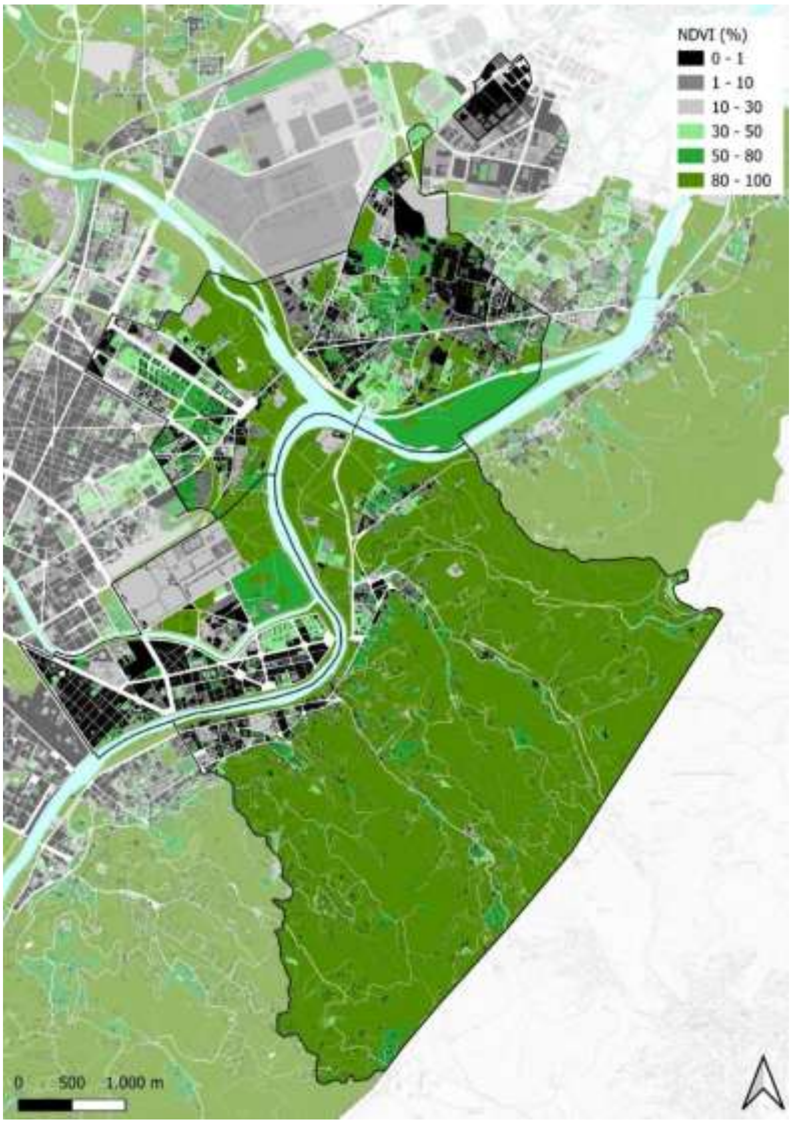

Figure 12. NDVI indicator (output map).

Table 4.6 Protected areas

Name	**Protected areas**
ID	**12**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☒Institutional
Topic	natural/green spaces
Definition	Proportion of protected areas over the total area
Direction	☒positive ☐negative ☐not defined
Formula	$$N = \frac{A_p}{A}$$ N= Protected areas, expressed as a percentage A_p= global surface of the protected area A= surface of the selected area
Unit of measure	% (km^2/km^2)
Data source	Regione Piemonte, Aree protette e altre aree tutelate
Territorial scale	Neighbourhood
Timescale	2024

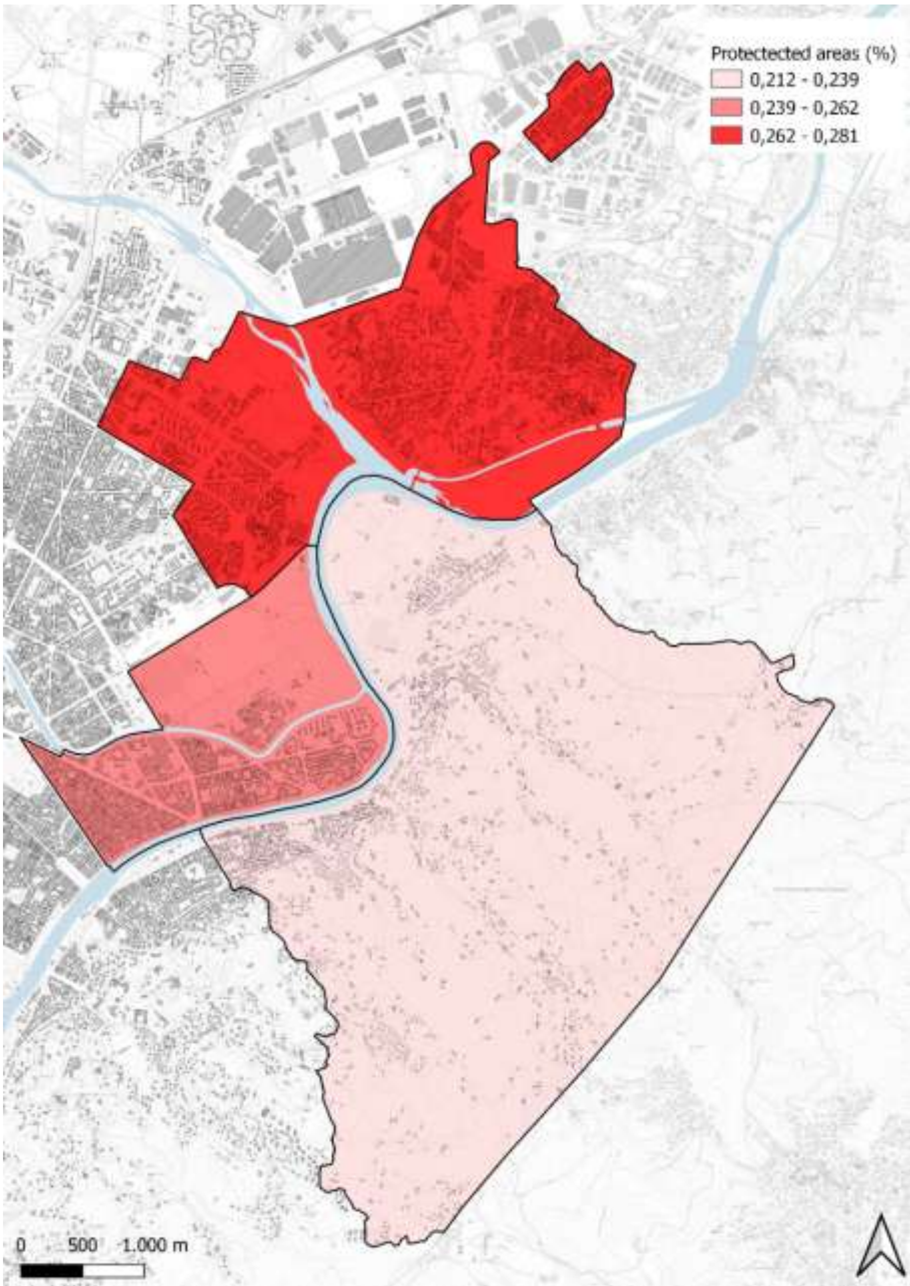

Figure 13. Protected areas indicator (output map).

Table 4.7 Public urban trees

Name	**Public Urban Trees**
ID	**13**
Dimension	☒Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Natural/green spaces
Definition	The ratio of publicly managed urban trees to the total population in the selected area.
Direction	☒positive ☐negative ☐not defined
Formula	$\boldsymbol{N}=\mathrm{N}\boldsymbol{t}$ N = Public Urban Trees Nt= number of Public Urban Trees
Unit of measure	Unit
Data source	Comune di Torino (aperTO), layer “Alberate”
Territorial scale	Sub-district
Timescale	2024

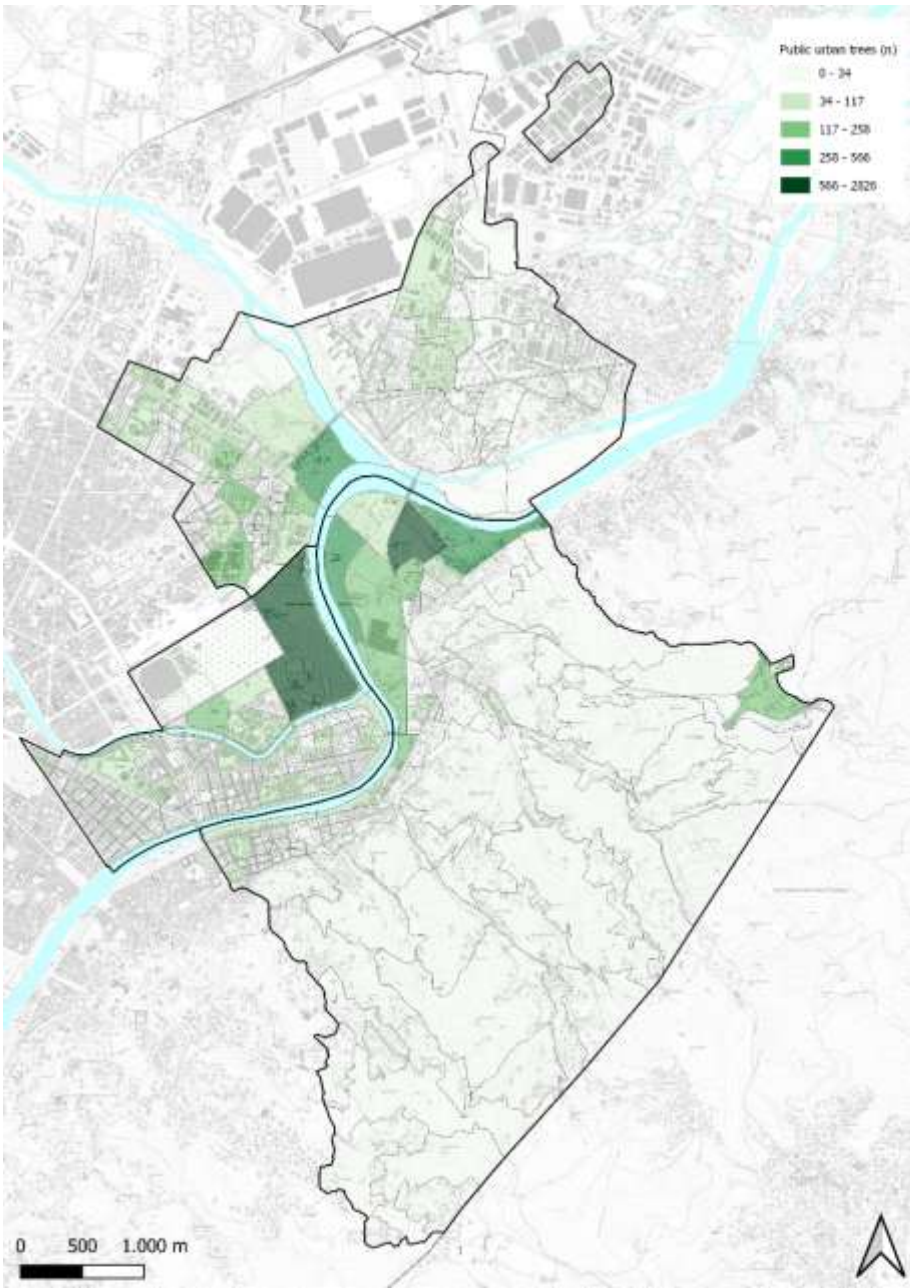

Figure 14. Public Urban Trees indicator (output map).

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Table 4.8 Forest cover

Name	**Forest cover**
ID	**14**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☒Institutional
Topic	natural/green spaces
Definition	Proportion of forest coverage over the selected area
Direction	☒positive ☐negative ☐not defined
Formula	$N = Af / A$ *N* = Forest cover Af = Global surface of forest cover *A* = Surface of the selected area
Unit of measure	% (km^2/km^2)
Data source	Land Cover Piemonte (Regione Piemonte), 2023 all classes included within CLC-level I “3. Forest and semi natural areas”
Territorial scale	Neighbourhood
Timescale	2018

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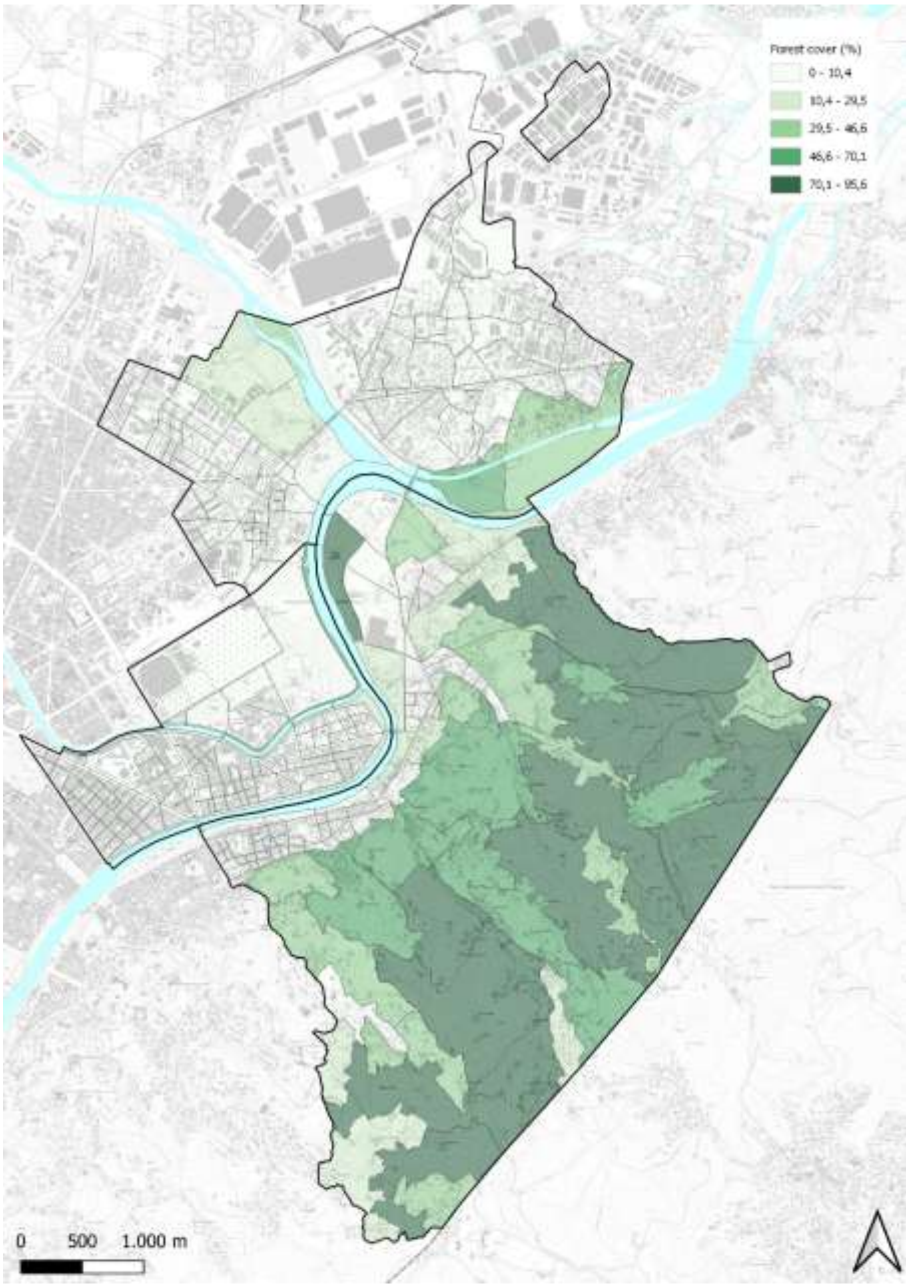

Figure 15. Forest cover indicator (output map).

Table 4.9 Imperviousness

Name	**Imperviousness**
ID	**15**
Dimension	☒Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	natural/green spaces
Definition	The covering of the impervious surface because of urban development and infrastructure construction, in the selected area
Direction	☐positive ☒negative ☐not defined
Formula	$\boldsymbol{N}=\boldsymbol{A}\mathrm{i}/\boldsymbol{A}$ N = Imperviousness, expressed as a percentage Ai=Global surface of the impervious areas A = Surface of the selected area
Unit of measure	(m^2/m^2) %
Data source	Land Cover Piemonte (Regione Piemonte), 2023
Territorial scale	Sub-district
Timescale	2018

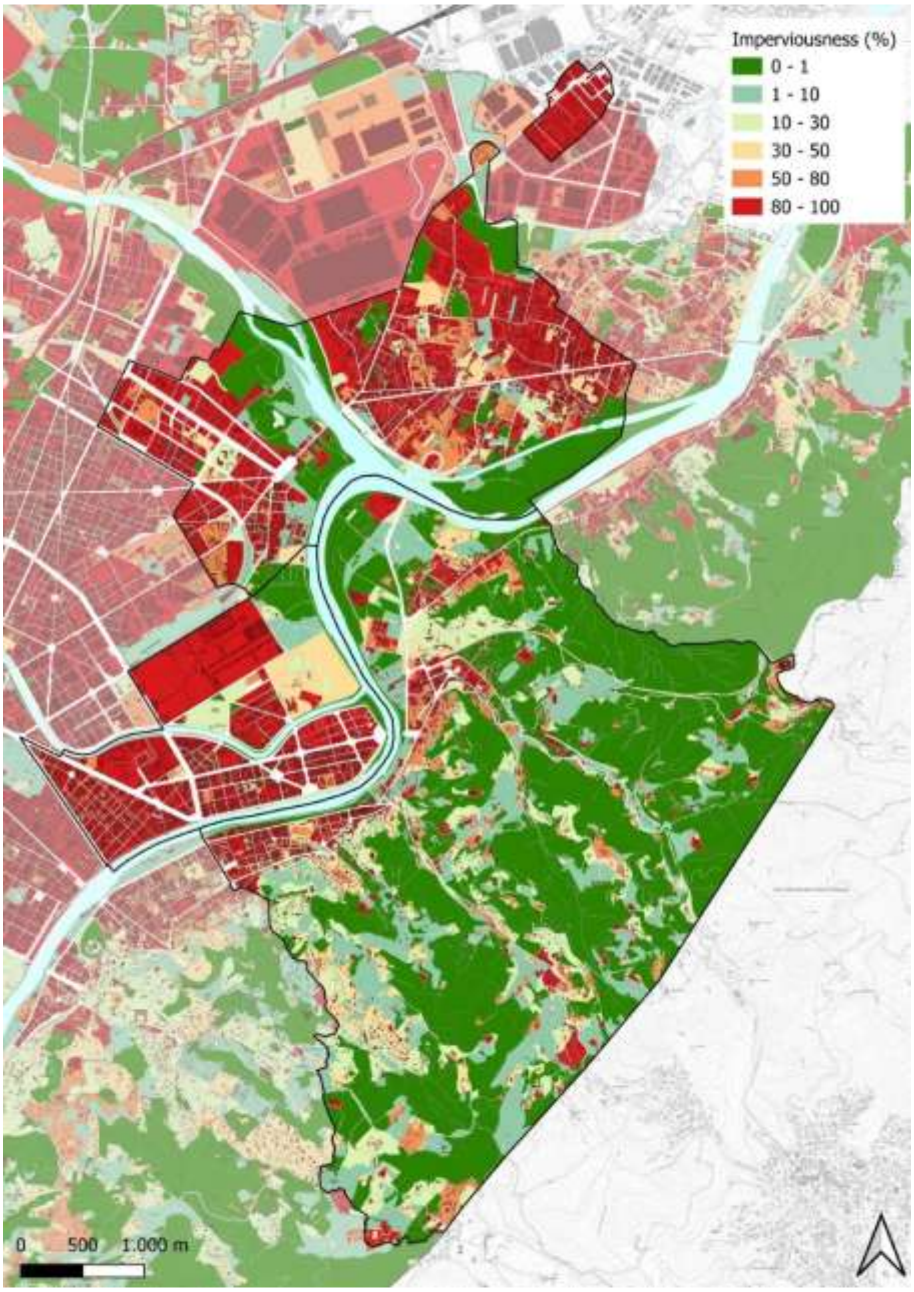

Figure 16. Imperviousness indicator (output map).

Table 4.10 Tree cover density

Name	**Tree cover density**
ID	**16**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	natural/green spaces
Definition	Extent of land area covered by the canopy of trees
Direction	☒positive ☐negative ☐not defined
Formula	$N = Ac/A$ N = Tree cover density, expressed as a percentage Ac = Area covered by tree canopy A = Surface of the selected area
Unit of measure	% (m^2/m^2)
Data source	Copernicus Dataset, Tree Cover Density 2018 (raster 10 m), Europe, 3-yearly (2018). DOI (raster 10 m): https://doi.org/10.2909/486f77da-d605-423e-93a9-680760ab6791
Territorial scale	Sub-district
Timescale	2018

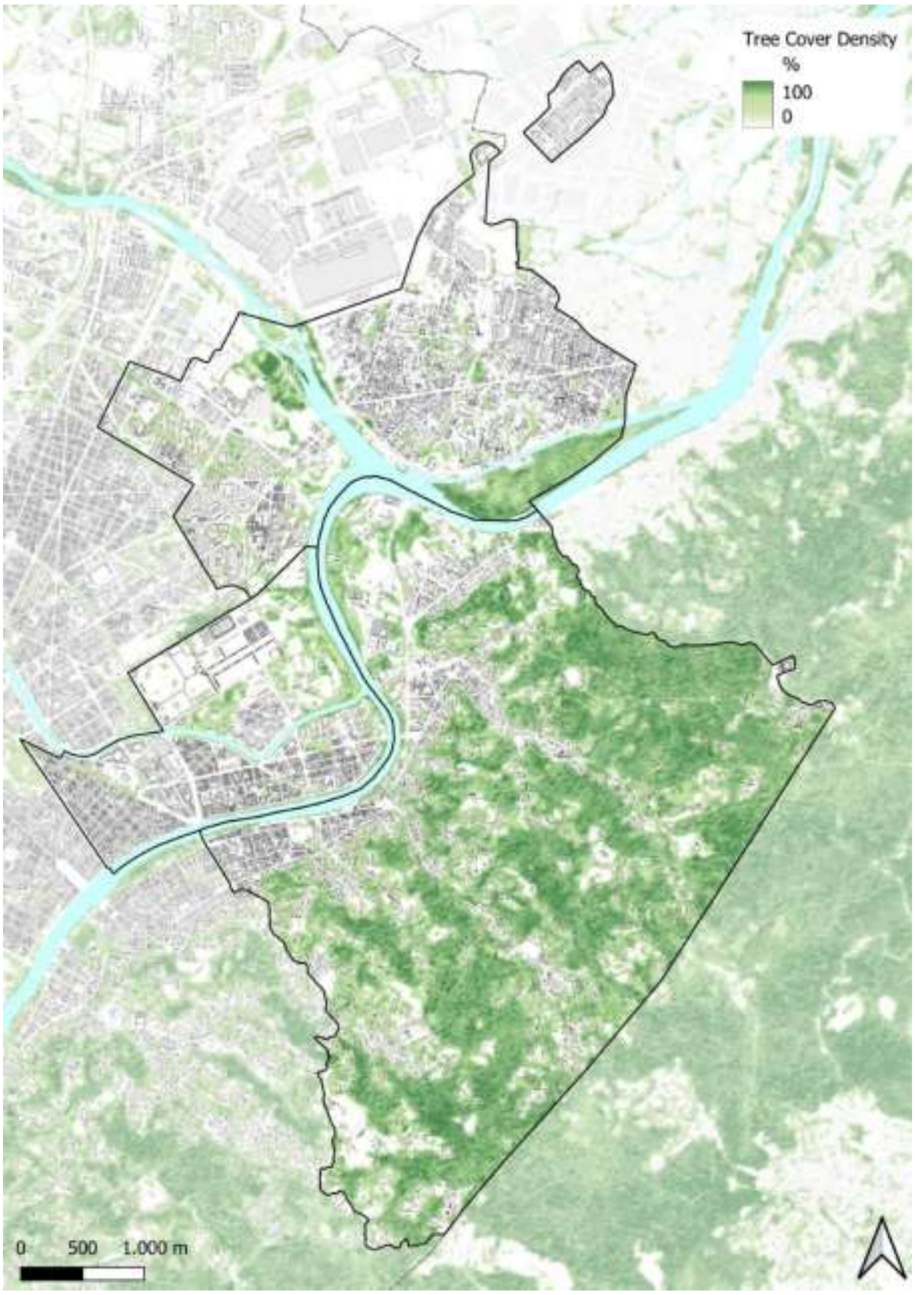

Figure 17. Tree cover density indicator (output map).

Table 4.11 Green urban spaces

Name	**Green urban spaces**
ID	**17**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Natural/green spaces
Definition	Lot area occupied by green urban spaces (public and private) compared to the resident population
Direction	☒positive ☐negative ☐not defined
Formula	$N=A/n$ N = Green urban spaces A= Surface of green urban spaces in the selected area n = Number of inhabitants in the selected area
Unit	m^2/inh
Data source	Carta Tecnica Comunale – CTC (Città di Torino, 2024)
Territorial scale	Sub-district
Timescale	2024

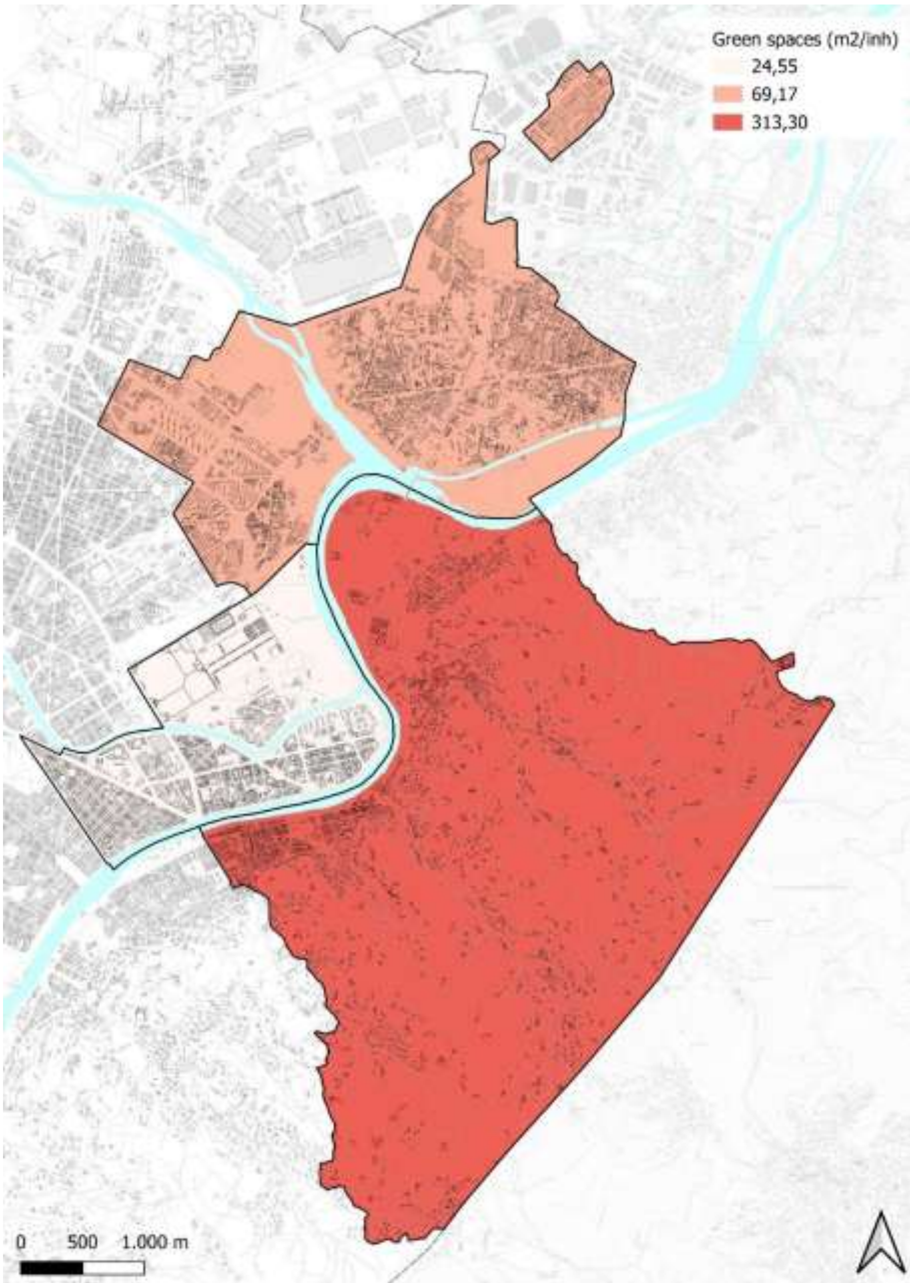

Figure 18. Green urban spaces indicator (output map).

Table 4.12 Natural and semi-natural areas

Name	**Natural and seminatural areas**
ID	**18**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Natural/green spaces
Definition	Proportion of Land use/Land cover classes related to natural and seminatural areas (Artificial, non-agricultural vegetated areas, Agricultural areas, Forest and semi-natural areas, Wetlands, Water bodies)
Direction	☒positive ☐negative ☐not defined
Formula	$N = A_n / A$ *N* = Natural and seminatural areas An= Surface of Land use/Land cover classes related to natural and seminatural areas in the selected area A= Total surface of the selected area
Unit	%
Data source	Land Cover Piemonte (Regione Piemonte), 2023
Territorial scale	Sub-district
Timescale of reference	2023

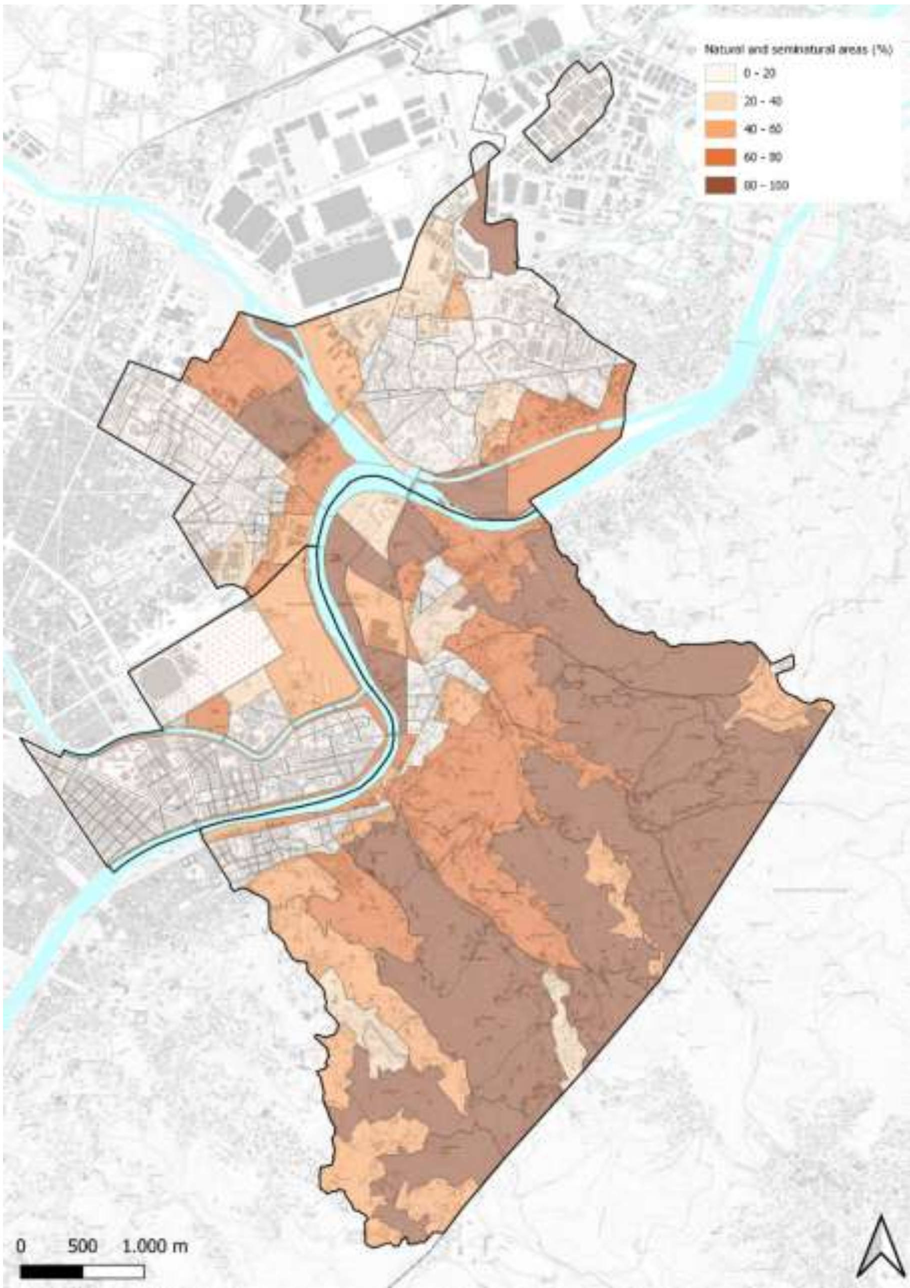

Figure 19. Natural and seminatural areas indicator (output map).

Table 4.13 Ecological network

Name	**Ecological network**
ID	**19**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Natural/green spaces
Definition	Areas with High and Moderate Ecological Functionality, according to ecological network analysis obtained with ENEA methodology
Direction	☒positive ☐negative ☐not defined
Formula	$N = J$ N= Ecological network J = Surface included in High and Moderate Ecological Functionality
Unit of measure	m^2
Data source	Land Cover Piemonte (Regione Piemonte), 2023
Territorial scale	Sub-district
Timescale of reference	2023

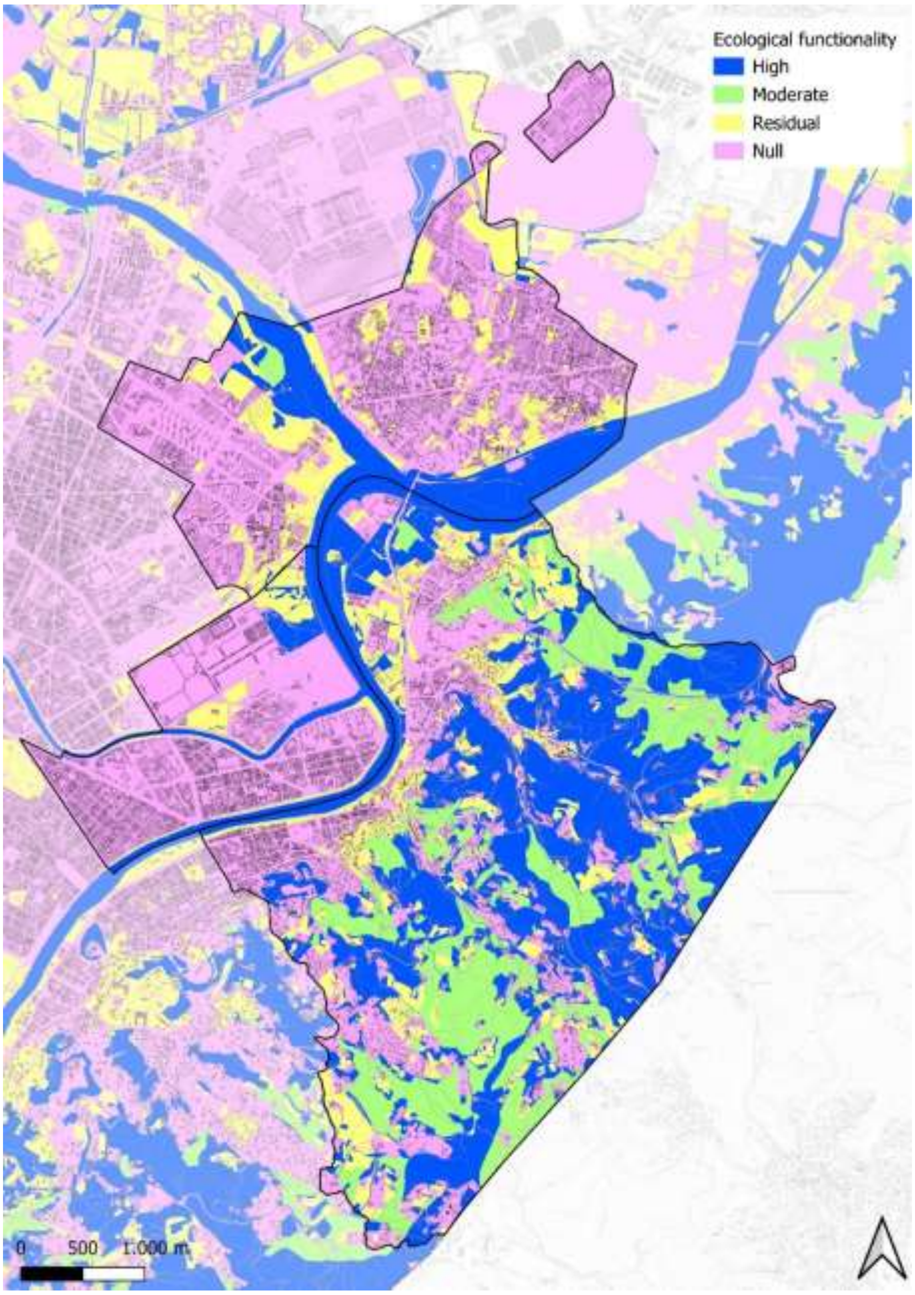

Figure 20. Ecological network indicator (output map).

Table 4.14 Elements of the ecological network

Name	**Elements of the ecological network**
ID	**20**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Natural/green spaces
Definition	Areas of ecological value, according to ecological network analysis obtained with ARPA Piemonte methodology (DGR n. 52-1979 del 31/7/2015)
Direction	☒positive ☐negative ☐not defined
Formula	$N = J$ N= Elements of the ecological network J = Surface included in AVE (Areas of ecological value)
Unit of measure	m^2
Data source	ARPA Piemonte
Territorial scale of reference	Sub-district
Timescale of reference	2024

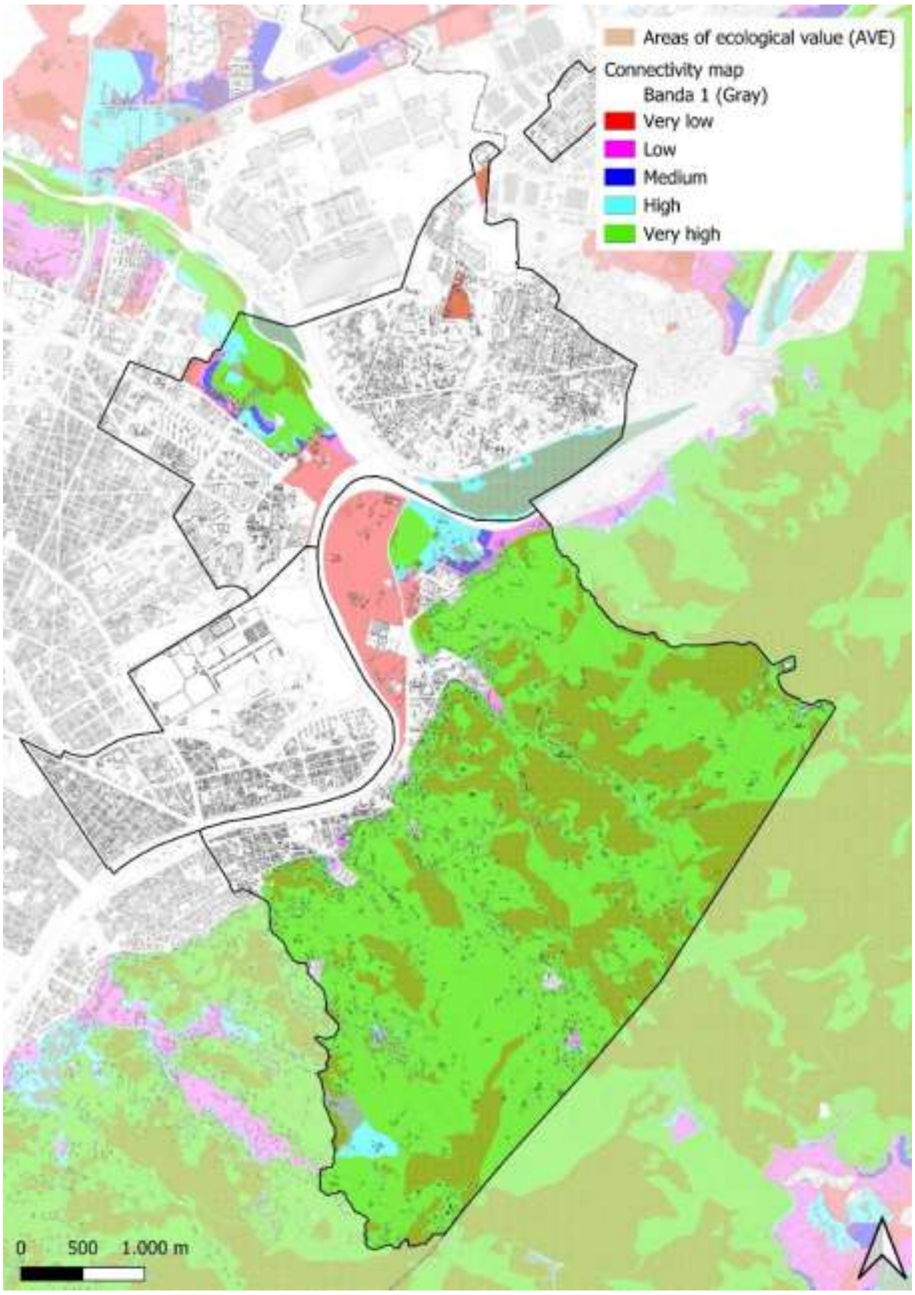

Figure 21. Elements of the ecological network indicator (output map).

Table 4.15 Land capability

Name	**Land Capability**
ID	**21**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Land use
Definition	The land-use capability makes it possible to differentiate soils according to their productive potential in the agro-silvopastoral sphere. There are eight classes that define the capacity of soil use and they are divided into two main groupings. Classes 1, 2, 3 and 4 concern soils suitable for cultivation and other uses. Classes 5, 6, 7 and 8 are in areas unsuitable for cultivation; a partial exception is class 5 where, under certain conditions and not for all years, some agricultural uses are possible.
Direction	☐positive ☒negative ☐not defined
Formula	$N = f(ED, Sl, St, F, O, F, W, Er. L)$ Land Capability ED= Effective Depth Sl= Slope St=Stoniness F= Fertility O = Oxygen Availability F= Flooding Risk W = Worka N= bility Er= Erosion L= Landslide Susceptibility
Unit of measure	classes
Data source	Regione Piemonte - IPLA, Carta dei suoli 1:50.000,
Territorial scale	Regional
Timescale	2005-2023

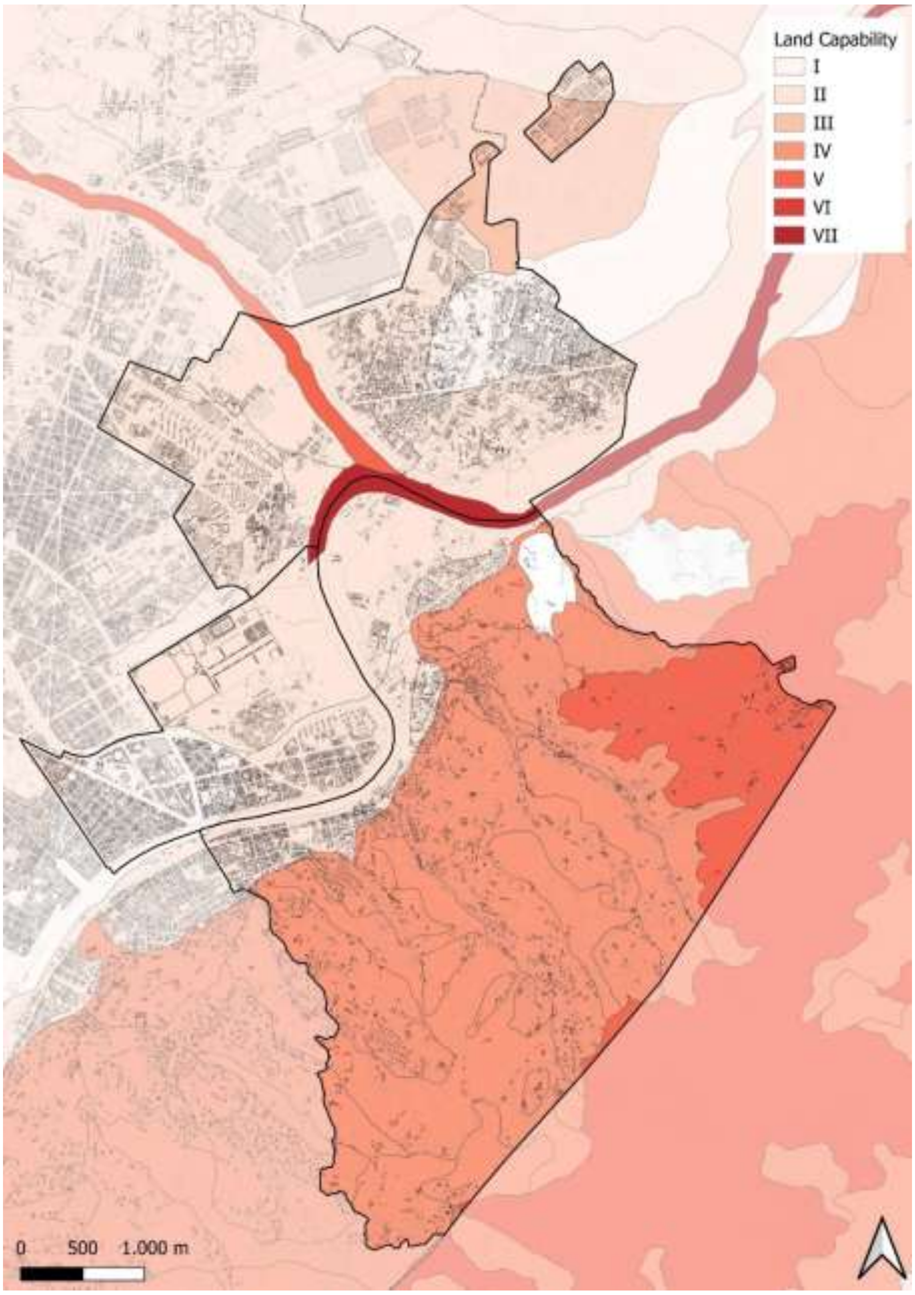

Figure 22. Land Capability indicator (output map).

Table 4.16 Accessibility to green public spaces

Name	**Accessibility to green public spaces**
ID	**22**
Dimension	☐Built ☒Environmental ☒Social ☐Economic ☐Institutional
Topic	Services
Definition	Percentage of population with access to a green public area less than 300m away
Direction	☒positive ☐negative ☐not defined
Formula	$N=n_a/n_t$ N = Accessibility to green public spaces n_a = Number of inhabitants living within a 300m buffer zone from green public spaces in the selected area n_t = Total number of inhabitants in the selected area
Unit	%
Data source	Piano strategico dell'infrastruttura verde (Città di Torino 2021)
Territorial scale	Sub-district
Timescale of reference	2021

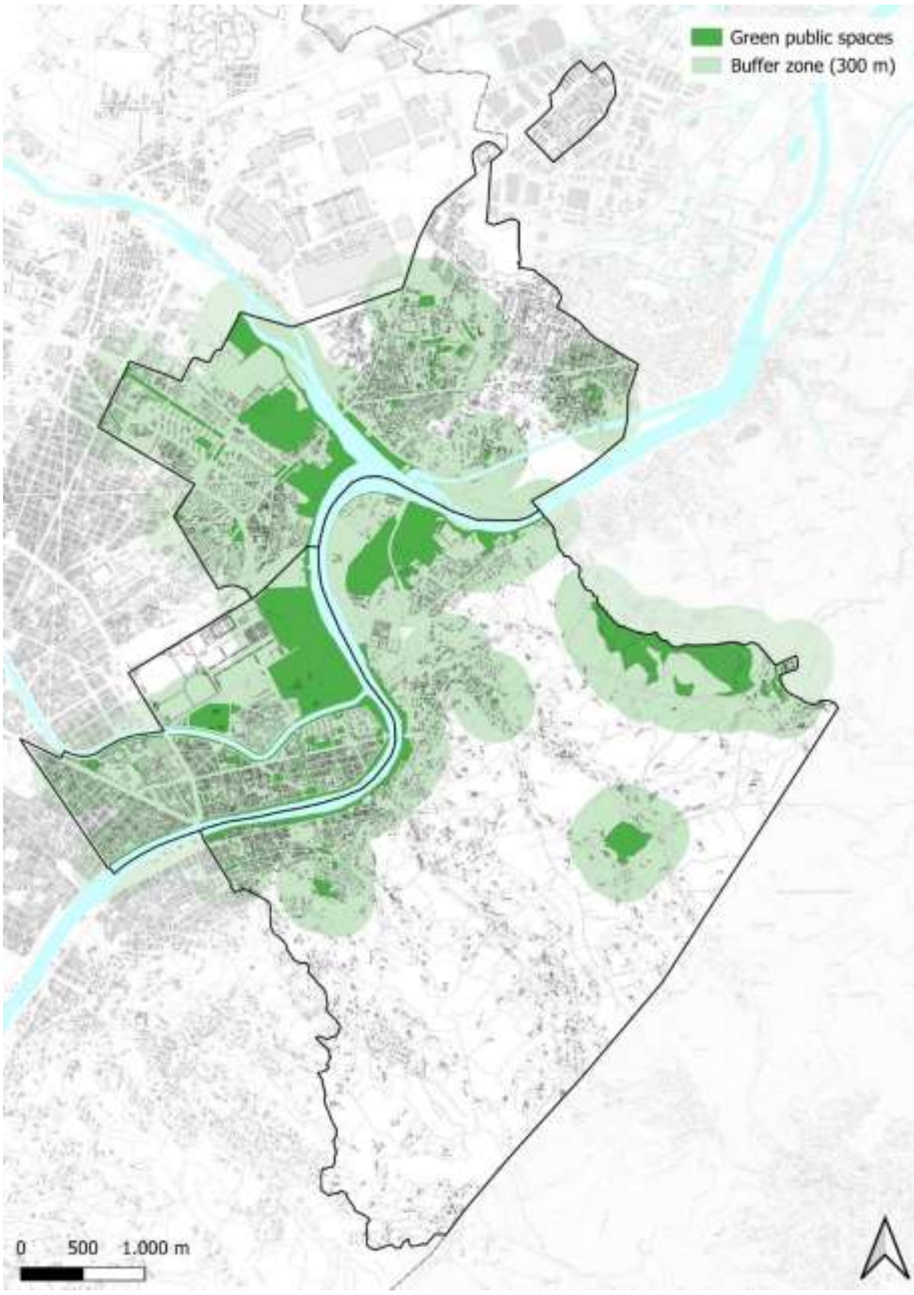

Figure 23. Accessibility to green public spaces indicator (output map).

Table 4.17 Cycling infrastructures

Name	**Cycling infrastructures**
ID	**23**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☐Institutional
Topic	infrastructures and network
Definition	The proportion of the census section area covered by a 300 m buffer from a bicycle lane
Direction	☒positive ☐negative ☐not defined
Formula	$\boldsymbol{N} = Ab/As \ {*}100$ N = Cycling infrastructure Ab = Area within 300 m buffer from bicycle lanes As = Area of the census section
Unit of measure	% (m^2/ m^2)
Data source	Comune di Torino (aperTO), layer “Infrastrutture ciclabili”
Territorial scale	Sub-district
Timescale	2018

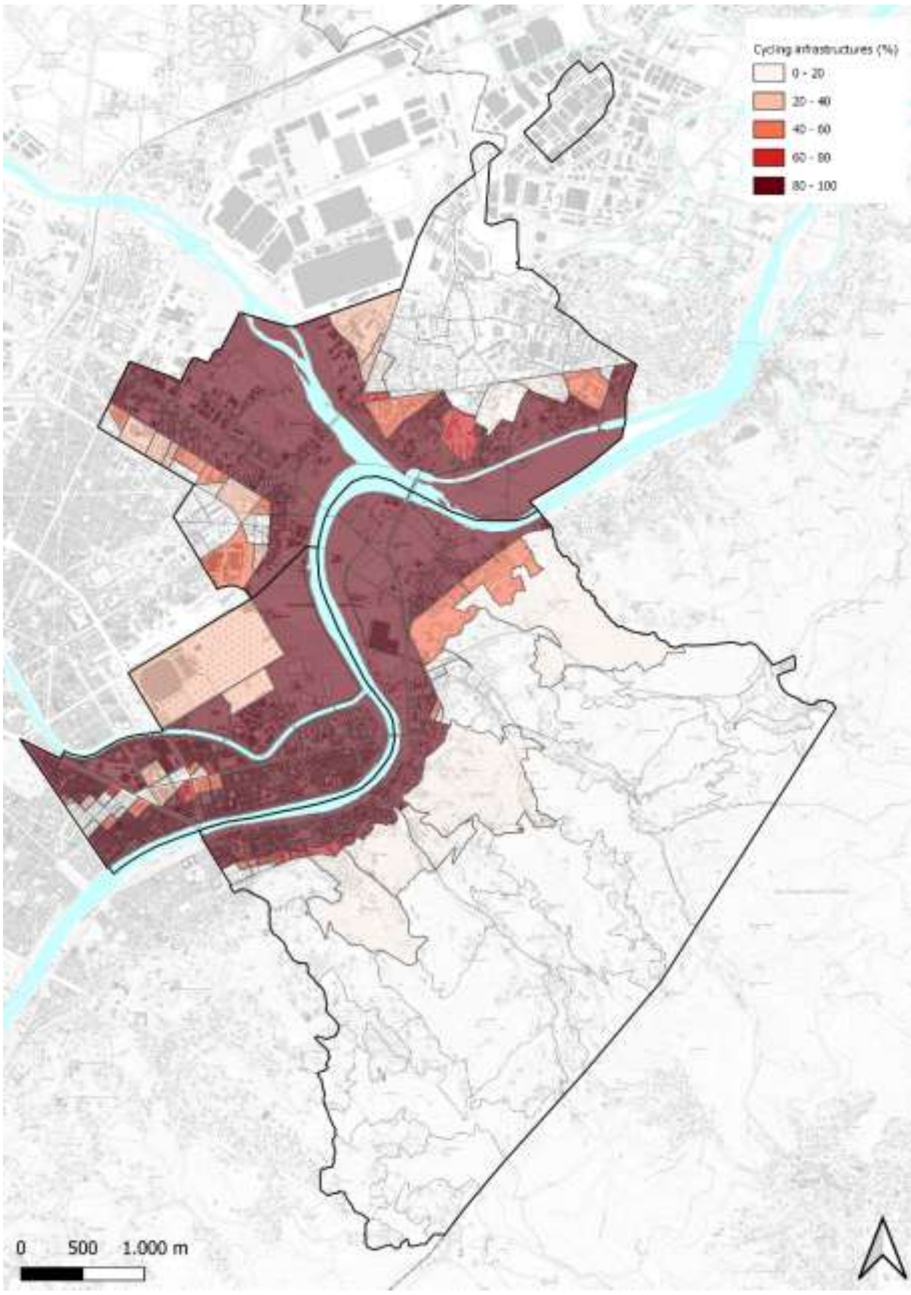

Figure 24. Cycling infrastructures indicator (output map).

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Table 4.18 Public transport

Name	**Public transport**
ID	**24**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☒Institutional
Topic	infrastructures and network
Definition	The concentration of bus and tram stops within a 300-meter radius, reflecting the accessibility and coverage of the local transportation network.
Direction	☒positive ☐negative ☐not defined
Formula	Kernel Density Estimation
Unit of measure	unit/m^2
Data source	Regione Piemonte, “Linee di trasporto pubblico locale”
Territorial scale	Sub-district
Timescale	2024

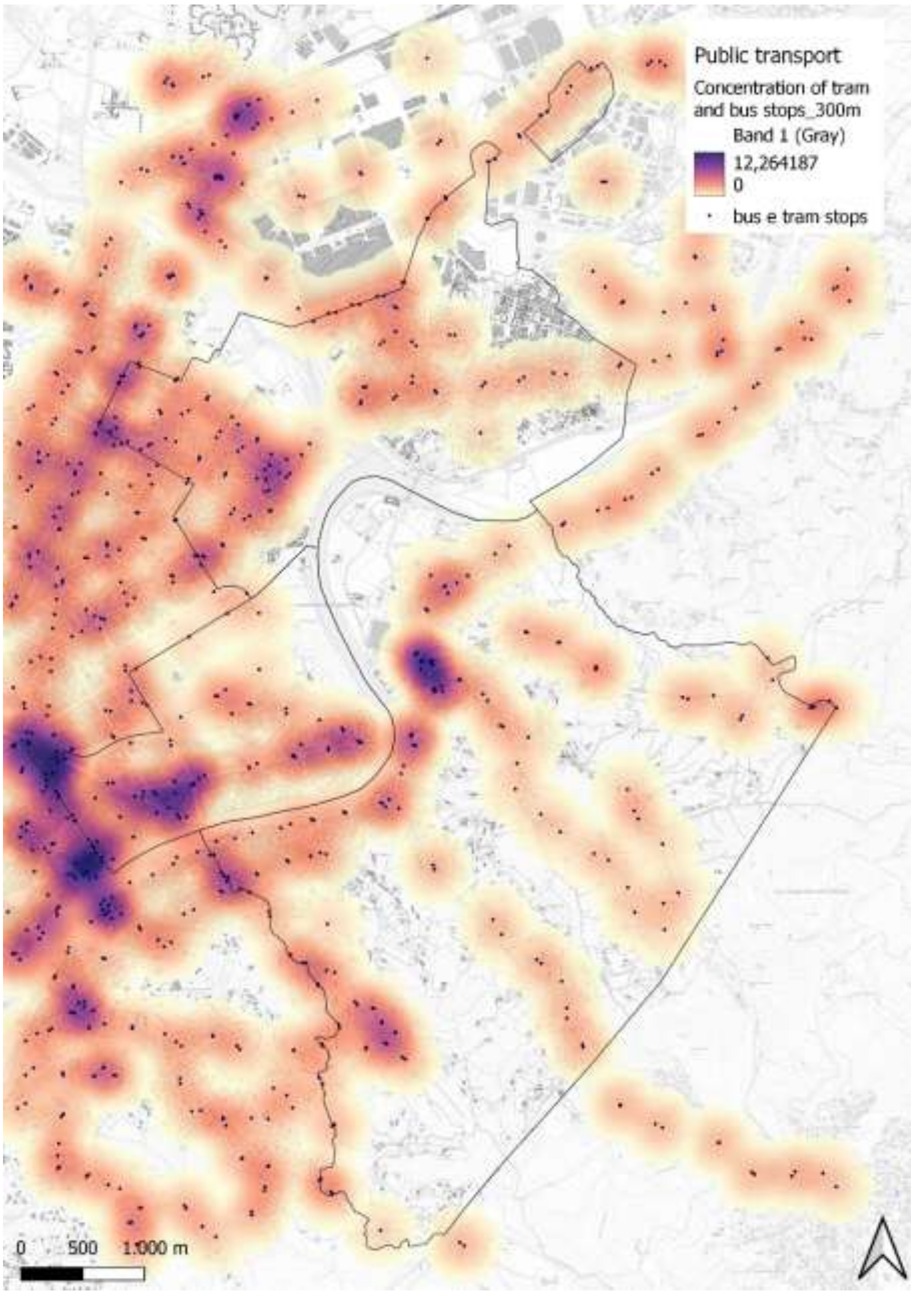

Figure 25. Public transport indicator (output map).

Table 4.19 Public water fountains

Name	**Public water fountains**
ID	**26**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☒Institutional
Topic	services
Definition	The density of public water fountains within a 300-meter radius, representing the accessibility of free, potable water in each area.
Direction	☒positive ☐negative ☐not defined
Formula	Kernel Density Estimation
Unit of measure	unit/m^2
Data source	Associazione di promozione sociale "I love toret", https://ilovetoret.it/it/mappa/
Territorial scale	Sub-district
Timescale	2022

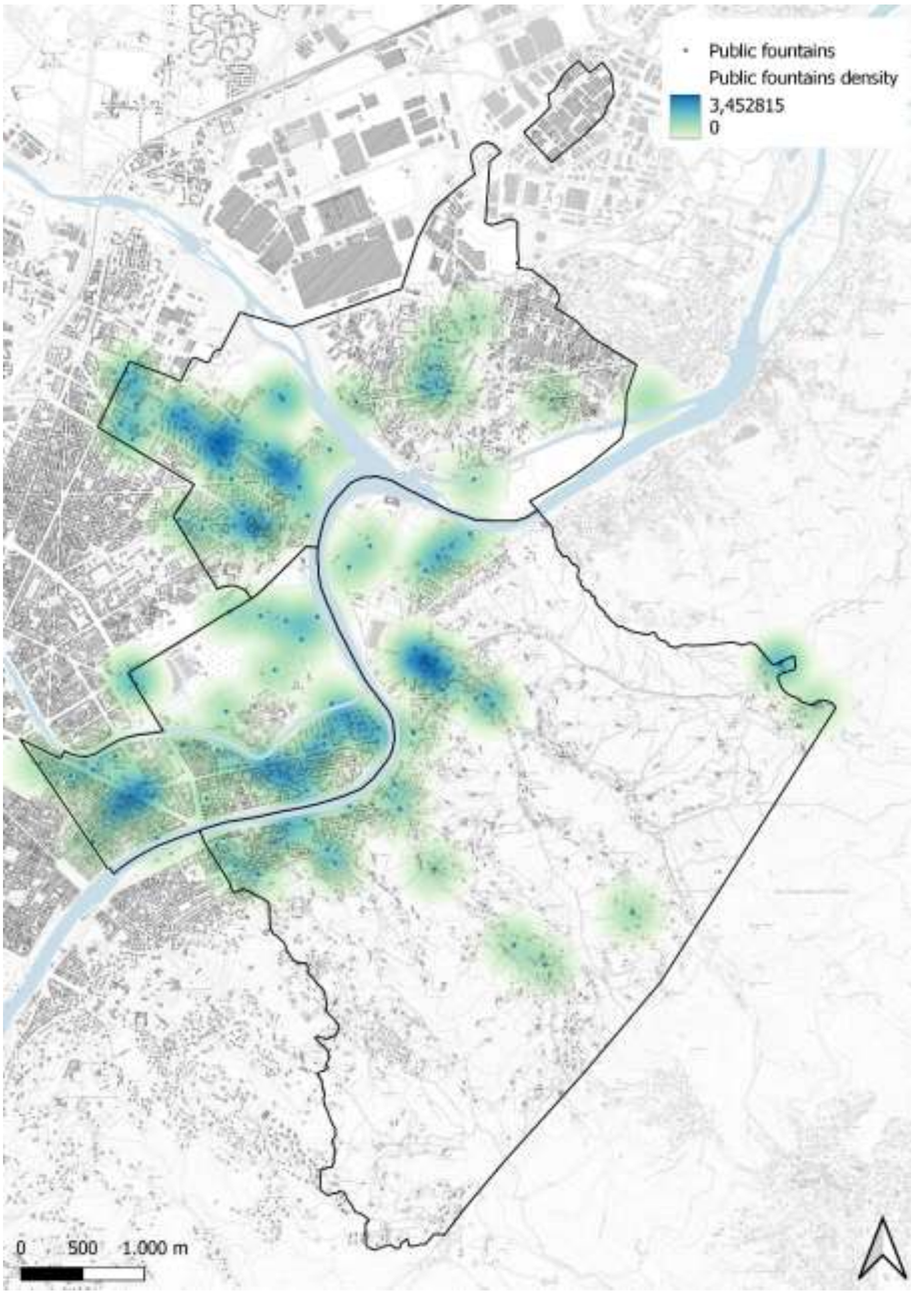

Figure 26. Public water fountains indicator (output map).

Table 4.20 Air pollution

Name	**Air pollution**
ID	**27**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	pollution
Definition	Number of days with concentrations above the local norm or standard for key criteria pollutants (PM 10) in a selected area.
Direction	☐positive ☒negative ☐not defined
Formula	$N = J$ N = Air pollution J = number of exceedances of the limit value (50 µg/m3) for the daily average
Unit of measure	Days
Data source	ARPA, Qualità dell'aria - valutazione modellistica annuale, field "LIM_PM10" (PM10 - n exceedances of the limit value (50 µg/m3) for the daily average)
Territorial scale	Sub-district
Timescale	2022

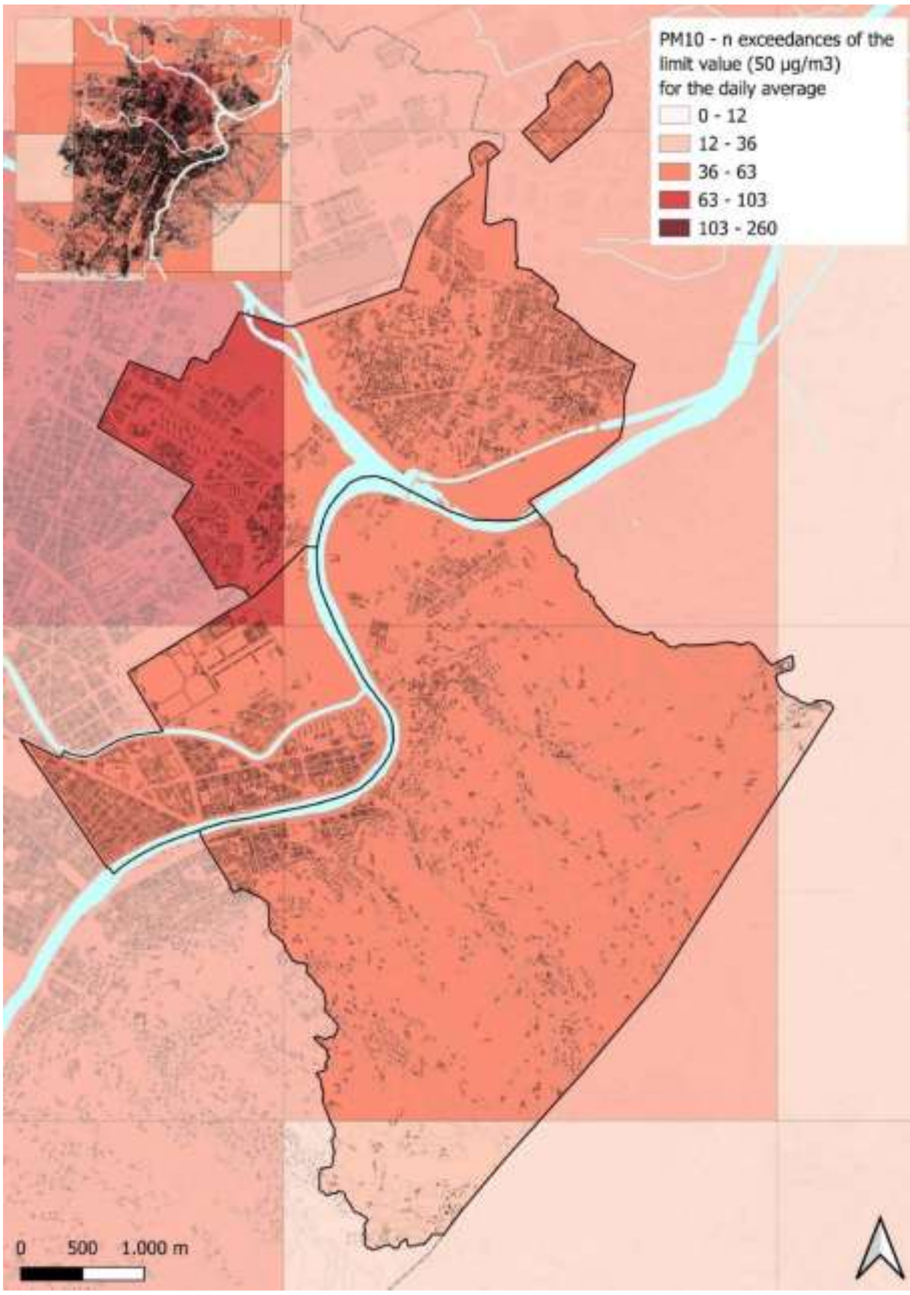

Figure 27. Air pollution indicator (output map).

Table 4.21 Land take

Name	**Land take**
ID	**29**
Dimension	☒Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Land use
Definition	Total land take area, which can be expressed as an absolute measure or a relative measure, with respect to the selected area
Direction	☐positive ☒negative ☐not defined
Formula	N=K/A N = Land take K= Total Land take area in the selected area A= Total surface of the selected area
Unit of measure	%
Data source	Land Cover Piemonte (Regione Piemonte), 2023
Territorial scale	Sub-district
Timescale	2023

Figure 28. Land take indicator (output map).

4.2 Indexes and indicators for the assessment of adaptation and mitigation capacity to climate change in urban districts

The increasingly intense and frequent impacts of climate change on urban settlements have led to a greater awareness of the human, environmental, social and economic consequences it causes. In particular, the need emerges to concretise processes that are able to read the responses of built systems, and the different levels of risk. In this framework, an operational approach to design based on the use of surveying, modelling and simulation tools and the measurement of indices and indicators assume relevance. Design, especially in particularly critical areas where different types of risk converge, should be preceded by actions aimed at understanding and verifying the applicability and effectiveness of the proposed design solutions (Milardi, 2021).

Urban districts represent critical units for addressing the challenges posed by climate change. In this context, adaptation and mitigation stand as two complementary strategies: adaptation aims to counter climate impacts by reducing vulnerability, while mitigation focuses on decreasing climate-altering emissions. The capacity of these districts to adapt to and mitigate climate change impacts is contingent upon various factors, including their physical infrastructure, social cohesion, and governance structures. To effectively assess their capacity to adapt to and mitigate climate impacts, a comprehensive framework of indexes and indicators is essential.

In this scenario, it is instrumental to use an approach to design at the urban and building scale that employs indices and indicators to assess the effectiveness of adaptation and mitigation strategies and to guide international and national policies for interventions in urban settlements. These tools mediate the inherent complexity of climate change and the need for informed decisions by synthesizing large amounts of complex information into simple, standardized, and easily interpreted metrics. Indicators can be used to measure specific aspects related to adaptation and mitigation capacity, such as, for example, the energy efficiency of buildings or the percentage of green areas in urban districts.

Indices and indicators can offer a broader and more structured overview, making it possible to compare different urban contexts at different scales, monitor the progress of interventions over time, and identify critical areas for action. Therefore, their development and application in the design of urban settlements means that indices and indicators are not only technical tools but also strategic elements to guide the green transition to more resilient cities. Moreover, also through the use of innovative technologies such as the use of big data, IoT sensors and GIS systems, the data obtained from index and indicator measurements can be further refined to respond to the specifics of each urban context using an evidence-based approach to design.

At the national level, the National Adaptation Plan to Climate Change defines sectoral and cross-sectoral modalities and tools for implementing the NAPCC measures, identifying methods for analysing and evaluating the introduced measures using specific sets of indicators for each proposed action.

The possible adaptation options - which will find application in the different planning tools at different scales (national, regional, and local) - are systematized in Annex IV of the PNACC: the Action Database. Annex IV reports a set of more than 300 sectoral adaptation actions for which a valuation methodology has been developed and applied to determine, for each individual action, a value judgment (high, medium-high, medium, low) based on certain criteria selected by a multidisciplinary group of experts based on the available literature. It is important to note that the value scale of the actions is not established in any absolute way as it can vary based on different factors such as the geographical and socioeconomic context, the reference climate scenario, or the risks taken into consideration.
The evaluation process has been simplified by classifying the actions into homogeneous macro-categories of adaptation that identify their project type (MASE, 2023).

The macro-categories are:

- Information,
- Organisational and participatory processes,
- Governance,
- Adaptation and improvement of facilities and infrastructure,
- Solutions based on ecosystem services

The actions are then further subdivided into:

- Type A -soft actions: actions that do not require direct structural and material interventions but are preparatory to the relationship of structural interventions at different scales, contributing to the creation of adaptive capacity through the implementation of knowledge bases and the development of a favourable governance context. The macro-categories of intervention that belong to this type of action are:
    - Information,
    - Organisational and participatory processes,
    - Governance.
- Type B actions - green and soft: actions that have a materiality and structural intervention component. Grey actions are those relating to the improvement and adaptation to climate change of facilities and infrastructures, which can in turn be subdivided into actions on facilities, materials and technologies, or on infrastructures or networks. Green actions are those that propose 'nature-based' solutions, i.e. the sustainable use or management of natural 'services', including ecosystem services, in order to reduce the impacts of climate change. The macro-categories that fall under this type of action are:
    - Adaptation and improvement of facilities and infrastructure,
    - Solutions based on ecosystem services.

The adaptation actions thus categorised are evaluated based on five criteria:

- Effectiveness,
- Efficiency,
- Second-order effects
- Performance in the presence of uncertainty,
- Policy implementation considerations.

Based on the evaluation of these criteria, each action is given a value rating based on the following classes:

- High,
- Medium-High,
- Medium,
- Medium-low,
- Low.

These criteria are more easily applicable to type B actions - infrastructural (green and grey).

The monitoring, reporting, and evaluation phases of these adaptation measures and actions are, in turn, conducted using an indicator system. The identification of these indicators is carried out considering that the monitoring phase aims to examine the progress made in implementing adaptation policies and measures over a specific period of time; the reporting phase focuses on the documentation and communication of the results achieved by these actions, and finally, the evaluation phase aims to assess their effectiveness. The data and information resulting from these MRE processes (monitoring, reporting, and evaluation processes) are fundamental to identifying which actions have priority for achieving the objectives of combating climate impacts.

The indicators identified to conduct MRE processes are divided into two groups:

- progress indicators,
- effectiveness indicators.

The set of indicators were selected based on the input of the same experts who selected the sectoral actions identified by the Plan and represent a portfolio of indicators that must be refined and adapted to individual territorial contexts to provide valid support to the national MRE system.

The work of the NAPCC is aligned with the EU Climate Adaptation Strategy of 2021. In the document, in fact, monitoring, communication, and evaluation are identified as fundamental phases for defining a solid baseline against which to measure progress made in adaptation (COM, 2021a) It is established that, to this end, the European Commission will:

- provide ex-ante project evaluation tools, to better identify the co-benefits and positive impacts on the economy of adaptation and prevention projects;

- develop appropriate indicators and a resilience assessment framework based on the experience gained with the adaptation capacity benchmarks for the 2013 adaptation strategy and in line with the work of the UNFCCC adaptation committee (COM, 2021b)

In general, the methods of calculation and aggregation of indices and indicators for assessing adaptive capacity and mitigation require a systemic approach to ensure consistency and reliability of results. The normalisation of data is one of the key steps, as it enables indicators expressed in different units to be made comparable. When using indices and indicators, it is also important to ensure the quality of the underlying data, verifying the accuracy of the sources and regularly updating them to reflect changes in the urban context. This provides a solid basis for reliable and useful assessments to support decision-making.

The indicator-based approach plays a key role in planning strategies for climate change mitigation and adaptation, precisely because of its ability to concisely represent complex issues. Over the years, indicators have been accredited as a valid tool for the integration of environmental issues in development policies and decision-making processes, becoming a significant driver in the information-decision-making relationship (D'Ambrosio, 2020). The use of sets of indices and indicators represents as a diagnostic tool capable of providing a measure of an objective to be achieved, monitoring the effectiveness of the actions activated for its achievement and anticipating the evolution of future scenarios.

Name	**Annual Solar Radiation**
ID	**31**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Built environment
Definition	The annual amount of solar radiation incident on building surfaces, considering geometrical and morphological factors such as orientation, tilt, shading, and the surrounding urban form. It reflects the cumulative energy potential from direct and diffuse solar inputs.
Direction	☐positive ☐negative ☐not defined ☒Context-dependent
Formula	Calculated through solar geometry algorithms using geographic coordinates, time, and surface orientation. Often expressed as $G_{\text{total}} = G_{\text{dir}} + G_{\text{diff}} + G_{\text{ref}}$ **Formula variables** ○ Gtotal is the global incident solar radiation. ○ Gdir is the direct solar radiation. ○ Gdir is the diffused solar radiation. ○ Gref is the reflexed solar radiation.
Unit of measure	kWh/m²/year
Data source	○ Climatic data from **Copernicus** or **UNI 10349** ○ Digital 3D building models ○ Terrain morphology (DSM/DTM)
Territorial scale	District or city-level analysis. It is used to evaluate exposure patterns across large urban surfaces, enabling strategic placement of solar technologies or identifying areas with low radiation potential.
Timescale	2025
Recommended software/tools	• **Ladybug Tools (Rhino/Grasshopper)**: for parametric and visual solar radiation studies based on EPW climate files. • **Solweig**: to assess solar radiation at pedestrian level, integrating shading and SVF. • **Radiance**: for high-fidelity daylight and radiation simulation. • **ArcGIS Solar Analyst**: for raster-based solar mapping using DSMs.

Notes

Extended Description and Use

Solar radiation is a fundamental driver of building energy performance and urban climate behavior. This indicator is crucial for:

- **Passive solar design** (thermal gains in winter)
- **Shading and overheating control** (in summer)
- **Location, tilt, orientation for the efficiency of pv systems**
- **Assessing walkability and thermal comfort in open spaces**

As noted in the literature (e.g., Akbari & Levinson, 2008; Santamouris, 2014), high-resolution solar radiation maps are essential in understanding **urban heat distribution**, especially in densely built environments. The expected outputs are simulation, models, catalogues and maps.

Methodological Note

To calculate annual solar radiation

1. **Input data required**
   - A georeferenced 3D model of the urban area (buildings, vegetation, terrain)

   - EPW Climatic data (solar position, direct and diffuse irradiance)
2. **Computation process**
   - The model simulates hourly solar radiation over a full year using local EPW weather files.
   - Ladybug Tools uses radiance-based engines to simulate the combined effect of direct and diffuse solar gain, taking urban shading into account.
   - Solweig integrates SVF and albedo to evaluate the **mean radiant temperature** at pedestrian level, useful in thermal comfort assessments.
3. **Output**

The following output can be obtained by Rhinoceros and its plugins (Grasshopper and Ladybug) or by GIS-based software Solweig:

   - A **raster or mesh map** representing incident radiation per surface (kWh/m²/year) that can be used to **prioritize building façades for retrofit**, **optimize PV positioning**, or **detect heat-exposed public spaces**.

This indicator is widely used in climate-resilient design strategies and referenced in standards such as **UNI 10349** for solar data normalization.

Name	**Thermal Phase Shift (Time Lag)**
ID	**32**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☐Institutional
Topic	Building's envelope performance
Definition	*Thermal time lag* is the delay between the peak external temperature (usually due to solar gain) and the corresponding peak internal temperature within a building envelope. It reflects the capacity of building materials and assemblies to buffer rapid temperature fluctuations, mainly through thermal mass and stratigraphy.
Direction	☒positive ☐negative ☐not defined Higher values are desirable, as a greater time lag reduces overheating risk and improves indoor comfort, especially for heatwaves hazard.
Formula	$\Delta t = t_{\text{indoor peak}} - t_{\text{outdoor peak}}$ **Formula variables** • **Δt** = Thermal time lag (hours) • **t_indoor peak** = Time of indoor temperature peak • **t_outdoor peak** = Time of outdoor temperature peak Calculated as the time difference (in hours) between the external temperature peak and the internal temperature peak at the innermost surface of the envelope (UNI EN ISO 13786:2017).
Unit of measure	Hours (h)
Data source	• Building stratigraphy and material properties (density, specific heat, thickness, thermal conductivity) • Climatic profiles (outdoor temperature curves)
Territorial scale	Building's stratigraphic surfaces - Applicable at the building or envelope component level, where detailed construction data is available.
Timescale	2025
Recommended software/tools	• **EnergyPlus**, **TRNSYS**, **IDA ICE**: dynamic thermal simulation engines capable of modeling transient heat flow. • **TERMUS G**: Italian software specialized for stratigraphy analysis and time lag/attenuation calculations according to UNI standards. • **WUFI Plus**: for hygrothermal simulation, when moisture interaction is relevant. • **PAN SOFTWARE**: for hygrothermal simulation

Notes

Extended Description and Use

Thermal time lag is a critical parameter in **passive building design**, especially for Mediterranean and continental climates subject to high diurnal temperature variations. It measures how well a construction assembly can **"smooth out" external thermal peaks**, thus improving indoor comfort and reducing cooling loads.

- **Purpose**
  - To select or retrofit envelope solutions (walls, roofs) that delay and dampen indoor heat gain.
  - To inform tecnical choices (high-mass materials vs. lightweight materials).
  - To support regulatory compliance (as required in UNI EN ISO 13786 and Italian energy regulaments).

Methodological Note

1. **Inputs**
   - Detailed layer-by-layer data on the envelope (materials, thickness, λ, density, heat capacity)
   - Hourly or sub-hourly outdoor temperature curves
2. **Computation**

   - The simulation (e.g., in EnergyPlus or TERMUS G) applies a periodic external temperature profile to the envelope.
   - PAN Software computes the response curve at the interior surface, quantifying the lag (in hours) between external and internal temperature peaks.
3. **Outputs**:
   - **Numeric value**: Time lag (h) for each building component.
   - **Graphical**: Temperature response curves (external vs. internal).
   - **Summary table**: Comparing alternatives or existing conditions.

Used mainly in **retrofit decision-making** and for assessing the suitability of passive cooling and heating strategies in existing or new buildings.
Values above 10 hours are typically considered optimal for summer comfort (see UNI EN ISO 13786).

Name	**Thermal Decrement Factor (Thermal Attenuation)**
ID	**33**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☐Institutional
Topic	Building's envelope performance
Definition	*Thermal decrement factor* (also known as Thermal attenuation) quantifies the reduction in the amplitude of temperature fluctuations as heat waves pass through a building element. It expresses the ratio between the maximum amplitude of the external temperature oscillation and the corresponding internal amplitude at the innermost surface.
Direction	☒positive ☐negative ☐not defined Higher attenuation (lower decrement factor) is preferable, as it means less heat enters the building, resulting in greater indoor thermal stability.
Formula	$f = \frac{\Delta T_{in}}{\Delta T_{out}}$ **Formula variables** • **ΔTin = the amplitude of the internal temperature fluctuation** • **ΔTout = the amplitude of the external temperature fluctuation (UNI EN ISO 13786:2017)**
Unit of measure	Dimensionless (0-1)
Data source	• Building stratigraphy and dynamic thermal properties of envelope materials • Periodic (diurnal) temperature profiles
Territorial scale	• Buildings stratigraphic surfaces - Evaluated at the component or building level, where detailed material layers are known.
Timescale	2025
Recommended software/tools	• **WUFI Plus**, **EnergyPlus**, **Delphin**: dynamic simulation of periodic heat flow through multilayer assemblies. • **TERMUS G**: tailored for decrement factor calculation according to UNI standards. • **PAN SOFTWARE**: for hygrothermal simulation

Notes

Extended Description and Use

Thermal attenuation is essential for evaluating how effectively a building envelope **dampens temperature swings**, helping to maintain a stable and comfortable indoor climate without excessive reliance on mechanical cooling.

- **Purpose**:
  - To select building assemblies that minimize overheating in summer.
  - To compare alternative wall and roof solutions in retrofitting or new design.
  - Required by Italian and European energy performance codes for envelope compliance.

Methodological Note

1. **Inputs**
   - Complete stratigraphy of the envelope (layers, thicknesses, densities, λ, c)
   - Hourly or sub-hourly outdoor temperature oscillation
2. **Computation**
   - Dynamic simulation models (e.g., WUFI Plus, EnergyPlus) process the periodic heat flow.
   - The output curve shows the amplitude of temperature variation at the internal surface versus the external stimulus.
3. **Outputs**
   - **Numeric value**: Attenuation/decrement factor (0–1)

- **Comparative charts**: Envelope alternatives or before/after retrofit
- **Graphs**: Internal and external temperature fluctuation amplitudes

High-performing assemblies should exhibit a decrement factor close to zero, indicating effective thermal attenuation.

Name	**Building's Shape Factor (S/V Ratio)**
ID	**34**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☐Institutional
Topic	Building's shape
Definition	The *Building Shape Factor* (surface-to-volume ratio, S/V) quantifies the ratio between the total external surface area of a building and its enclosed volume. This parameter is crucial in determining the building's thermal behavior, as it directly impacts heat exchange with the outdoor environment.
Direction	☐positive ☒negative ☐not defined Lower S/V values are preferable, as a more compact shape reduces heat losses (in winter) and heat gains (in summer).
Formula	$\text{Shape Factor (S/V)} = \frac{\text{Total External Surface Area } (m^2)}{\text{Volume } (m^3)}$
Unit of measure	m^2/m^3
Data source	Digital 3D building models (BIM, CAD)
Territorial scale	Building / Urban block - Applies to individual buildings or blocks where detailed geometry is available. Can be aggregated to mesoscales (urban blocks) for comparative urban analysis.
Timescale	2025
Recommended software/tools	• **Revit**, **Rhino**, **SketchUp**: 3D modeling tools for extracting geometric parameters. • **QGIS 3D tools**: for urban-scale assessments.

Notes

Extended Description and Use

The building shape factor is a fundamental indicator in both energy simulation and urban resilience studies. It:

- Determines the effectiveness of envelope insulation measures.
- Affects the building's sensitivity to external temperature fluctuations and solar gains.
- Guides urban design choices for compactness versus spread (useful in climate adaptation and urban density planning).

References:

- Stevanović, V. (2013). "Optimization of surface-to-volume ratio for buildings in different climate zones," Energy and Buildings.
- UNI EN ISO 13790:2008 – "Energy performance of buildings – Calculation of energy use for space heating and cooling."

Methodological Note

1. **Inputs**:
    - 3D geometry of the building or block (external walls, roof, ground contact, gross volume)
2. **Computation**:
    - Calculation performed within BIM software or 3D modeling environments.
    - For large datasets, automated scripts (e.g., Python for Rhino or Dynamo for Revit) can process multiple buildings.
3. **Outputs**:
    - **Numeric value**: S/V ratio for each building or block.
    - **Comparative tables or maps**: spatial distribution of S/V across urban areas.
    - **Charts**: Relationship between S/V and energy performance.

Used in early-stage design, retrofit prioritization, and as a proxy for energy demand or vulnerability to heat waves.

Name	**Predicted Mean Vote (PMV)**
ID	**35**
Dimension	☐Built ☐Environmental ☒Social ☐Economic ☐Institutional
Topic	Thermal comfort
Definition	Thermal comfort perception index ranging from -3 (cold) to +3 (hot), 0 is neutral comfort.
Direction	☐positive ☐negative ☐not defined ☒near zero
Formula	$PMV = f(T_a, T_r, v, RH, M, I_{cl})$ **Formula variables** • **T_a = Air temperature (°C)** • **T_r = Mean radiant temperature (°C)** • **v = Air speed (m/s)** • **RH = Relative humidity (%)** • **M = Metabolic rate (W/m^2)** • **I_cl = Clothing insulation (clo)**
Unit of measure	Dimensionless (-3 to +3)
Data source	On-site measurements or simulation (EnergyPlus, EN ISO 7730) Building
Territorial scale	Building's indoor
Timescale	2025
Recommended software/tools	EnergyPlus, CBE Comfort Tool, DesignBuilder, Envimet
References	EN ISO 7730, ASHRAE 55

Name	**Aspect Ratio**
ID	**36**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☐Institutional
Topic	Urban morphology
Definition	Ratio between the building's external envelope surface and its internal heated/cooled volume.
Direction	☐positive ☒negative ☐not defined
Formula	$AR = \frac{H}{W}$ **Formula variables** • **AR = Aspect Ratio (dimensionless)** • **H = Mean building height (m)** • **W = Width of the street or open space (m)**
Unit of measure	Dimensionless
Data source	LiDAR, GIS, photogrammetry
Territorial scale	Building / Urban block
Timescale	2025
Recommended software/tools	ENVI-met, ArcGIS, Rhino + Grasshopper
References	ISPRA, national building codes

Name	**Mean Building Height**
ID	**37**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☐Institutional
Topic	Urban Morphology
Definition	Weighted average of building heights in a given area.
Direction	☐positive ☐negative ☐not defined ☒Context-dependent
Formula	$H_{\text{mean}} = \frac{\sum(H_i \cdot A_i)}{\sum A_i}$ **Formula variables** • **H_mean = Mean building height (m)** • **H_i = Height of building i (m)** • **A_i = Footprint area of building i (m^2)**
Unit of measure	Meters (m)
Data source	LiDAR, aerial photogrammetry, municipal GIS
Territorial scale	Buildings / Urban blocks
Timescale	2025
Recommended software/tools	ArcGIS 3D Analyst, QGIS, Rhino (with plugins)
References	Oke (Urban Climates), Regional GIS portals

Name	**Sky View Factor (SVF)**
ID	**38**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Urban Morphology
Definition	Fraction of sky visible from a ground point.
Direction	☒positive ☐negative ☐not defined
Formula	$SVF = \frac{\text{Visible Sky Hemisphere}}{\text{Total Sky Hemisphere}}$ **Formula variables** • **SVF = Sky View Factor**
Unit of measure	Dimensionless (0–1)
Data source	DSM, LiDAR, photogrammetry
Territorial scale	Micro-Urban
Timescale	2025
Recommended software/tools	ENVI-met, RayMan, QGIS, ArcGIS
References	Oke (Urban Climates), ENVI-met docs

Name	**Hillshade (Topographic Shading)**
ID	**39**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Urban Morphology
Definition	Shadow analysis based on terrain slope and elevation.
Direction	☐positive ☐negative ☐not defined ☒Context-dependent
Formula	$\text{Hillshade} = 255 \cdot \cos(\theta)$ **Formula variables** • **θ = Angle between surface normal and solar vector (from DEM, solar azimuth & altitude)**
Unit of measure	Grayscale value (0–255)
Data source	DEM, DTM, GIS raster tools
Territorial scale	Urban
Timescale	2025
Recommended software/tools	ArcGIS Hillshade Tool, QGIS Raster Analysis
References	ESRI, QGIS documentation

Name	**Albedo**
ID	**40**
Dimension	☐Built ☒Environmental ☐Social ☐Economic ☐Institutional
Topic	Urban Environment
Definition	**Albedo** is the dimensionless ratio of the reflected shortwave solar radiation to the incoming solar radiation received by a surface. Higher values = greater reflectivity and lower heat absorption.
Direction	☒ Positive ☐negative ☐not defined ☐Context-dependent
Formula	$\alpha = \frac{R}{I}$ **Formula variables** • **α = Albedo (dimensionless)** • **R = Reflected shortwave solar radiation (W/m²)** • **I = Incoming (incident) shortwave solar radiation (W/m²)** COMMENTO: Inserisci sempre la fonte delle formule
Unit of measure	Dimensionless (0–1)
Data source	MODIS, Landsat, Sentinel-2, Material datasheets, GIS surface classification
Territorial scale	Urban area
Timescale	2022
Recommended software/tools	QGIS, ArcGIS.
References	IPCC (2021); Santamouris (2020); Akbari & Levinson (2008); EEA (2022)

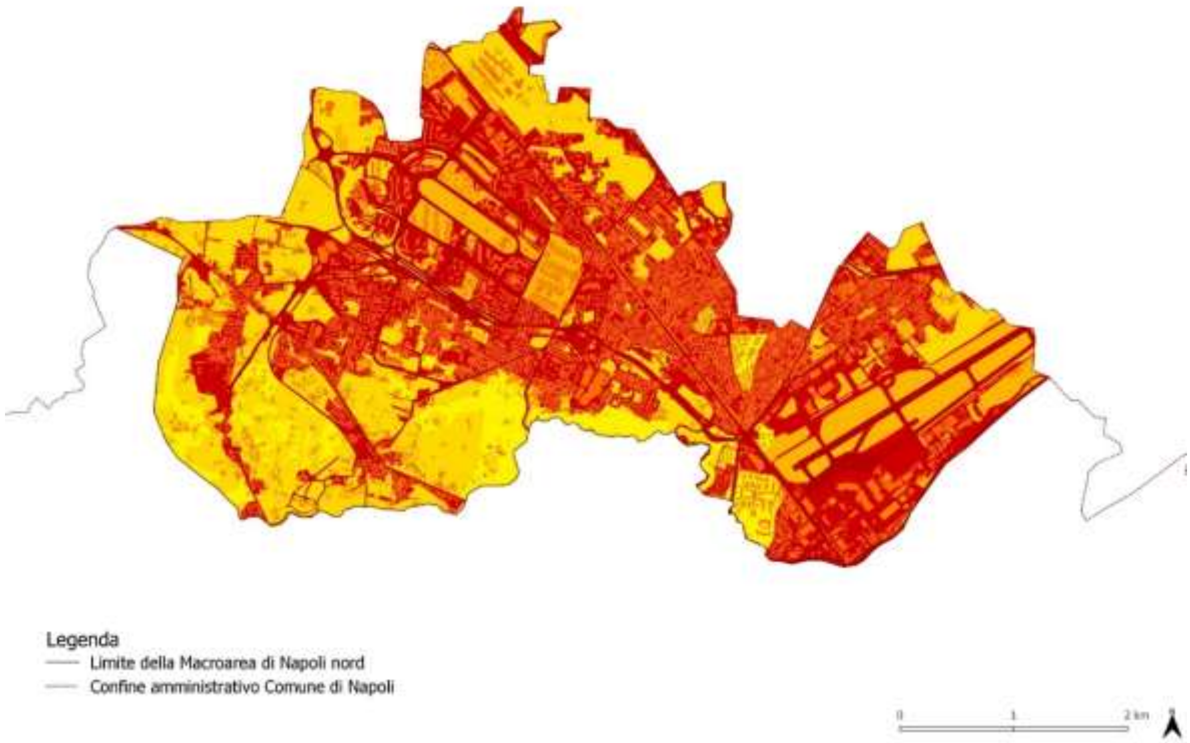

Figure 29. Albedo thematic map for the North Naples' macroarea . Elaboration by D. Morelli as part of the internship project "Percent-periferie al centro", UNINA, 2022.

Name	**Runoff**
ID	**41**
Dimension	☒Built ☐Environmental ☐Social ☐Economic ☐Institutional COMMENTO: Il runoff fa riferimento alla dimensione ambientale
Topic	Urban Water management
Definition	**Runoff** is the volume of surface water that flows across a terrain after precipitation, due to insufficient infiltration or interception. It is influenced by surface permeability, land cover, slope, and rainfall intensity.
Direction	☐ Positive ☒negative ☐not defined ☐Context-dependent
Formula	$Q_p = C \times i \times A$ **Formula variables** • **Q_p = Peak runoff (m^3/s)** • **C = Runoff coefficient (dimensionless, 0–1)** • **i = Rainfall intensity (mm/h)** • **A = Catchment area (ha)**
Unit of measure	Dimensionless (0–1)
Data source	MODIS, Landsat, Sentinel-2, Material datasheets, GIS surface classification
Territorial scale	Urban blocks / drainage basins
Timescale	2022
Recommended software/tools	QGIS, SWMM, HEC-HMS, SAGA GIS, GRASS GIS
References	Alshammari et al. (2023); Dowtin et al. (2023)

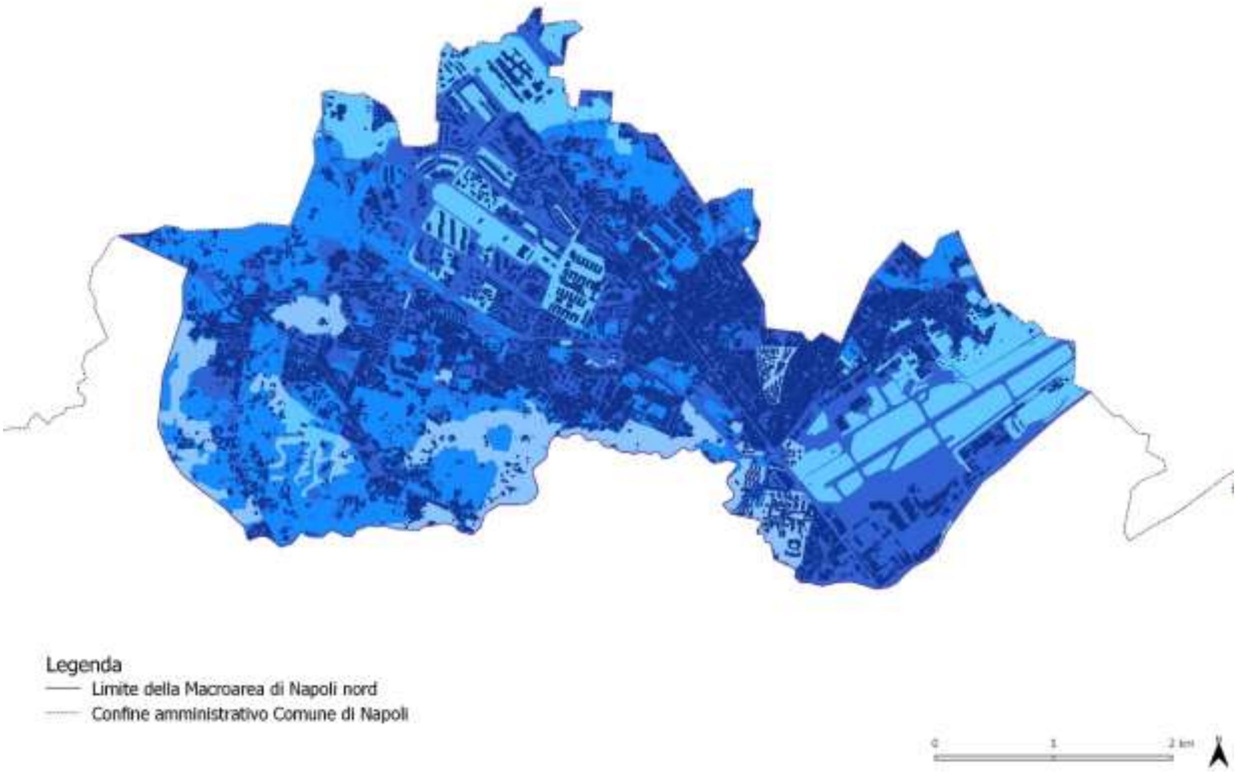

Figure 30. Runoff thematic map for the North Naples' macroarea. Elaboration by D. Morelli as part of the internship project "Percent-periferie al centro", UNINA, 2022.

4.3 A review of protocols and tools for urban integrated resilience

This section illustrates the analysis conducted on the main existing resilience assessment protocols, aimed at the construction of a shared and flexible methodology that may allow resilience planning and design. Through such analysis, common and relevant themes, objectives and areas of intervention have been identified, to be then declined into multi-level operational guidelines.

The analysis of the protocols therefore has a twofold function: on the one hand, it allows us to understand the metrics and categories already in use to assess resilience; on the other hand, it provides content and criteria to build a methodological framework that favors the integration of assessment, planning and design.

Urban and building-scale protocols has been considered, selected for their international and national relevance, methodological approach and ability to deal with integrated resilience, i.e. simultaneously considering environmental, social, economic, technological and management factors, consistent with green transition principles. The protocols were classified through a common analytical grid, which enabled the systematization considering:

- general objectives and operational aims;
- thematic areas covered;
- reference scale;
- target audience and application contexts;
- methodology (prescriptive, performance, indicator-based);
- internal structure of the document;
- supporting tools (checklists, tables, indicators, roadmaps).

In order to enhance comparison and operationalize the analysis, two summary tables were constructed for the urban and building scales respectively.

Table 4.22 Urban scale protocols

Title	**Developer**	**Publication**	**Objective**	**Audience**	**Type of document**	**Contents**	**Methodology**
City Resilience Framework	ARUP	2024	Assessing, planning, and strengthening urban resilience	Policy makers, technicians, NGOs, academics	Strategic/operational	4 dimensions and 12 objectives; resilience qualities	Holistic, participatory, adaptable
UNDRR MCR2030	UNDRR	2020	Strengthen urban resilience and reduce the risk of disasters by 2030	Local administrations, urban stakeholders	Operational guide	3-step roadmap; 12 thematic areas; self-assessment tools	Progressive, flexible, with support tools
OECD Resilient Cities	OECD	2023	Building systemic climate resilience through an integrated approach	Policy maker, local administrators	Analytical paper	4 key elements, 6 policy approaches, case studies	Comparative, peer-learning, policy-oriented
LEED for Cities & Communities	U.S. Green Building Council	2021	Certifying urban and community sustainability	PA, planners, professionals, stakeholders	Certification	9 thematic categories, scoring system, prerequisites, and credits	Checklist + score with certification levels

Table 4.23 Building scale protocols

Title	**Developer**	**Pubblication**	**Objective**	**Audience**	**Type of document**	**Contents**	**Methodology**
BREEAM In-Use	BRE (UK)	2009	Assessing the sustainability of buildings in operation	Managers, designers, investors	Environmental certification	Assess energy, CO2, water, waste, air quality, noise, safety	Multi-criteria score with weighted credits
LEED v4 BD+C	USGBC	2016	Certify sustainability throughout the entire	Designers, builders, clients	Voluntary certification	Checklist with prerequisites, optional credits,	Tiered structure with

			life cycle of the building			thresholds for certification	thematic credits
WELL Building Standard	IWBI	2016	Certifying the impact of buildings on the health and well-being of occupants	Designers, developers, managers	Health certification	7 concepts: Air, Water, Nutrition, Light, Fitness, Comfort, Mind; 102 features	Prescriptive and performance mix
CASBEE	IBEC / JSBC (JP)	2014	Assessing the environmental performance and impact of new buildings	Designers, authorities, certifiers	Technical manual	Q (Quality) and L (Environmental Load); BEE index; 5-level score	Q/L calculation, summary score
Protocollo ITACA	ITACA	2003	Assessing environmental sustainability and energy efficiency in residential construction	Technicians, PA, designers	Technical document	7 areas: external environment, resources, loads, comfort, management, transport	Scale from -2 to +5, with evaluation sheets
CasaClima	Agenzia CasaClima	2011	Certifying energy efficiency and environmental quality	Designers, users, technicians	Technical regulatory directive	Energy classes; verification of building envelope, ventilation, summer; 6 technical annexes	Classification from GOLD to G, technical verification

The review revealed methodological and functional differences related to the scale of intervention and complementarities useful to build an integrated assessment system.

Regarding urban scale, the protocols (e.g. City Resilience Framework, UNDRR MCR2030, LEED Cities, OECD Resilient Cities) are configured as strategic planning tools, often built on flexible and multi-level frameworks. Their focus is on strengthening the systemic capacity of cities, through three key elements:

- defining long-term visions and goals;
- construction of progressive roadmaps;
- supporting governance and participation.

Regarding building scale, on the other hand, protocols (e.g. BREEAM, LEED BD+C, WELL, ITACA, CasaClima, CASBEE) are more oriented towards performance measurement and quality certification, providing detailed tools for:

- sustainable design and management of the life cycle of buildings;
- control of specific environmental and functional parameters;
- guarantee of comfort, health and safety.

4.4 NEB dedicated monitoring and assessment framework

In the context of New European Bauhaus, the Joint Research Centre (JRC) has developed a roadmap to operationalise the NEB's core values through a dedicated monitoring and assessment framework (Lourenço et al., 2024). This framework aims not only to track progress but to shape the way cities plan, design, and regenerate their built environments. Unlike traditional metrics focused narrowly on technical performance or economic growth, the NEB calls for integrated indicators that account for subjective well-being, cultural identity, beauty, and participatory quality.

The JRC report highlights the need to move from siloed, quantitative-only models of monitoring toward multi-dimensional systems that can reflect the complex interplay between ecological, social, and aesthetic dynamics in cities. It argues that data collection and indicator design should be informed by place-specific characteristics, and should include experiential and narrative-based data, alongside standard environmental and socio-economic measures.

To address this challenge, the report identifies three strategic layers for NEB-oriented monitoring:

1. **Principles and values**, linked to the overarching goals of NEB.
2. **Domains of intervention**, such as housing, public space, energy or mobility.
3. **Operational indicators**, structured to capture both outcome- and process-based dimensions.

Proposed Indicators

The JRC outlines a preliminary set of indicators aligned with NEB values, structured across five thematic clusters. These are designed to support cities and regions in assessing their alignment with NEB principles while leaving room for contextual adaptation and co-designed refinement.

1. Aesthetic and Cultural Experience

- Perceived beauty and visual quality of public space
- Integration of cultural and historical identity in the built environment
- Use of art, crafts, and creative installations in public design
- Cultural programming and access to local traditions

2. Environmental Performance and Circularity

- Use of bio-based, recycled, or locally sourced materials in construction
- Energy efficiency of buildings and infrastructure
- Green space per capita and biodiversity presence
- Urban heat island mitigation (e.g., through shading, vegetation)
- Water retention and management systems

3. Social Inclusion and Equity

- Accessibility for people with disabilities or reduced mobility
- Socio-spatial equity in access to green infrastructure
- Diversity of participants in planning and co-design processes
- Availability of affordable housing and inclusive services

- Community cohesion and social mix indicators

4. Participation and Co-Creation

- Number and quality of participatory design workshops
- Degree of citizen influence in decision-making (e.g., via participatory budgeting)
- Stakeholder diversity in project implementation
- Presence of co-managed spaces and civic commons

5. Emotional and Psychological Well-being

- Reported levels of comfort, safety, and mental well-being in public spaces
- Citizens' sense of belonging and place attachment
- Emotional perception of transformation projects
- Spaces promoting care, intergenerational exchange, and learning

The report emphasizes that these indicators should be implemented with methodological flexibility, combining quantitative metrics, such as land use ratios or air quality indices, with qualitative assessments, such as photo-elicitation, storytelling, or participatory mapping. Moreover, these indicators should not be static but evolve dynamically through iterative validation with communities and experts, ensuring their relevance and legitimacy.

Towards a NEB-Aligned Monitoring Ecosystem

The JRC stresses that the success of the NEB monitoring approach depends not only on the design of new indicators, but also on the development of enabling protocols, governance tools, and digital infrastructures. Data collection should be inclusive and transparent, respecting data justice and privacy standards, while fostering data literacy and shared ownership among citizens.

The report also encourages cities to use the NEB framework to innovate their evaluation cultures, shifting from compliance-driven reporting to transformative learning systems. Monitoring should be seen as a tool for navigating complexity, enabling reflection and adaptation over time, and helping cities build legitimacy and trust in the transition process.

In conclusion, by embedding indicators and protocols that reflect the NEB's integrative vision, cities can better align their strategies with the aspirations of a just, beautiful, and sustainable future. Monitoring, in this light, is not a technical formality, but a cultural practice—an invitation to make values visible and actionable in the urban fabric.

4.4.1 Circularity

A core thematic axis of the NEB's sustainability dimension is what has been termed Circular Sustainability or the Circular Economy in NEB (Lourenço et al., 2024; Mazzucco et al., 2024). NEB provides Europe with a unique opportunity to lead in the global transition from a linear development model to a circular one, embedding principles of regeneration, resource efficiency, and adaptability into the design of buildings, neighbourhoods, and infrastructures.

Rather than addressing circularity and climate adaptation as separate objectives, NEB promotes a holistic vision in which material reuse, nature-based design and co-creation converge to create urban spaces that are efficient, resilient, and emotionally meaningful. The initiative challenges traditional planning paradigms by linking technical innovation with cultural transformation and by promoting sustainability as a living and experiential quality of space (Rosado-García et al., 2021).

NEB's circular approach involves a fundamental shift from the linear "take, produce, consume, dispose" model to a restorative and regenerative one (Lourenço et al., 2024). Its principles—eliminating waste and pollution, keeping products and materials in use, and regenerating natural systems—are integrated not only into construction practices but into the broader urban metabolism.

In particular, NEB encourages:

- Prioritizing reconstruction over new construction, recognising that 80% of the building stock for 2050 already exists. Retrofitting and remediation are therefore essential to reduce embodied emissions and material flows (Lourenço et al., 2024).
- Minimizing construction and demolition waste (CDW) through selective demolition, sorting systems, and the reuse or recycling of at least 70% of non-hazardous CDW, as mandated by the Waste Framework Directive.
- Using sustainable materials, including bio-based, secondary and renewable resources, such as timber and hemp-derived products, which help close material loops and support ecological resilience.
- Designing for disassembly and adaptability, ensuring that buildings and components can be reused, repaired and reconfigured over time to meet evolving needs.
- Leveraging digital tools, such as digital twins, to monitor energy use, water systems and material flows throughout the building lifecycle.

These strategies are supported by the NEB Compass, which articulates three levels of ambition—repurposing, closing the loop, and regenerating—and integrates them with the EU's climate neutrality and resource efficiency goals (Lourenço et al., 2024).

Indicators for Monitoring NEB Circularity

The NEB self-assessment framework ((Lourenço et al., 2024) provides a structured way to monitor circularity through specific indicators. One of the main key performance indicators is S.9 – Promote circular economy in the built environment, which quantifies the use rate of secondary, bio-based and recycled materials. This is operationalised through the Circularity of Material (CM) score, calculated as the ratio of the mass of circular materials to the total mass of materials used (Lourenço et al., 2024).

Climate Adaptation in the NEB Vision

In addition to material circularity, NEB contributes to circular urban climate adaptation strategies. Within the New European Bauhaus, climate adaptation is conceived not as an isolated technical function but as a circular and regenerative urban strategy. NEB can promote an integrated vision where the principles of circular economy—resource efficiency, regenerative cycles, and adaptive reuse—are applied to build resilience against climate risks while enhancing the ecological, aesthetic and social quality of urban environments.

Circular climate adaptation in NEB-aligned projects means designing urban systems that are not only low-carbon and low-waste, but also cyclical in their function, modular in their design and inclusive in their governance. Climate adaptation becomes a circular process of anticipating, absorbing, and evolving with environmental stressors through closed-loop, locally embedded interventions.

Key NEB-oriented strategies for circular climate adaptation include:

- Water-sensitive circular design, which integrates systems such as rain gardens, bioswales, and permeable pavements to manage stormwater in situ. These interventions reduce runoff, recharge aquifers, and minimize flood risk while mimicking and supporting natural hydrological cycles.
- Biophilic and thermally regenerative design, where vegetation, urban forests, and green infrastructure serve not only to beautify but also to regulate microclimates, reduce the urban heat island effect, and sequester carbon. These systems operate within a living circular logic, regenerating local ecosystems as they cool and shelter public space.

- Flexible and modular infrastructure, developed with circular principles such as disassembly, reuse, and material recovery in mind. These elements are designed to respond dynamically to changing climate conditions, population needs, and resource availability, extending their functional lifespan and reducing environmental load.
- Circular social resilience, where community-driven governance and co-creation are viewed as essential resources to be nurtured and sustained. Through participatory design and shared ownership of adaptive infrastructure, citizens become active contributors to resilient circular systems tailored to local environmental and cultural contexts (Lygnerud et al., 2023).
- The use of digital technologies, particularly urban digital twins, further embeds circularity into climate adaptation by enabling continuous simulation, monitoring, and optimization. These tools facilitate real-time feedback loops that support resource-efficient adaptation actions and help cities align short-term responses with long-term circular planning (Mazzucco et al., 2024).

Despite these strengths, NEB-aligned circular and adaptive strategies face significant challenges. These include the cost competitiveness of circular materials, limited standardisation and regulatory gaps that hinder large-scale reuse. Certification processes for alternative materials remain complex and public procurement frameworks often do not reward regenerative or flexible designs.

Moreover, achieving a fully circular and adaptive system requires a cultural shift—from linear thinking to systemic imagination, from efficiency alone to aesthetics, care and co-ownership.

4.4.2 Primary benefits, co-benefits and multiple-benefits

The New European Bauhaus, when applied to climate adaptation, offers a wide range of interconnected benefits that extend well beyond the technical domain of resilience. By embedding circularity, beauty, inclusion, and participatory governance into adaptive strategies, NEB projects generate direct advantages, co-benefits, and multiple synergistic effects across environmental, social, economic, and cultural dimensions.

Primary Benefits

NEB-aligned strategies directly improve the adaptive capacity of urban systems. This includes better building performance in response to climate stressors (such as floods, heatwaves, or drought), increased energy efficiency, and lower material and carbon intensity. For example, applying NEB principles leads to the construction of buildings designed with climate hazard resilience (flood-, wind-, or seismic-proof structures), improved microclimatic conditions, and enhanced resource efficiency through adaptive reuse and modularity (Lourenço et al., 2024)

Co-benefits are secondary, positive outcomes that result indirectly from a policy or action primarily designed to achieve another goal. In the context of NEB and climate adaptation, these are benefits that accompany resilience-focused interventions, even if they were not the primary objective.

In NEB-aligned projects, co-benefits include:

- Social co-benefits: strengthened community cohesion through participatory planning and co-creation processes;
- Economic co-benefits: local job creation, green innovation, and mobilisation of sustainable finance tools (e.g. climate bonds, impact investment);
- Environmental co-benefits: improved air quality, biodiversity restoration, and reduced land consumption through the adaptive reuse of existing buildings(Lourenço et al., 2024)

These co-benefits are particularly evident in nature-based solutions promoted by the NEB, such as green roofs or urban forests, which not only mitigate urban heat and manage water but also support recreation, aesthetics, and mental well-being.

Multiple benefits refer to the simultaneous generation of several primary benefits across sectors or dimensions, often through synergistic actions that address complex urban challenges holistically.

In the NEB framework, multiple benefits arise when a single intervention (e.g., climate-adaptive public space design) improves urban resilience, social inclusion, aesthetic quality, and economic value at once. For example:

- Introducing urban green corridors increases stormwater absorption (adaptation), provides cooling (health), supports biodiversity (ecology), and raises neighbourhood attractiveness (economic value).
- Designing buildings for disassembly improves material circularity (resource efficiency), eases future adaptation (resilience), and stimulates architectural innovation (cultural value).

The NEB's integrative nature enables these multiple benefits by encouraging co-design processes, local anchoring of innovation, and systemic thinking in planning and design.

Enabling Systemic Synergies

By combining digital tools such as urban digital twins with participatory governance, NEB strengthens a city's capacity to anticipate, simulate, and respond to climate risks while maximizing co- and multiple benefits. These tools facilitate real-time monitoring, guide the optimisation of resource flows, and align local adaptation efforts with long-term sustainability transitions (Lourenço et al., 2024)

Moreover, assessment frameworks such as **Social Return on Investment (SROI)** help quantify the full value generated by NEB-based interventions, including less tangible yet highly relevant aspects like sense of belonging, reduced vulnerability, and improved mental health.

5. Design proposal (modelling and testing)

5.1 Proof of Concept processes through design proposal

Climate mitigation and adaptation require the introduction of decision-support tools to guide sustainable and resilient design. In this context, the role of design proposals has been investigated as an innovative tool to integrate multi-scalar approaches in urban planning and design in multi-hazard contexts and to verify the effectiveness of design strategies targeting integrated urban resilience. Moreover, such design proposals contributed to the definition of the Design Guidelines, providing in-depth information regarding planning and design decision-making factors.

Following a 'transformative' approach, design proposals are defined through the identification and systematisation of multi-scalar and multi-disciplinary factors. Such approach allows them to be used throughout the design process, supporting the identification of design strategies and actions best suited to the specific needs of the intervention according to hazard and site-specific criteria. Different contexts of application (both urban and metropolitan) are identified, considered in relation to the minimum impact surfaces and the significant effects in terms of applicability of the interventions. The relationship with the temporal dimension, as strongly related to the risk management phases in the integrated urban resilience framework, is considered. The application contexts (both urban and metropolitan), are as well identified, considering the minimum impact areas and the significant effects in terms of applicability of the intervention.

Design proposals are also defined accounting for impact reduction capacity, as related to specific risks (environmental, natural or anthropogenic). Moreover, suitable strategies and solutions that can be integrated to maximise the achievement of the imposed objectives are also identified, and indications of the benefits and co-benefits deriving from the intervention are provided. A key role is assigned to the identification of indicators and indices for the evaluation of the effectiveness and monitoring of climate-resilient strategies and solutions in relation to ex-ante and ex-post scenarios.

To this end, as reported in section 3.1.1, the cyclicity of the Proof-of-Concept methodology corresponds to the approach to observation, knowledge, identification of weaknesses, assessment of vulnerability and exposure, assessment of impacts, identification of requirements, scenarios, objectives, strategies and actions to tackle the same impacts or mitigate some of their causes (ref. to DV2.2). Through PoC, it would be possible to assess the impact of different policies, urban interventions and design proposals on reducing the impacts of hazards, improving quality of life and creating more resilient communities, and to help identify gaps and synergies between different instruments, enabling the refinement of long-term planning strategies. The contribution to the deepening of PoC contents developed in this chapter is addressed as much to observation and knowledge as to transformation, prefiguring development of planning tools for the transition of urban district in urban eco-districts.

In this context, the development of design proposals with a Proof-of-Concept methodology is an essential tool to develop short-, medium- and long-term strategies to bridge adaptation, mitigation and impact reduction in urban settlements through strategies and actions. Design proposals strengthen the connection between strategic planning, governance and operational implementation and enable alignment with sustainable development goals and international climate strategies.

5.2 Design proposal at Territorial/urban scale

5.2.1 Urban green infrastructure, ecosystem services supply and ecological corridors: the FUA of Cagliari

This section proposes a methodology for defining an urban green infrastructure (UGI) in the spatial contexts of functional urban areas (FUAs) identified by the OECD and the European Commission in 2012. The methodology refers to UGIs as systems that integrate the characteristics of green infrastructures, as spatial networks of natural and semi-natural areas that provide a wide range of ecosystem services, and the properties of urban infrastructures, as devices that respond to the needs and expectations that, in different respects, are expressed by communities settled in cities. UGI is identified, in the context of a FUA, as a succession of green areas, spatially connected to each other, which contribute to the provision of certain ecosystem services. This infrastructure includes the connecting elements that are identified as urban ecological corridors. The methodology, which supports the spatial taxonomy of the UGI on the classification of the FUA territory proposed by the Joint Research Center (JRC) of the European Commission in relation to enhancing the resilience of urban ecosystems through UGIs, is applied to the FUA of Cagliari, located in the regional island context of Sardinia, with reference to the provision of some ecosystem services such as climate regulation, flood risk mitigation, outdoor recreation, and biodiversity and habitat quality enhancement.
The sub-section "Urban green infrastructures: Introduction and general context" describes the concept of Urban green infrastructures (UGIs) and discusses their role within urban areas.
The sub-section "Methodological approach and case study" describes the case study, i.e., the Functional urban area (FUA) of Cagliari, and explains the methodological approach developed for identifying a UGI, which is comprised of three steps. First, the UGI is identified through the spatial taxonomy of the provision of a set of ESs that define and characterize the quality of urban settings, such as areas for outdoor recreation, flood control, carbon capture and storage, quality of flora and fauna habitats, and urban heat mitigation. Second, the UGI is structured as a spatial network whose nodes are the terrestrial natural protected areas (core areas) and whose branches are identified as the connecting green corridors of the core areas, detected on the basis of a methodology based on ecological integrity and degree of naturalness. Finally, the connecting corridors are superimposed on the spatial taxonomy of ESs to identify whether, and to what extent, the inclusion of areal elements in the corridors is related to the supply of the different types of ESs.
The sub-section "Results" presents the outcomes from the implementation of the methodological approach.

Urban green infrastructures: Introduction and general context
The European Commission identifies a green infrastructure (GI) as "[A] strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings" (European Commission, 2013, p. 3), and, "The work done over the last 25 years to establish and consolidate the network means that the backbone of the EU's GI is already in place. It is a reservoir of biodiversity that can be drawn upon to repopulate and revitalize degraded environments and catalyze the development of GI. This will also help reduce the fragmentation of the ecosystems, improving the connectivity between sites in the Natura 2000 network and thus achieving the objectives of Article 10 of the Habitats Directive" (European Commission, 2013, p. 7). Spatial planning policies aimed at protecting and increasing the availability of ecosystem services (ESs) should thus focus on GIs as qualitatively and quantitatively relevant production networks of ESs (Liquete et al., 2015; Dover, 2015; Naumann et al., 2011).
The European Commission, therefore, identifies GIs as key spatial systems for the conservation and improvement of biodiversity conditions, the effectiveness of spatial linkages of natural ecosystems, and the enhancement of ESs production (Directorate–General Environment, 2015). Moreover, improving the biodiversity situation and increasing the supply of ESs are two priority purposes concerning spatial planning policies aimed at strengthening the functionality of GIs (Liquete et al., 2015; European Environment Agency, 2014).
The concept of UGI fits within the conceptual and technical horizon outlined by the European Commission, and is developed, in a relevant way, through contemporary urban planning practices to characterize urban green area systems as relevant overall references of planning processes (Sandström, 2022; Tzoulas et al., 2007).

UGI is a network composed of natural and semi-natural elements designed with the aim of increasing its ESs supply, in which green spaces, open spaces and water bodies are recognized and included. These elements are located in built-up areas and also in correspondence with non-permeable soils, thus completely artificial. The network of natural structures of different size, location, and ownership should be maintained and further developed as a joint responsibility of the various political, economic, and civic actors, working in the context of city management.
In terms of contributing to social, ecological and sustainable urban development, UGIs are characterized as follows (Breuste, 2021):

- be accessible to all users of the urban context;
- improve the users' health and well-being;
- conserve and enhance both biological diversity and direct and sustained enjoyment of natural resources;
- contribute to the aesthetics of the city and improve the quality of life in urban settings, and especially in densely urbanized ones;
- preserve and increase the supply of ESs by users of the urban environment, whether residents, commuting workers, occasional visitors, tourists, or out-of-town students.

Even fully urbanized and artificialized areas can become part of UGIs through removal of non-permeable surface covers, greening, and tree planting. The strong inclusiveness of UGIs is emphasized by Tzoulas et al. (2007) in relation to natural and semi-natural areal and related ecological systems, both with reference to individual conurbations and in relation to multicenter spatial organizations, including with reference to transitional, peri-urban and rural areas.
UGIs play a particularly important role in urban areas in relation to the continuity of urban green spaces, which are characterized by significant fragmentation due to the widespread presence of sealed areas, as well as physical obstacles of different kinds, such as buildings and their appurtenant areas and transportation infrastructure, a condition that has a strong negative impact on biodiversity. If, therefore, UGIs are not always able to limit the fragmentation of urban greenery, however, they make available important ESs also not directly related to spatial continuity, such as, for example, the improvement of air quality, linked to the presence of vegetated surfaces, whose positive impact is amplified when these are characterized by the presence, more or less widespread, of trees (Echevarria Icaza et al., 2016; Salata and Yiannakou, 2016).
Green walls and roofs contribute, significantly, to absorbing the heat generated by sunlight, thus mitigating the negative effects of high temperatures in the established settlement fabrics of cities and, in particular, the urban heat island phenomenon (Eggermont et al., 2015).
The protection, management and development of UGI takes place with the following principles in mind (Breuste, 2021):

- adapt the usability of available urban ESs according to the needs of users through measures that involve, in a strategic manner, the definition and implementation of urban planning;
- promote the multipurpose use and multifunctionality of UGIs;
- make sure that the use of ESs is continuous and effective, and make maintenance operations, which limit, often problematically, these uses, as efficient as possible;
- integrate UGIs into the parts of the urban context whose soils are largely sealed, through partial permeabilization of the soils, as part of the implementation of nature-based solutions;
- defining and implementing urban planning policies, aimed at increasing the effectiveness of UGIs, which are characterized by inclusiveness and participation of local societies, with special reference to private entrepreneurship of the for-profit and non-profit sectors, citizens' committees, voluntary associations, especially those working in the field of environmental protection, trade union representatives, and all public administrations responsible for the management of the urban environment.

The implementation of a proactive, participatory and inclusive approach to urban planning geared toward strengthening UGIs is the foundation of a new holistic strategic vision of spatial policymaking that effectively integrates, with reference to local contexts, sustainable economic development and social equity (Zoppi, 2012; Walmsley, 2006; Schrijnen, 2000; van der Ryn, 1996). On the profile of the compact city within the ecological network is based the overall approach of urban planning in Dresden, aimed at implementing a green city (Breuste, 2021). The guiding principle is the planning of compact urban settlements embedded in a network of ecologically functional spaces. The river system (400 waterways and the Elbe River basin) is the basis of the ecological network, which will be gradually expanded together with the provision of freely usable urban green space. The following operational functions are assigned to it (Breuste, 2021):

- improvement of air quality and progressive adaptation to climate change;
- effective recharge of underground aquifers;
- flood prevention and runoff control;
- increased areas available for outdoor recreation;
- protection and improvement of habitat quality for flora and fauna, and functioning and adequate usability and walkability, of corridors connecting hubs of concentration of urban ES provision;

- protection and improvement of the aesthetic quality of the urban, built and natural environment.

Dresden's UGI is structured through green connecting hubs and corridors, with respect to which urban policies are, on the one hand, aimed at improving the ecological quality of the network of hubs and connections, and, on the other hand, oriented toward operationalizing a system of regulations to limit or prevent the expansion of the urban built environment. The intentionality of the Dresden municipality's approach is to ensure that the framework of urban ES provision is perceived by the local community as a complex GI, and open spaces as the building blocks of this infrastructure (Buijs et al., 2019; Fors et al., 2015).

Methodological approach and case study

This section is organized as follows. In the second part, after a preliminary synthetic description of the FUA of Cagliari, taken as a case study, the methodology used to define the spatial taxonomy of the UGI is outlined, with reference to the different typologies of ESs that define it and, namely, the areas available for outdoor recreation, the identification of areas with strong potential for flood control and mitigation, and carbon capture and storage (CCS) capacity, the location of habitats particularly significant for the quality of flora and fauna, and the identification of the phenomenon of urban heat mitigation through the spatial definition of land surface temperature (LST). In the third part, the methodology implemented for the identification of urban ecological corridors (UECs) is defined, with reference to the integration of the spatial taxonomies of ecological integrity and naturalness conditions. Finally, a linear regression model is presented which identifies, in comparative terms, in relation to the spatial taxonomy of UGI, the ability of different ESs to contribute to the identification and development of UECs.

<u>Study area: the FUA of Cagliari</u>

As per the definition offered by the Organization for Economic Cooperation and Development (OECD), a FUA is comprised of a city and its commuting zone. By accounting for cities' areas of influence in terms of daily movements of commuters, FUAs represent an effort to identify meaningful "integrated socio-economic units" (Bettencourt and Lobo, 2019) consistent across countries, and integrate core built-up areas having high residential density and at least 50,000 inhabitants within their labor markets (OECD, 2012), usually composed of smaller settlements with lower density, but also rural areas (Dijkstra et al., 2019).

The FUA of Cagliari, which spans over around 1,950 km^2, comprises 32 local authorities, shown in Figure 1. The resident population totaled 476,717 people as of 2022 (EUROSTAT, 2022), of which around 30 percent live in the FUA's core area, i.e., the municipality of Cagliari. While the population in the FUA core city has been decreasing for years, its commuting zone shows a steadily increasing trend.

Green spaces, defined after McDonald et al. (2023) as the combination of ecological systems having various degrees of naturalness, represent 42.06 percent of the FUA, including green urban areas, which amount to a mere 0.47 percent of the FUA. In addition, blue spaces, mostly coinciding with wetlands and saltpans, make up a further 3.87 percent. Significant differences as to green areas endowment emerge between the core urban center (Cagliari) and its commuting zones: the percentage of green and blue spaces amounts to 57.56% in Cagliari and 45.02% in the commuting area; however, because a significant share of the municipality of Cagliari is occupied by wetlands, when blue spaces are removed and only vegetated land covers are considered, the percentage in Cagliari drops to 12.27%, whereas the commuting area shows a negligible decrease to 43.54%.

To implement the methodological steps described in the next sub-sections, a vector fishnet, next referred to as "grid", made up of 100-meter-wide squares and covering all the FUA, was created. Each of the almost 988,000 cells comprised in the grid was then used as the reference spatial unit where to map the values of the variables that feed the inferential model.

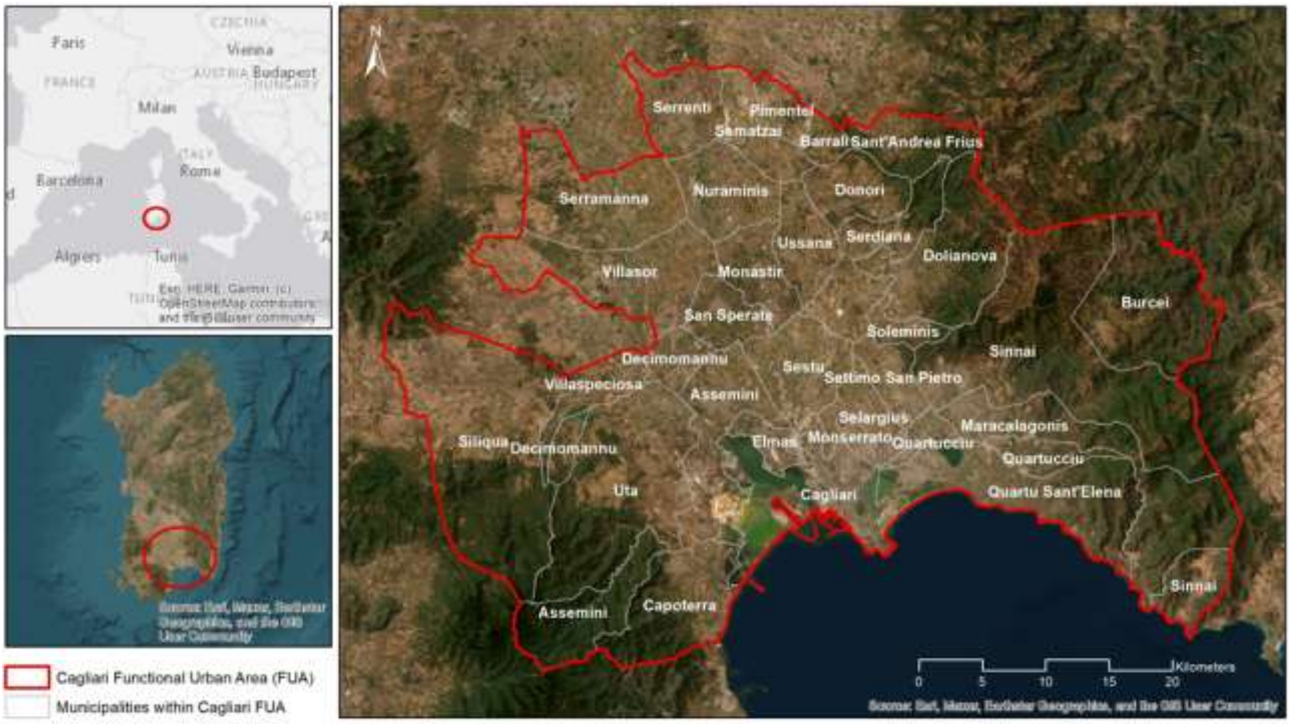

Figure 31. The Functional Urban Area (FUA) of Cagliari in Sardinia, Italy, and its municipalities..

The spatial taxonomy of the UGI

As per the introductory section, the spatial layout of the UGI is here identified based on the spatial distribution of the supply of five selected ESs, by biophysically assessing and mapping the following: nature-based recreation opportunities; water retainment capacity in case of heavy rainfalls; climate regulation through carbon sequestration and storage; habitat quality as a proxy for habitats' potential to provide niche, food and shelter for wildlife; LST as an indicator of green areas' cooling capacity. This sub-section briefly describes the methodological approach used to assess and map the five chosen ESs, listed in Table 1.

Table 5.1. Selected ecosystem services: input data used to feed the models, and their data sources.

Label	**Input data**	**Data sources**
RECR_OUT	Land cover map	Copernicus land monitoring service
	Population data (census tract level) Census tracts	National census
FLD_CNTR	Land cover map Soil permeability map Curve number values Areas of interest	Regional geoportal
	Precipitation (rainfall depth)	Regional hydrologic annals
CA_CP_ST	Land Cover map	Regional geoportal
	Carbon pools (above ground, below ground, dead organic matter, organic carbon)	Regional pilot project on land units and soil capacity in Sardinia National inventory of forests and carbon pools
HAB_QUAL	Land Cover map	Copernicus land monitoring service
	Protected areas	Regional geoportal
	Threats on habitats	Natura 2000 standard data forms Regional geoportal
	Threats' weights and distance decay Habitats' sensitivity to threats	Expert survey

L_S_TEMP	Landsat collection 2, level 2 imagery	Landsat Collection 2 Surface Temperature

1. Nature-based Recreation Opportunities

Nature-based recreation opportunities were assessed based on two indicators, respectively concerning areas suitable for outdoor recreational activities, and resident population living close to such areas, as potential beneficiaries of the ES.

As for the first, areas available for nature-based recreation inside the FUA were identified based on the 2018 Urban Atlas land cover dataset issued by the European Land Monitoring Service[10]. Despite having a coarse classification of vegetated areas, the Urban Atlas dataset has a much finer spatial resolution than the 2018 CORINE Land Cover (CLC) dataset[11]: its minimum mapping unit equals 0.25 ha for urban classes (including urban green areas) and one hectare for rural classes, against the 25-hectare CLC's one. Land cover types relating to green urban areas (Urban Atlas code 14100), sports and leisure facilities (Urban Atlas code 14200), and vegetated natural areas, i.e., land cover codes beginning with 3, were selected, as well as the edges of inland and marine waters (respectively, codes starting with 4 and 5), because of the significance of the coastline and of riverbanks or wetland or lake shores for nature goers (Hale et al., 2019; Guo et al., 2022; Ebner et al., 2022). Next, for each 100*100 cell in the grid, the share of green and blue areas offering nature-based recreation opportunities was assessed in percentage terms.

Concerning the second, population data was retrieved from the 2021 national census[12], having census tracts as spatial units of reference. A series of GIS operations was therefore performed to estimate the number of residents in each 100*100 cell in the grid, by assuming that the resident population is evenly distributed in each census tract once water areas (when present) are removed. Next, for each cell that might potentially attract nature-based outdoor recreation, i.e., for each cell having non-null shares of green and blue areas, the population living within 500 meters from the cell was calculated. This is consistent with previous studies (among many, (Giles-Corti et al., 2005; Kabisch and Haase, 2014; De Sousa Silva et al., 2018; Wysmułek et al., 2020)), where the distance of green areas from home was considered as a factor driving urban outdoor recreation and therefore affecting residents' health and environmental (in)justice. For this reason, as pointed out by previous research (De Sousa Silva et al., 2018; Kabisch et al., 2016; van Herzele and Wiedemann, 2003), some cities have issued regulations whereby every household should have access to urban green areas within a distance that ranges from 300 to 1000 meters. In this study, and in line with Berlin's regulations (Kabisch and Haase, 2014), a 500-m distance was chosen, since it allows slow walkers such as children and the elderly to reach green areas within a 10-minute walk, having regard to the climate and hilly topography of the urbanized areas within the FUA of Cagliari.

Finally, the RECR_OUT variable was calculated as the percentage of the green and blue areas in each 100*100 cell times the population living within 500 meters from that cell. The process whereby RECR_OUT was assessed is graphically summarized in Figure 2.

[10] Available online: https://doi.org/10.2909/fb4dffa1-6ceb-4cc0-8372-1ed354c285e6 (accessed on 25 June 2024).

[11] Available online: https://doi.org/10.2909/71c95a07-e296-44fc-b22b-415f42acfdf0 (accessed on 25 June 2024).

[12] Available online: https://www.istat.it/it/archivio/285267 (accessed on 26 June 2024).

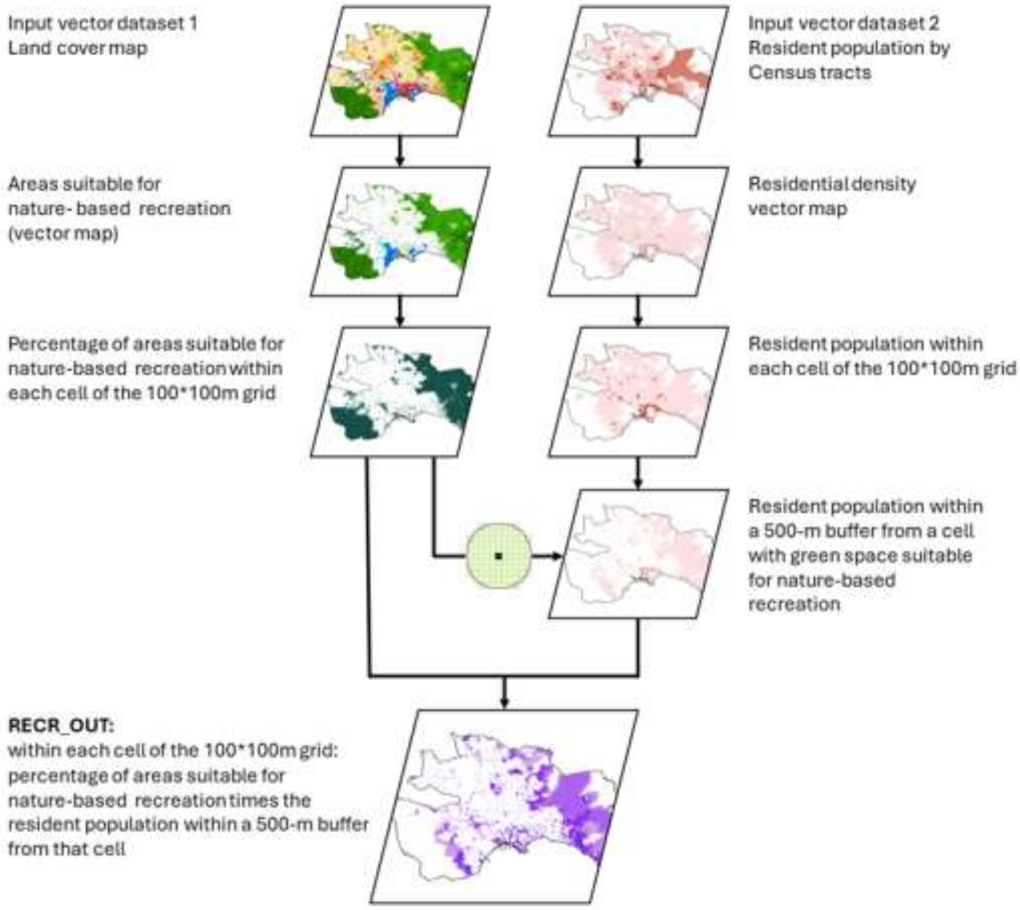

Figure 32. Graphical flow of the assessment of the variable RECR_OUT.

2. Water Runoff Retention
The "Urban Flood Risk Mitigation" model, part of the InVEST suite[13], was used to map the variable FLD_CNTR. This tool estimates the contribution of ecosystems towards flood regulation by biophysically assessing both runoff levels and the water volume intercepted by vegetation and infiltrated by pervious soils in the event of a cloudburst. Input data needed to run the model include the following: two raster datasets, one for land cover types and the other for soil hydrologic groups (SHGs); a vector dataset providing the area of interest; the value of precipitation depth in the area of interest for which runoff and water retention are to be assessed; a biophysical table assigning the curve number to each possible combination of SHG and land cover type. The runoff retention volume is modeled as dependent on the precipitation depth and on the runoff level, which, in turns, is a function of the curve number; the latter is a dimensionless parameter representing the potential runoff after a cloudburst, and it is empirically estimated based on land cover types and on SHGs (Unites States Department of Agriculture, 2004).
The model requires that SHGs be categorized into four groups, labeled A, B, C, and D, consistently with the classification used in the United States of America (Unites States Department of Agriculture, 2009), ranging from highly permeable soils that lead to low runoff (A), to low permeable soils, conducive to high runoff (D). To develop the SHG raster map, a regional 1:25,000 vector permeability map[14] was reclassed to match the four required groups, and next converted into a raster map.

[13] Natural Capital Project Stanford University. What is InVEST? Available online: https://naturalcapitalproject.stanford.edu/software/invest (accessed on 26 June 2024).
[14] Sardegna Geoportale. Carta della permeabilità dei substrati della Sardegna [Sardinian Geoportal. Permeability map of the Sardinian substrates]. https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=94083&es=6603&na=1&n=100&esp=1&tb=14401 (accessed on 26 June 2024).

As for land covers, the 2008 Sardinian 1:10,000 vector map[15] was used, which details the standard CLC nomenclature (Kosztra et al., 2019) up to the fifth level in the hierarchical taxonomy. This data source was selected because a report published by the Sardinian Environmental Agency (Agenzia Regionale per la Protezione dell'Ambiente della Sardegna, 2019) contains a look-up table that meets the model's requirements concerning the biophysical table, meaning that it provides curve number values for each land cover type in Sardinia, differentiated according to SHG, by making use of the detailed classification of land covers contained in the regional land cover map.

Concerning the precipitation value, it is worth noting that the temporal dynamics of the rainstorm are not accounted for in the model (Quagliolo et al., 2021), as InVEST only requires a single rainfall value. Therefore, an examination of the 2012-2022 regional hydrological annals, available from the Regional Environmental Agency's website[16], was performed, to retrieve the largest precipitation depth documented in the study area in a day, which amounted to 101.8 mm, recorded on November 13, 2021.

Finally, the vector map of the area of interest, containing the polygons where retention volumes are aggregated, was developed from the regional digital terrain model raster map[17] by delineating watershed boundaries. Through zonal statistics, the variable FLD_CNTR was calculated as the total volume of water retained in the 100*100 cells.

3. Carbon Sequestration and Storage

The "Carbon Storage and Sequestration" model, part of the InVEST suite[18], was used to map the variable CA_CP_ST. Within this model, the amount of carbon stored on a parcel of land is regarded as the sum of four fractions, each representing the quantity of carbon stored within one of four terrestrial carbon pools, i.e., soil, dead organic matter, belowground biomass, and aboveground biomass. The input data required by the model are a land cover map and a look-up table where carbon density values (i.e., amounts of stored carbon per unit of land) are provided for each land cover type in the map and for each carbon pool. Carbon density values to be provided as input data in the look-up table can be obtained in several ways, including review from the literature, use of inventories and databases, expensive and time-consuming on-site surveys, or allometric equations in case of aboveground biomass.

The model was applied using only carbon density values concerning dead organic matter, organic soils, and aboveground biomass, because no information about carbon stored in the belowground pool in the study area could be retrieved. Carbon density values for the three remaining pools were obtained from two sources: the first is a pilot project carried out jointly by the regional agency for rural development and by AGRIS, the Regional Agency for Scientific Research and Technological Innovation in the Agricultural Sector, and the second is the 2005 National Inventory of Italian Forests (Floris and Zoppi, 2020). Through zonal statistics, the variable CA_CP_ST was calculated as the carbon density in the 100*100 cells.

4. Habitat Quality

A third model comprised within the InVEST suite[19], termed "Habitat quality", was used to spatially assess the variable HAB_QUAL. This tool requires as input data a raster land cover map, which was retrieved from the already mentioned 2018 CLC dataset[20] for two reasons: first, the analysis needed to take into account also areas outside the FUA, where the Urban Atlas dataset is not available; second, the coarse classification of vegetated areas provided by the Urban Atlas dataset is inappropriate for this model.

Moreover, two mandatory tables are required by the model. The first concerns the threats that, in the study area, affect the quality of habitats; to build the list of such pressures, the standard data forms of Natura 2000 sites[21]

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[15] Sardegna Geoportale. Carta dell'uso del suolo [Sardinian Geoportal. Land use map]. https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=14480&es=6603&na=1&n=100&esp=1&tb=14401 (accessed on 25 June 2024).

[16] Idrologia e Idrometria [Hydrology and Hydrometry]. Available online: https://www.sardegnaambiente.it/index.php?xsl=611&s=21&v=9&c=93749&na=1&n=10 (accessed on 25 June 2024).

[17] Sardegna Geoportale. Modelli digitali del terreno e delle superfici [Sardinian Geoportal. Digital terrain and surface models]. Available online: https://www.sardegnageoportale.it/areetematiche/modellidigitalidielevazione/ (accessed on 25 June 2024).

[18] Natural Capital Project Stanford University. What is InVEST? Available online: https://naturalcapitalproject.stanford.edu/software/invest (accessed on 5 June 2024).

[19] Natural Capital Project Stanford University. What is InVEST? Available online: https://naturalcapitalproject.stanford.edu/software/invest (accessed on 25 June 2024).

[20] Copernicus Europe's Eyes on Earth. Land Monitoring Service. CORINE Land Cover. Available online: https://doi.org/10.2909/71c95a07-e296-44fc-b22b-415f42acfdf0 (accessed on 25 June 2024).

[21] Commission Implementing Decision of 11 July 2011 Concerning a Site Information Format for Natura 2000 Sites. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011D0484 (accessed on 25 June 2024).

were scrutinized; out of the many threats that are listed in the standard data forms, the ones that concern marine areas were dismissed, as well as those for which no spatial information was available, such as illegal hunting or undefined noise disturbance, which led to identifying ten threats as follows: urban areas, roads and motorways, airports, paths and tracks, agriculture, grazing, removal of forest undergrowth, saltpans, landfills, fire and burnt areas. Next, local experts in environmental assessments were surveyed to score the significance of each threat, using a zero-to-five Likert scale, and their decay distance and function, as both pieces of information are required by the model. Significance scores provided by local experts were averaged and normalized in the zero-one range, whereas decay distances, to be provided in kilometers, were only averaged.

The second table required by the model is a look-up table where, for each land cover that can be classed as habitat, its sensitivity to each threat is scored. Sensitivity scores were assigned through expert-based judgments ranging from zero to one, where higher scores correspond to higher sensitivity.

Finally, accessibility to threats that might degrade the quality of habitats can be accounted for in the model as optional input data. The assumption of the model is that legal and institutional restrictions to accessibility and movement, as the ones associated with natural protected areas, may reduce the negative effects on habitats that would otherwise stem from threats. Therefore, the spatial layout of natural protected areas was considered; in Sardinia, on land, these include national and regional parks, the Natura 2000 network, and public forests managed by the regional forestry agency; for each type, the spatial dataset was retrieved from the regional geoportal[22]. Each type of protected area was assigned a score ranging from zero to one, where higher scores correspond to higher accessibility, hence lower barriers against threats. Through zonal statistics, the variable HAB_QUAL was calculated as the mean habitat quality value modeled by InVEST in the 100*100 cells.

5. Land Surface Temperature

   The spatial distribution of LST is globally available through the United States Geological Survey (USGS)'s Earth Explorer interface[23]. Several remotely sensed datasets can be searched through the interface by setting the user's parameters, such as area of interest, cloud cover, data range; among the datasets, Landsat Collection 2 Level-2 products, which comprise 30-m LST raster maps, are included.

   The FUA of Cagliari corresponds to the area of interest, whereas for the time range a five-month interval, ranging from May to October 2023, hence fully including the summer season, was selected. Additionally, only images having cloud cover smaller than 10 percent were considered. Among the thirteen LST maps retrieved, the one with the highest average LST across the terrestrial study area was selected, having unique identifier LC08_L2SP_192033_20230730_20230805. Through zonal statistics, the variable L_S_TEMP was calculated as the mean LST in the 100*100 cells.

<u>The identification of the urban ecological corridors</u>

Various methodologies have been used in the literature to identify UECs. According to a study by Peng et al. (2017), the methodologies can be grouped into four classes: empirical judgment, suitability/sensitivity analysis, network analysis, and minimum cumulative resistance analysis/least-cost path analysis. The first group is included within qualitative methods and relies on expert judgments related to the natural and landscape context of the study area to identify the most suitable areas for the identification of UECs. The second group represents a quantitative method that evaluates the ecological and natural characteristics of the study area to understand which areas are most suitable for hosting UECs. For example, Ferretti and Pomarico (2013) propose an integrated approach that uses spatial analysis in a GIS environment and multicriteria analysis to create maps based on sensitivity analysis that may address planning choices and strategies. Network analysis is based on graph theory, which conceptualizes the landscape as a network structure consisting of points, lines and polygons. For example, Li et al. (2022) propose a methodological approach that integrates land-use simulation models and graph theory to assess the landscape connectivity of the ecological network in the Chaoyang District, in Beijing, in order to support planning choices and strategies in terms of biodiversity conservation in urban areas. The fourth group concerns the analysis of minimum cumulative resistance or least-cost path analysis (LCP), conceived as the resistance wildlife experiences to move along a given pathway. For instance, Li et al. (2021) develop a methodological approach for defining an ecological network within Shenzhen City, China, by integrating a morphological spatial pattern analysis and a minimum cumulative resistance model. Methodologies based on graph theory and LCP models are widely used in the literature to measure connectivity (Mahmoudzadeh et al., 2022). We propose an approach that combines graph

[22] Sardegna Mappe Aree Tutelate. [Sardinian Geoportal. Protected Areas]. Available online: https://www.sardegnageoportale.it/webgis2/sardegnamappe/?map=aree_tutelate (accessed on 25 June 2024).

[23] USGS Science for a Changing World. Earth Explorer. Available online: https://earthexplorer.usgs.gov/ (accessed on 25 June 2024).

theory with LCP model through the Linkage Mapper (LM) tool, an extension of ArcGIS software (McRae and Kavanagh, 2011).

The methodology is based on the research developed by Cannas et al. (2017a; 2017b, 2018a; 2018b) and Isola et al. (2022a; 2022b; 2022c) for the identification of ecological corridors (ECs). In these studies, ecological corridors are conceived as linear elements, which connect the natural protected areas of the Sardinia Region. Specifically, the methodological approach based on the LCP model consists of four steps, each of which results in the definition of a spatial map, as follows.

1. Step 1: land naturalness mosaic map.
2. Step 2: ecological integrity map.
3. Step 3: resistance map.
4. Step 4: map of Cost-Weighted Distance (CWD) and map of ecological corridors.

The methodology developed differs from Cannas et al.'s methodology (2017a; 2017b, 2018a; 2018b) in relation to Phase 1. Indeed, this study focuses on UECs, which must not only meet ecological needs, but also integrate recreational, cultural, aesthetic, and social functions (Pend et al, 2017). Therefore, the methodology considers the naturalness degree rather than the suitability according to which a habitat is likely to be used by species. The habitat suitability map, identified in several studies (Cannas et al., 2017a; 2017b, 2018a; 2018b; Isola et al., 2022a; 2022b; 2022c), exclusively takes into account the ecological functions performed by corridors. The identification of the degree of naturalness is based on the Landscape mosaic methodology (LMM) developed by the Joint Research Centre (JRC) and the European Commission's science and knowledge service (Maes et al., 2019; European Commission, 2023). LMM is based on a tripolar classification scheme, where a given patch is classified by taking into account the influence exerted by patches placed within a window surrounding that patch. All patches are classified in relation to three land covers, that is, agricultural, natural, and artificial. This methodology has been used in several studies (Wickham and Norton, 1994; Riitters et al., 2000; Riitters, 2009; 2011) and is implemented through the Guido Toolbox (Graphical User Interface for the Description of image Objects and their shapes - GTB)[24], a free and open-source software, developed by Vogt (2017), that offers a comprehensive range of general raster image processing functions. LMM classifies the land surface into 19 classes defined in relation to three threshold values, 10%, 60% and 100%, which indicate the presence, the dominance or the uniqueness of a land cover class, namely, agricultural, natural, and artificial. Figure 3 shows the tripolar classification scheme where each axis represents one of the three land covers, and the three vertices correspond to the uniqueness of a land cover type. Each class is identified by the initial letters of each land cover. The letter "A" or "a" identifies agricultural cover, the letter "N" or "n" natural cover, and the letter "D" or "d" artificial cover. The capital letters indicate that the corresponding land covers contribute a value equal to, or greater than, 60% but lower than 100%. The lowercase letters indicate that corresponding land covers contribute a value equal to, or greater than, 10% but lower than 60%. The non-presence of letters indicates that the corresponding land covers contribute less than 10%. In the map obtained by applying the LMM, each pixel shows three values indicating the contribution of the corresponding land covers (agricultural, natural, and artificial) (Vogt et al., 2017). The final map was developed by assigning each of the 19 classes a value ranging from 0 to 1, where 0 represents maximum artificialization, while 1 represents maximum naturalness.

[24] GuidosToolbox (GTB). Available online: https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/#Productsheets (accessed on 25 June 2024).

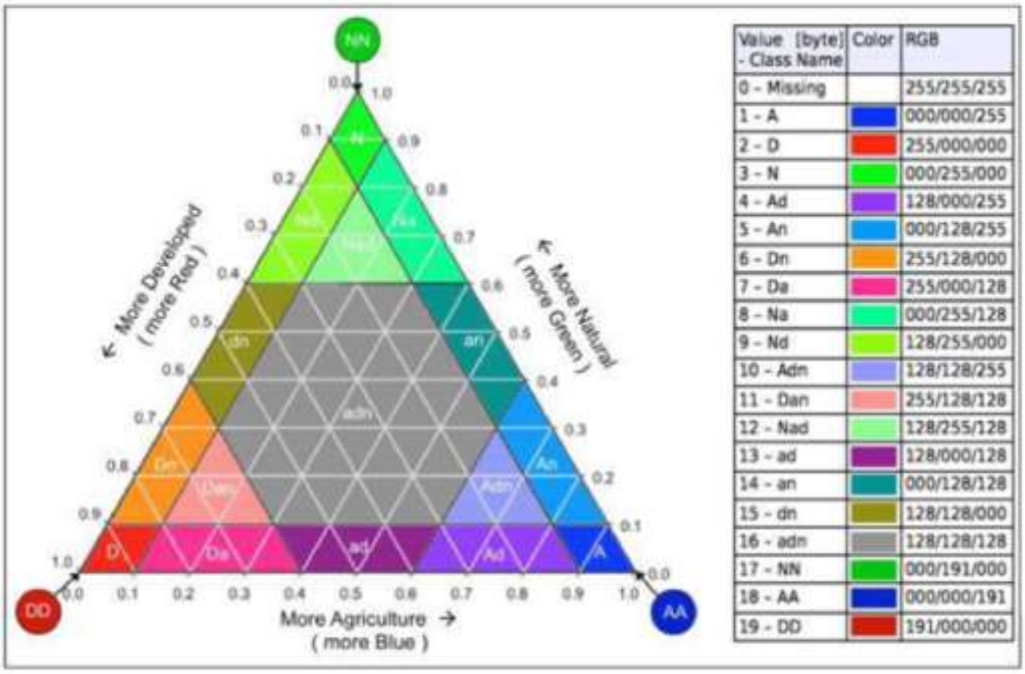

Figure 33. Figure 5.3. Tripolar classification scheme of LMM displaying 19 classes and their proportions of the three land covers. Source Vogt, 2024, p. 33.

The second phase focuses on elaborating a map of ecological integrity, building on Burkhard et al. (2009; 2012). This phase involves assessing the capacity of various land cover classes to provide ESs based on expert judgments. The foundational concept is that the higher the ecological integrity, the higher the suitability for 'species' transition and movement. Ecological integrity pertains to supporting ESs, which help sustain and enhance the supply of other ES types, namely provisioning, regulating, and cultural ESs. The ecological integrity index is calculated as the sum of the scores derived from seven ES-supply indicators (abiotic heterogeneity, biodiversity, biotic water flows, metabolic efficiency, exergy capture, nutrient loss reduction, and storage capacity). These indicators represent supporting ESs in relation to each of the 44 third-level land cover classes of the CLC nomenclature. Consequently, mapping the values of the ecological integrity index results in an ecological integrity vector map for the entire FUA of Cagliari.
The third phase of defining the resistance map involves some key steps that utilize land naturalness mosaic map and ecological-integrity map, drawing on methodologies from LaRue and Nielsen (2008). A detailed breakdown of the process is provided below.

1. Conversion of the two vector maps (land naturalness mosaic and ecological integrity) into raster maps.
2. Elaboration of two new raster maps by computing the inverse of the naturalness degree index and the ecological-integrity index.
3. Scaling the newly raster maps on an ordinal scale from 1 to 100, based on guidelines from the European Environment Agency (2014), where 1 represents the lowest resistance and 100 represents the highest resistance.
4. Summing the values of the two rescaled raster maps on a patch-by-patch basis. The resulting map represents the resistance map. The resistance map provides a spatial taxonomy that identifies varying levels of resistance across the landscape, which can be crucial for ecological planning and management.

The fourth phase involves spatially identifying UECs that connect natural protected areas included within the FUA boundaries using the Linkage Pathways Tool (LPT) from the GIS LM Toolbox. The terrestrial natural protected areas (NPAs) included in the study as core areas to be connected through UECs are regional natural parks, Natura 2000 sites and Ramsar sites. This phase employs the LCP approach by calculating the Cost-Weighted Distance (CWD). Figure 4 provides a visual explanation of the process. The results of this process are linear mapping of UECs and raster mapping of CWD values. Specifically, CWD along a path between two areas is obtained through a three-step process: i. average of the resistance values between pairs of adjacent cells; ii. product between the average of the resistance values and the geometric distance between pixels (Shirabe, 2018); and, sum of all products along the path. Once CWD is calculated, LPT identifies the LCP between two core areas, A and B, through the following formula:

$$ND_{AB}=CWD_{A}+CWD_{B}-LCWD_{AB}$$

where:

- ND_{iAB} represents the normalized distance between core areas A and B measured along a path that passes through patch *i*;
- CWD_{iA} e CWD_{iB} are the CWDs between patch *i* and core areas A and B, respectively;
- $LCWD_{AB}$ is the minimum CWD that is the CWD calculated along the LCP that connects A and B (McRae and Kavanagh, 2017).

UECs are identified as the pathways in which ND is equal to zero.
Table 2 shows the input and output data for each phase.

Table 2. Selected ecosystem services: input data used to feed the models, and their data sources.

Phase	**Input Data**	**Source**	**Output Data**	**Tool/Model**
Step 1: land naturalness mosaic map.	Land cover map	Copernicus Land monitoring service	Land naturalness mosaic map	Guido Toolbox (Vogt, 2024)
Step 2: ecological integrity map.	Land cover map	Copernicus Land monitoring service	Ecological integrity map	Burkhard et al.'s matrix (2009)
Step 3: resistance map.	Land naturalness mosaic map.	Step 1	Resistance map	Analysis in GIS environment
	Ecological integrity map.	Step 2		
Step 4: map of Cost-Weighted Distance (CWD) and ecological corridors.	Resistance map	Step 3	CWD map Spatial identification of UCS	Linkage Pathways Tool from the GIS Linkage Mapper Toolbox.
	Map of core areas	Regional geoportal[25]		
		European Environmental Agency dataset[26]		

[25] Parchi e le riserve nazionali o regionali, nonché i territori di protezione esterna dei parchi [National or regional parks and reserves, as well as the external protection territories of parks]. Available online: https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:585dc615-71d2-4318-ade6-6b3341781987 (accessed on 25 June 2024).
Zone umide incluse nell'elenco previsto dal D.P.R. 448/76 (dati indicativi) [Wetlands included in the list provided by Presidential Decree 448/76]. Available online at: https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:f52f111d-2a2e-4870-a623-6d6f11dc4f1d (accessed on 25 June 2024).

[26] Natura 2000 - Spatial data. Available online at: https://www.eea.europa.eu/data-and-maps/data/natura-14/natura-2000-spatial-data (accessed on 25 June 2024).

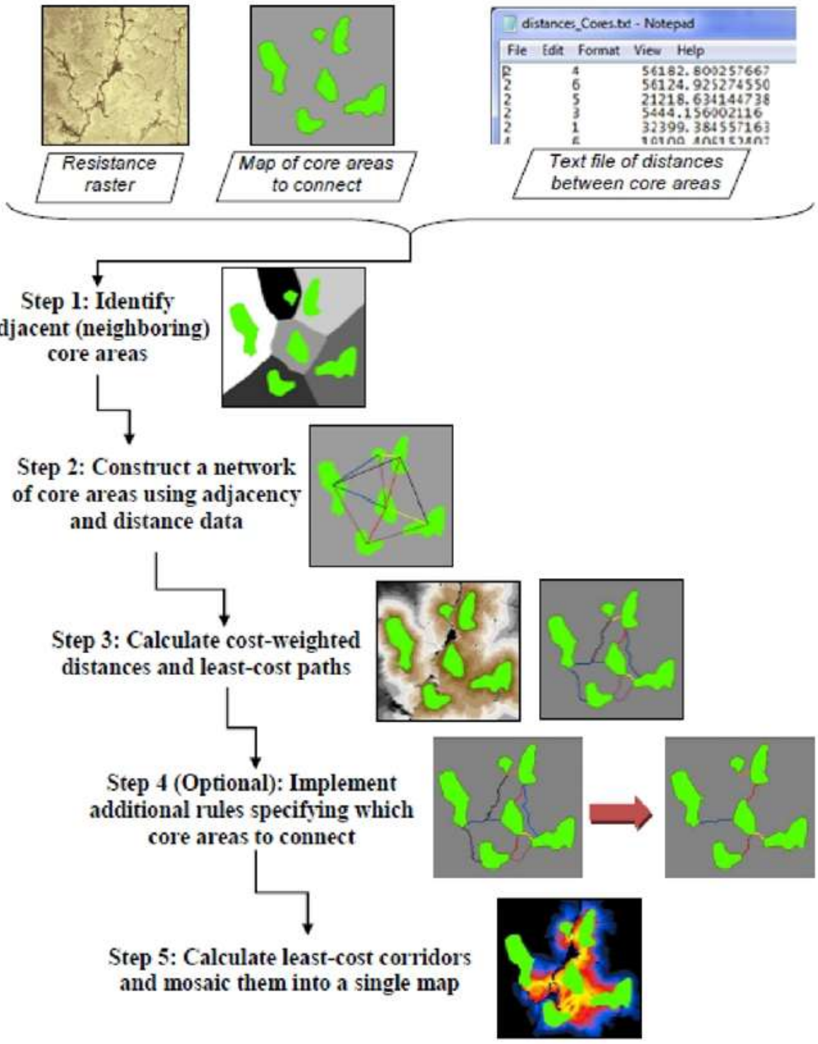

Figure 34. . LPT process. Source: McRae and Kavanagh, 2017, p. 11.

<u>The spatial relations between ecosystem service supply and ecological corridors</u>

The relationships between the supply of ESs and the identification of UECs are estimated by a multiple linear regression model, in which the UECs, linearly identified through the application of the LCP algorithm to the spatial taxonomy of CWD, are considered to consist of the patches having CWD values within the threshold of the twentieth percentile of the statistical distribution. This threshold makes it possible to uniquely select the contours of the linear elements of the UECs, which conjunct the patches in a way that minimizes CWD among the nodes of the UGI network.

The model operationalizes in the following form:

$$CO\_W\_DIS = \beta_0 + \beta_1 RECR\_OUT + \beta_2 FLD\_CNTR + \beta_3 CA\_CP\_ST + \beta_4 HAB\_QUAL + \beta_5 L\_S\_TEMP + \beta_6 ALT\_ELEV, \quad (1)$$

in which the dependent and explanatory variables relate the spatial structure of the ECs to the supply of the different types of ESs, characterizing the UGI. All variable observations refer to the areal units consisting of the patches included in the UECs.

The dependent variable and covariates are defined as follows:

- CO_W_DIS identifies CWD;
- RECR_OUT identifies the percentage share of the area available for outdoor recreational activities times the resident population in a buffer of 500 meters;
- FLD_CNTR identifies the volume of water runoff which is prevented to flow away;
- CA_CP_ST identifies the amount of organic carbon that can be sequestered and stored;
- HAB_QUAL identifies habitat quality;
- L_S_TEMP identifies LST as the urban heat measure and reference for its mitigation;
- ALT_ELEV identifies a control variable related to average elevation.

The values of the regression coefficients identify, in quantitative terms, the relationships between the CWDs of the areal units included in the UECs and the supply of the different types of ESs.
In this case, concerning the spatial taxonomy of the CWD of the patches that are part of the UECs, as in many studies investigating phenomena involving interactions between spatial variables, the multiple linear regression model is used since no a priori hypotheses are identified about the correlations between the variables themselves (Zoppi at al., 2015; Sklenicka et al., 2013; Stewart and Libby, 1998; Cheshire and Sheppard, 1995).
The multiple linear regression is, in fact, in an n-dimensional space, the hyperplane tangent to a surface, of unknown equation, which represents the phenomenon under study, in the case we analyze here the CWD spatial taxonomy of patches that are part of the UECs and its seven covariates, and represents, therefore, in the infinitesimal surrounding of the tangency point, the linear approximation of the unknown equation of the surface. The linear equation (1) constitutes, therefore, the trace of a hyperplane on a surface of unknown equation in an eight-dimensional space (Wolman and Couper, 2003; Byron and Bera, 1983).
The variable ALT_ELEV is a control covariate that identifies the impact of elevation on CWD. The estimation of the β_6 coefficient, if it were significant, would imply that the elevation would be associated with a positive or negative impact, depending on the sign, and of greater or lesser magnitude, depending on its quantitative size.
Finally, in relation to the estimated values of the model's β's coefficients (1), we implement a set of p-value tests to assess their significance.

Results

This section presents the results of the implementation of the methodological approach related to the FUA of Cagliari. In the first part, these refer to the UGI taxonomy based on the spatial organization of ESs concerning outdoor recreation, flood control and mitigation, CCS, habitat quality and urban heat mitigation. The second part proposes the outcomes concerning the identification of UECs, based on the taxonomy of CWD and the LCP algorithm. Finally, the coefficient estimates of multiple linear regression offer the picture of the contribution of different ESs to defining the spatial organization of UECs.

<u>The spatial taxonomy of the UGI</u>

As for nature-based recreation opportunities (Figure 5, panel "A"), almost two third of the cells in the grid show null RECR_OUT values; these include both cells without any green areas suitable for nature-based recreation, for instance cells located in the agricultural plain or in the densest parts of the FUA built-up areas, and cells with vegetated land covers in whose proximity no resident population is recorded in the national census, such as the woods to the Eastern and the Western border of the FUA. Cells showing the highest values coincide either with urban green areas in the inner parts of the settlements (an example is provided in Figure 6, panels "A1" to "A3"), or with green peri-urban areas in their outskirts (an example is provided in Figure 6, panels "B1" to "B3"), whereas notable clusters of low-to-intermediate values characterize the eastern part of the FUA, where low-density developments have taken place in otherwise natural areas (an example is also visible in Figure 6, panels "B1" to "B3").
Second, the variable FLD_CNTR, associated with water runoff retention, takes null or extremely low values in built-up areas, while high values (dark blue in Figure 5, panel "B") tend to correspond to agricultural and natural land covers associated with highly permeable soils located in low elevation areas. However, high values are also featured in two small promontories along the coastline, which split the bay into two parts, and whose rocks are characterized by karstification and fracturing.
Third, extremely low values of CA_CP_ST (yellow in Figure 7, panel "A"), the indicator representing carbon sequestration and storage, aggregate in the south-central part of the FUA, corresponding to the urban fabric of Cagliari and to the wetlands; moreover, two yellowish linear clusters departing from Cagliari to the north, coinciding with the main road arteries, are also clearly visible. The highest values can be found in the woods to the East and to the West, the former managed by the Regional Forestry Agency and the latter included in a Regional Natural Park. Agricultural plains and hilly areas with low or sparse vegetation tend to show intermediate values.

Fourth, null values of the variable HAB_QUAL (yellow in Figure 7, panel "B"), taken as a proxy for the quality of biodiversity and its capacity to maintain or regulate either refuge habitats or nursery populations and habitats, characterize 6.8 percent of the cells, largely coinciding with artificial land covers. The highest values (green in Figure 7, panel "B") can mostly be found in wooded areas distant from degradation sources and in the inner areas of the wetlands, whereas agricultural areas always show intermediate values.

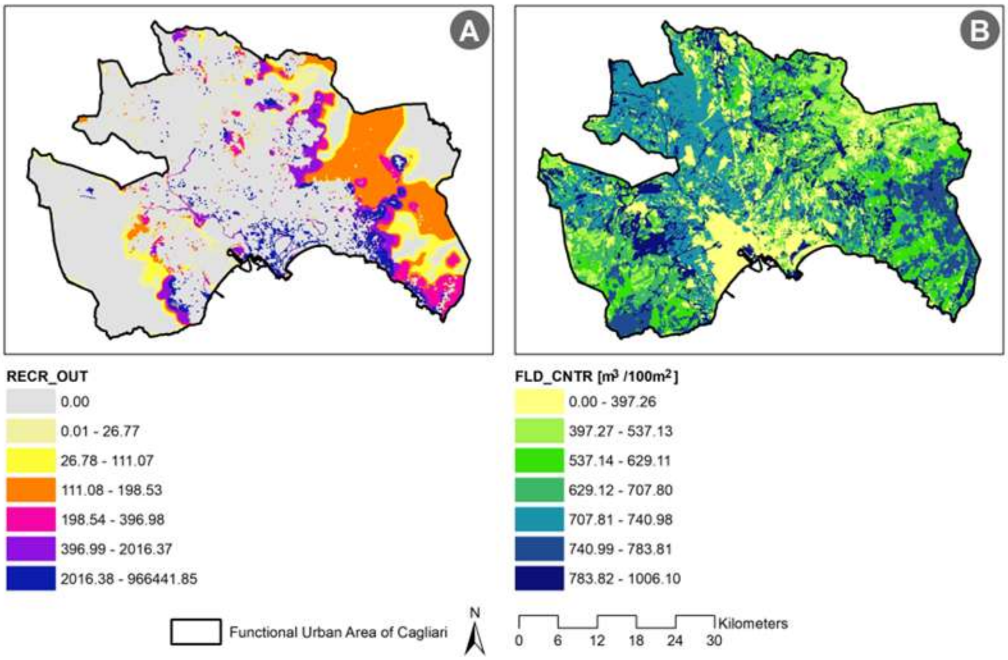

Figure 35. Spatial layout of the first and second selected ESs in the study area: RECR_OUT (panel A) and FLD_CNTR (panel B).

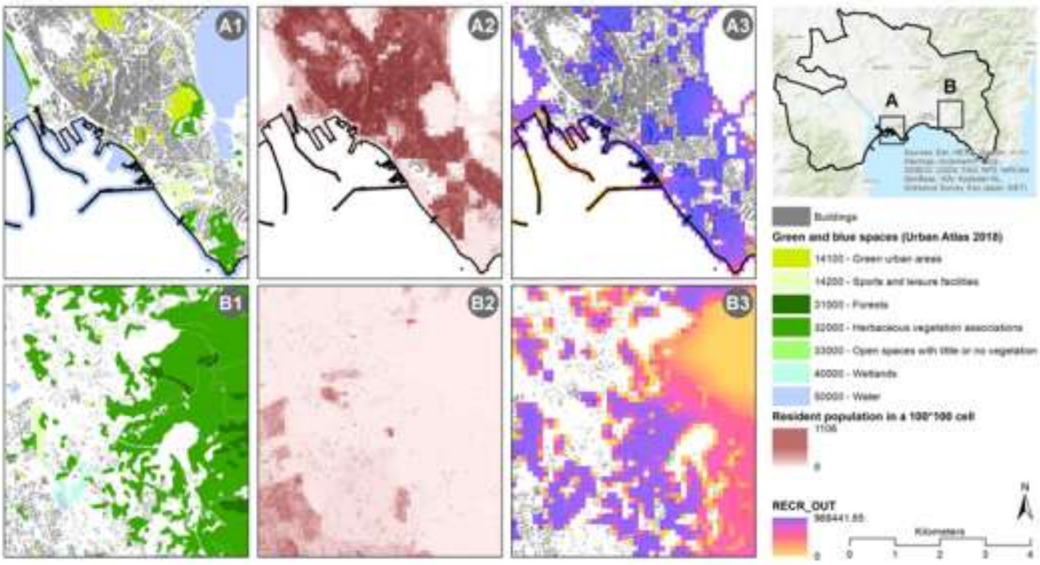

Figure 36. Two snapshots concerning recreational nature-based opportunities in a dense urban area (panel A) and in a peri-urban area (panel B): availability of green and blue spaces (A1 and B1), distribution of the resident population (A2 and B2), RECR_OUT (A3 and B3).

With reference to the fifth selected ES, i.e., biodiversity capacity to regulate and mitigate temperature, assessed through the variable L_S_TEMP during the summer 2023, the map in Figure 8, panel "A" clearly shows that the highest temperatures cluster not only in built-up areas, but also along the Campidano agricultural plain, while the lowest

temperatures, corresponding to higher values of the ES, characterize wetlands, reservoirs, and the peaks of the hills and of the mountains to the East and to the West of the FUA.
Finally, Figure 8, panel "B" depicts the spatial distribution of the only control variable used in the inferential model, i.e., elevation. The most prominent landscape feature in this map is the Campidano agricultural plain (green), which stretches diagonally from North-East to South-West separating the two mountain chains to the eastern and western edges of the FUA, and which transitions into the coastal area with two wetlands surrounding the core built-up area of the municipality of Cagliari.

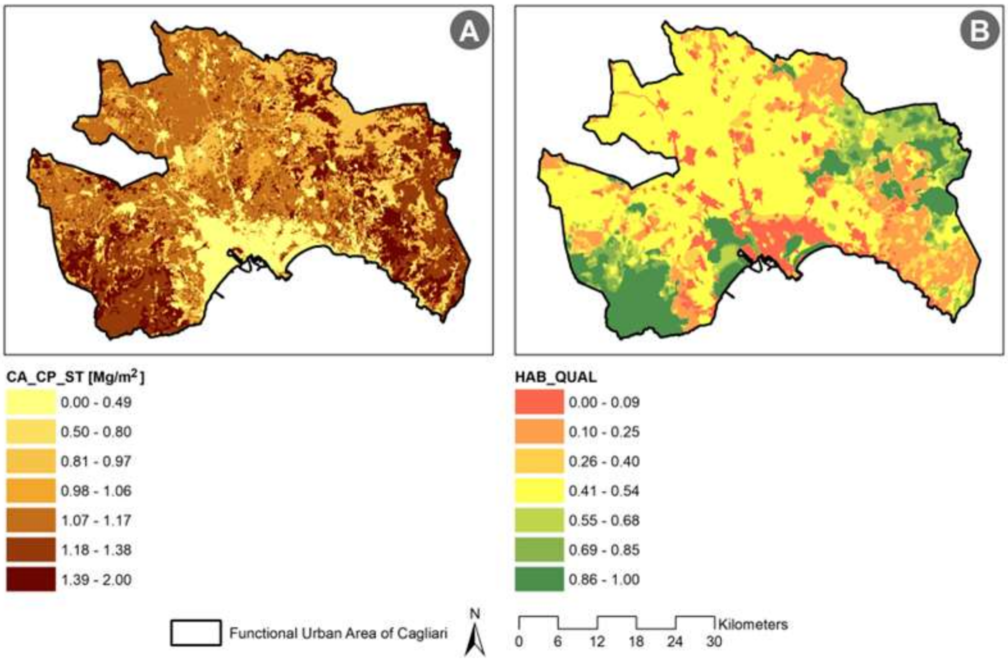

Figure 37. The spatial layout of the third and fourth selected ESs in the study area: CA_CP_ST (panel A) and HAB_QUAL (panel B).

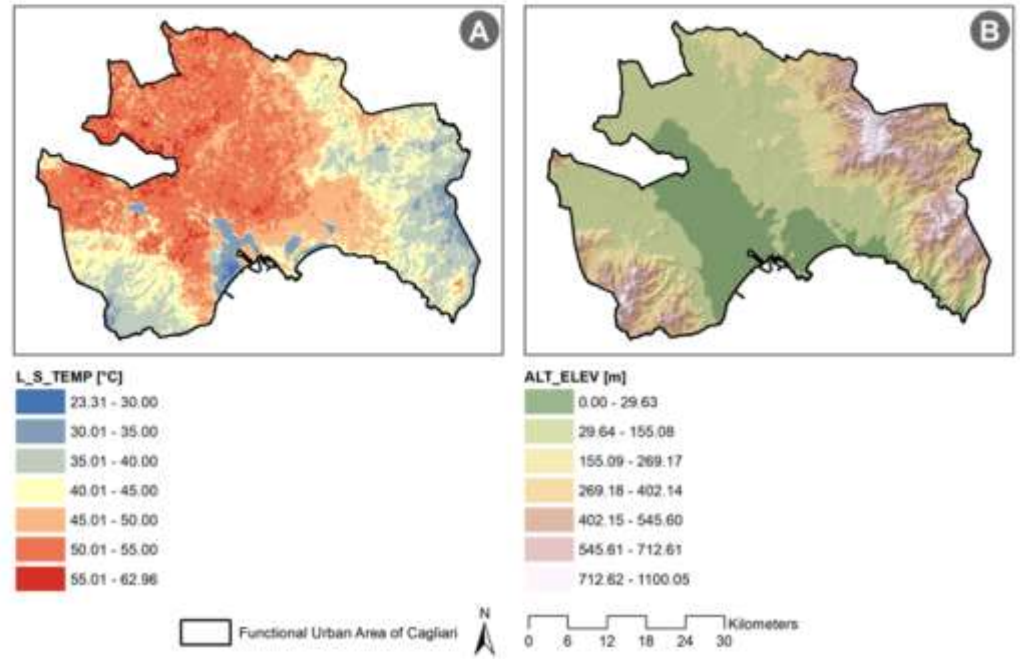

Figure 38. The spatial layout of the fifth selected ES (L_S_TEMP, panel A) and of the elevation (ALT_ELEV, panel B) in the study area.

<u>The identification of the urban ecological corridors</u>

The methodological approach based on the LCP model consists of four steps. Each step provides an output. Figure 9 shows the land naturalness mosaic map (Panel A) and the ecological integrity values map (Panel B), the output of step 1 and step 2, respectively. Figure 10 shows the map of resistance values (Panel A), the output of step 3, and the map of core areas, which shows the spatial identification of natural protected areas (Panel B).

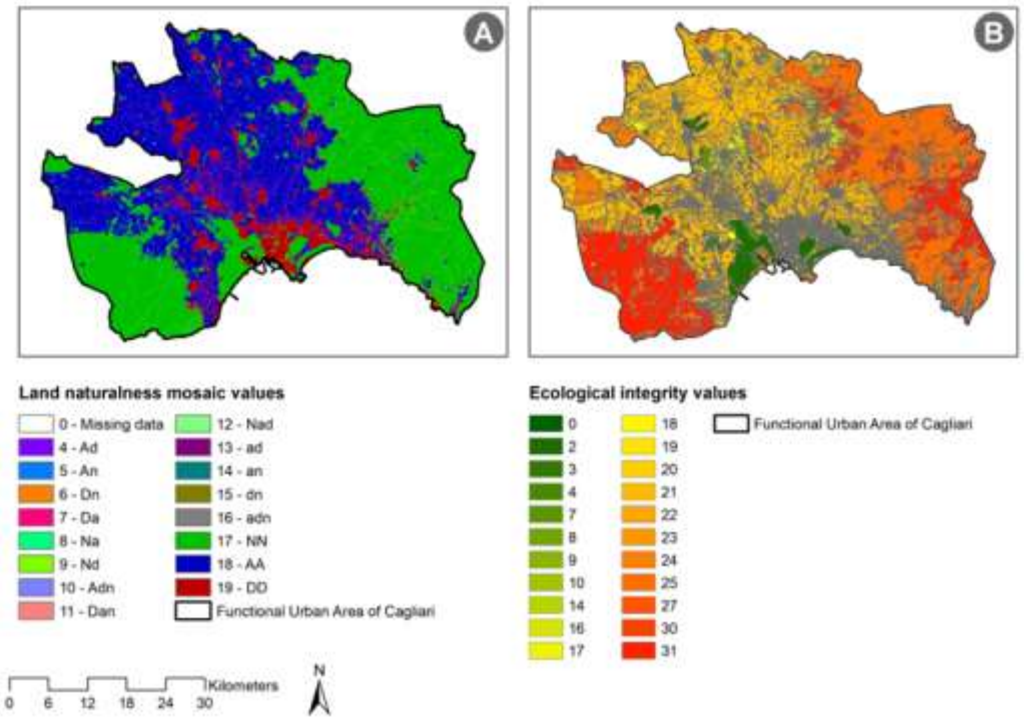

Figure 39. Land naturalness mosaic map (Panel A) and map of ecological integrity values (Panel B).

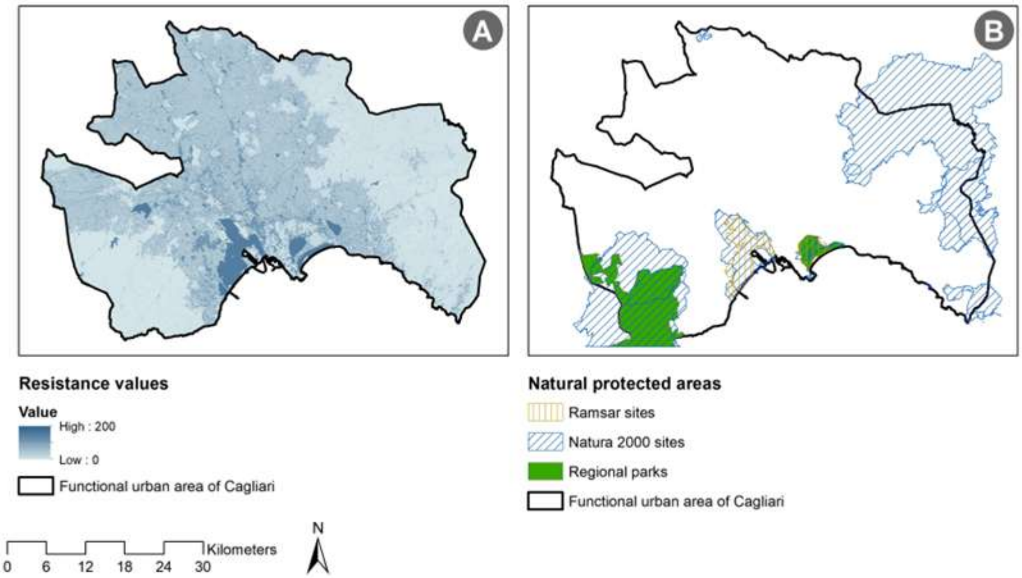

Figure 40. Map of resistance values (Panel A) and spatial identification of natural protected areas (Panel B).

Two are the results of the application of the methodological approach: a raster map of the CWD values, and the linear identification of the UECs that connect natural protected areas within the FUA of Cagliari. Figure 11 shows the CWD values (panel A) and the spatial identification of UECs (panel B). Specifically, LM identifies 11 UECs, and the CWD values range from 0 to 108.760 km.

Moreover, LM provides two indicators, which are: CWD/ED and CWD/LCP (Feng at al., 2021; Dutta et al., 2016). The first indicator, calculated as the ratio of CWD to Euclidean distance, provides an indication about the quality of the connection between two adjacent core areas. Low values of this indicator show high connection quality. The second indicator, calculated as the ratio of CWD to EC length, provides indications of the average resistance of species movement along a given pathway. In this case, low values of the CWD/LCP indicator correspond to low resistance to species movement. Corridors nos. 8 and 4, which connect core areas nos. 3 and 8, and 2 and 3, respectively, show the lowest values of the CWD/ED indicator and, therefore, the highest quality of connection. Corridors nos. 9 and 10, which connect core areas nos. 4 and 5, and 5 and 6, respectively, show the highest values and, consequently, the lowest quality of connection. With reference to the CWD/LCP indicator, corridors nos. 8 and 4 show the lowest values and, therefore, the least resistance to movement; while corridors nos. 9 and 10 show the highest values and, consequently, the greatest resistance to movement. Figure 12 shows the core areas with the UECs connecting them. Table 3 shows the values for the two indicators for all identified corridors.

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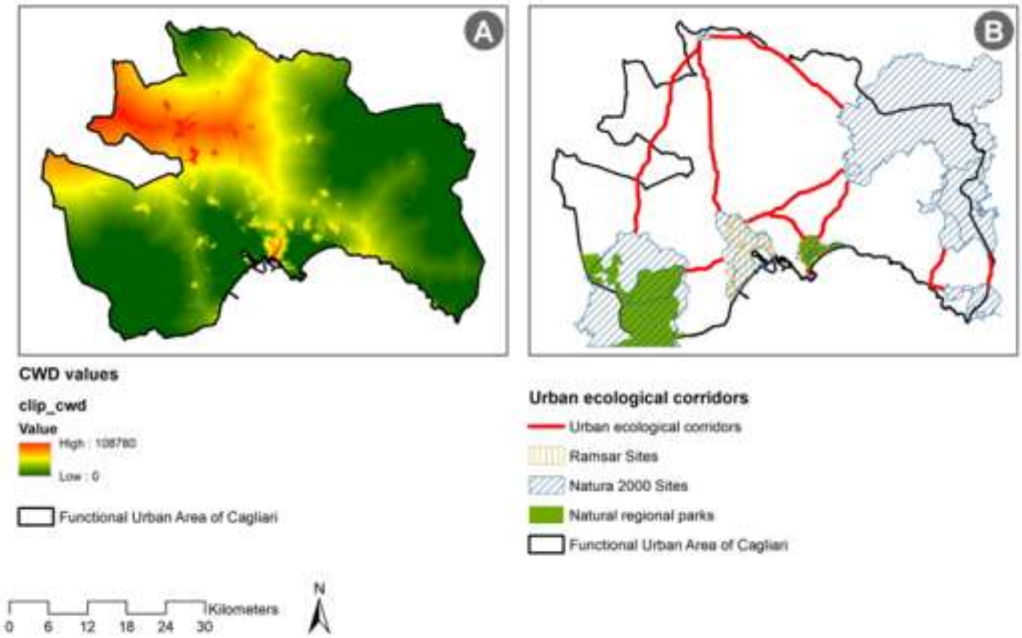

Figure 41. Map of CWD values (Panel A) and spatial identification of UECs within the FUA of Cagliari (Panel B).

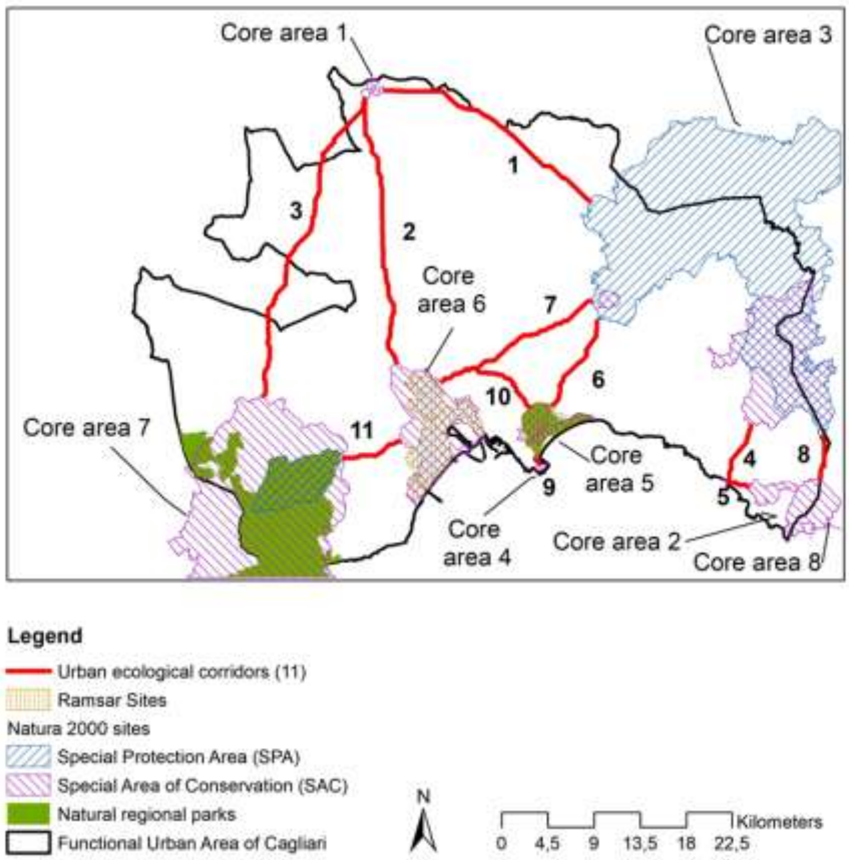

Figure 42. Spatial identification of UECs and core areas, classified in relation to their typology.

Table 5.3. Urban ecological corridors, name and typology of natural protected areas, and values of indexes CWD/ED and CWD/LCP

UEC code	Core area code	Name of connected NPA	Typology of NPA	CWD/ ED	CWD/ LCP
1	1	Monte Mannu – Monte Ladu (colline di Monte Mannu e Monte Ladu)	SAC	4.15	3.83
	3	Monte Sette Fratelli	SPA		
		Monte dei Sette Fratelli e Sarrabus	SAC		
		Riu S. Barzolu	SAC		
2	1	Monte Mannu – Monte Ladu (colline di Monte Mannu e Monte Ladu)	SAC	5.40	5.06
	6	Stagno di Cagliari	Ramsar Site		
		Stagno di Cagliari	SPA		
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC		
3	1	Monte Mannu – Monte Ladu (colline di Monte Mannu e Monte Ladu)	SAC	4.93	4.45
	7	Foresta di Monte Arcosu	SAC		
		Foresta di Monte Arcosu	SPA		
		Parco naturale regionale di Gutturu Mannu	Natural regional park		
4	2	Bruncu de Su Monte Moru – Geremeas (Mari Pintau)	SAC	3.87	3.56
	3	Monte Sette Fratelli	SPA		
		Monte dei Sette Fratelli e Sarrabus	SAC		
		Riu S. Barzolu	SAC		
5	2	Bruncu de Su Monte Moru – Geremeas (Mari Pintau)	SAC	4.43	3.87
	8	Costa di cagliari	SAC		
		Isola dei Cavoli, Serpentara, Punta Molentis e Campolongu	SAC		
6	3	Monte Sette Fratelli	SPA	5.49	4.83
		Monte dei Sette Fratelli e Sarrabus	SAC		
		Riu S. Barzolu	SAC		
	5	Saline di Molentargius	SAC		
		Stagno di Molentargius e territori limitrofi	SAC		
		Stagno di Molentargius	Ramsar site		
		Parco naturale regionale di Molentargius-Saline di Cagliari	Natural regional park		
7	3	Monte Sette Fratelli	SPA	5.63	4.52
		Monte dei Sette Fratelli e Sarrabus	SAC		
		Riu S. Barzolu	SAC		
	6	Stagno di Cagliari	Ramsar Site		
		Stagno di Cagliari	SPA		
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC		
8	3	Monte Sette Fratelli	SPA	3.51	3.26
		Monte dei Sette Fratelli e Sarrabus	SAC		
		Riu S. Barzolu	SAC		
	8	Costa di Cagliari	SAC		
		Isola dei Cavoli, Serpentara, Punta Molentis e Campolongu	SAC		
9	4	Torre del Poetto	SAC	13.85	10.02

		Monte Sant'Elia, Cala Mosca e Cala Fighera	SAC		
	5	Saline di Molentargius	SPA		
		Stagno di Molentargius e territori limitrofi	SAC		
		Stagno di Molentargius	Ramsar site		
		Parco naturale regionale di Molentargius-Saline di Cagliari	Natural regional park		
10	5	Saline di Molentargius	SPA	20.79	5.51
		Stagno di Molentargius e territori limitrofi	SAC		
		Stagno di Molentargius	Ramsar site		
		Parco naturale regionale di Molentargius-Saline di Cagliari	Natural regional park		
	6	Stagno di Cagliari	Ramsar Site		
		Stagno di Cagliari	SPA		
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC		
11	6	Stagno di Cagliari	Ramsar Site	5.18	4.23
		Stagno di Cagliari	SPA		
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC		
	7	Foresta di Monte Arcosu	SAC		
		Foresta di Monte Arcosu	SPA		
		Parco naturale regionale di Gutturu Mannu	Natural regional park		

The spatial relations between ecosystem service supply and ecological corridors

The results of the multiple linear regression (1) estimation are described, in the section, as regards Table 4, which reports the marginal effects, in value and sign, of the variables expressing the supply of the different ESs on CWD, and the related p-values, key references for assessing the reliability of the estimates.

Table 5.4 Regression estimates.

Explanatory variable	**Coefficient**	**t-statistic**	**p-value**	**Mean of the explanatory variable**	**Elasticity at the mean values of CWD and expl. var's, related to a 10% increase in expl. var's [(Δy/y)/(Δx/x), %]**
RECR_OUT	-0.019	-11.183	0.000	2059.537	-0.199%
FLD_CNTR	1.574	7.189	0.000	614.434	4.797%
CA_CP_ST	-2569.171	-19.302	0.000	1.044	-13.308%
HAB_QUAL	-4254.389	-28.333	0.000	0.466	-9.835%
L_S_TEMP	1728.278	237.612	0.000	46.143	395.542%
ALT_ELEV	-17.013	-78.048	0.000	205.219	-17.317%

Dependent variable: CWD: Mean: 20,161.61 km; Standard deviation: 21,180.06 km; Adjusted R-squared: 0.436.

For the reading and description of the results, recall how the suitability of a patch to be part of a UEC located in the FUA of Cagliari increases as CWD decreases and how, therefore, the negative sign of the estimated coefficient in the regression implies a positive impact on this suitability by the variable to which the ES refers, and vice versa.

The outcomes of the multiple linear regression (1) all show significant p-values. Thus, the estimated coefficients are to be considered as reliable references of the relationships between CWD and the supply of ESs that the associated variables represent. An effective representation of the behavior of the CWD with respect to the supply of the different ESs is given by the elasticities of the CWD with respect to the supply of the different ESs. These elasticities are given in the last column of Table 4, and are calculated, at the mean values of the CWD and of the supply of the different ESs, for a 10 percent increase in the supply, that is, of each explanatory variable.

While, therefore, all of the estimated coefficients are significant in terms of p-values, nevertheless the impact of an increase in the supply of the ESs associated with them on CWD is definitely quite diverse. It can be seen, therefore, that a 10 percent increase in the average L_S_TEMP would generate a fourfold increase in CWD, meaning that ESs that decrease L_S_TEMP are particularly effective in making a patch eligible to be recognized as part of a UEC. Equally effective in this direction are the carbon capture and storage service (variable CA_CP_ST) and habitat quality (variable HAB_QUAL), of which a 10 percent increase in supply is associated with a decrease of about 13 percent and 10 percent in CWD respectively, which shows that they go, essentially, in the same direction, also in terms of proportion, the strengthening of UECs in the FUA of Cagliari and the availability of ESs for carbon capture and storage and habitat quality.

Regarding the relationship between CWD and ES related to the supply of recreational services, we show that the negative impact of RECR_OUT on CWD is positive in relation to the eligibility of a patch to be included in the UGI, with an elasticity of about 2‰. Since variable RECR_OUT comes from the percentage share of the area available for outdoor recreational activities times the resident population in a buffer of 500 meters, it has to be noticed that an average 10 percent increase in recreational area at the average value of resident population (2057 residents) in a 500-meter buffer of census tracts (2057 residents) is associated to a decrease of 11,151 meters in CWD, which identifies a 52.69 percent decrease of CWD at its mean value. The provision of recreational services, within the FUA of Cagliari, is thus configured as significantly relevant.

With regard to flood control, i.e., the ES associated with water retention capacity, the estimated coefficient reports an increasing trend in CWD in relation to supply (variable FLD_CNTR), with an elasticity of just under 5 percent. It shows, therefore, how the suitability of a patch to be included in a UEC of the FUA of Cagliari is associated with low values of water retention, or, in other words, how in urban areas the greater presence of permeable surfaces is associated with a loss of connectivity of patches.

Finally, the coefficient of altitude, taken as a control variable, indicates how land elevation is negatively correlated with CWD and, therefore, how increasing altitude is associated with an increase in the suitability of patches to be part of UECs, everything else being equal. This result is related to the fact that, at altitude, connectivity between patches in the FUA of Cagliari is facilitated by the lower presence of road infrastructure, which makes the coefficient estimate of ALT_ELEV consistent with expectations. In addition, at higher altitudes connectivity is likely to be enhanced by the more structured presence of scrub or woodland vegetation.

5.2.2 Urban Heat Island: a multi-scale testing case in Bolzano

Introduction

Urban Heat Island (UHI) effects are a major concern in cities facing increasing frequency and intensity of heatwaves due to climate change. Within the RETURN project, a multi-scale testing case was developed in the city of Bolzano to analyze UHI dynamics and assess the effectiveness of climate adaptation strategies.

Since 1979, Bolzano has experienced a significant increase in mean yearly temperatures, rising from 6.4°C to 10.9°C, peaking in 2023. A 2018 report by Eurac Research indicates that both summer and winter temperatures have significantly increased over the past few decades (Zebisch et al., 2018) Bolzano's climatic characteristics make the city susceptible to extreme heat stress, with a concerning trend in the increase of tropical nights where temperatures remain above 20°C. The number of tropical nights peaked at 29 in 2015 and is projected to double to 60 nights by 2100.

The testing case of Bolzano integrates satellite data, in-situ mobile monitoring, numerical climate and microclimate models, and building-level energy simulations. The goal is to support design proposals that enhance urban resilience and comply with New European Bauhaus (NEB) principles, particularly those promoting sustainable, inclusive, and aesthetically enriching transformations.

The strength of this testing case lies in its **multi-scale integration**, where each data source and model informs and supports the others. Satellite-derived temperature maps provide large-scale screening and support climate simulations at city level. Local mobile observations validate and refine these datasets, while microclimate simulations serve to downscale urban effects and inform building-level strategies.

Multi-Scale Approach Overview

To capture the complexity of UHI phenomena in Bolzano, a combination of observational and modelling tools was deployed at multiple spatial and temporal scales:

- **Metropolitan/territorial/urban scale**: assessment of land surface temperatures using remote sensing and urban climate projections.
- **Neighborhood scale**: detailed microclimate simulations evaluating mitigation potential of Nature-Based Solutions.

- **Building scale**: evaluation of indoor comfort and energy performance during heatwaves through coupled simulations.

Mesoscale Analysis of August 2023 Heatwave using WRF

To understand the interaction between urban form, local wind regimes, and thermal stratification, the WRF model was employed during the August 2023 heatwave. Vertical cross-sections of along-valley wind and isopotential temperature contours were analysed for both daytime and nighttime periods. These mesoscale simulations help to interpret the background climate context in which urban heat accumulates, and offer important boundary conditions for urban-scale models.

By coupling mesoscale outputs with local meteorological and mobile data, WRF simulations can be refined to reflect real conditions. This is particularly valuable in complex alpine settings such as Bolzano, where valley topography amplifies UHI effects through stagnant air layers and weak nighttime ventilation.

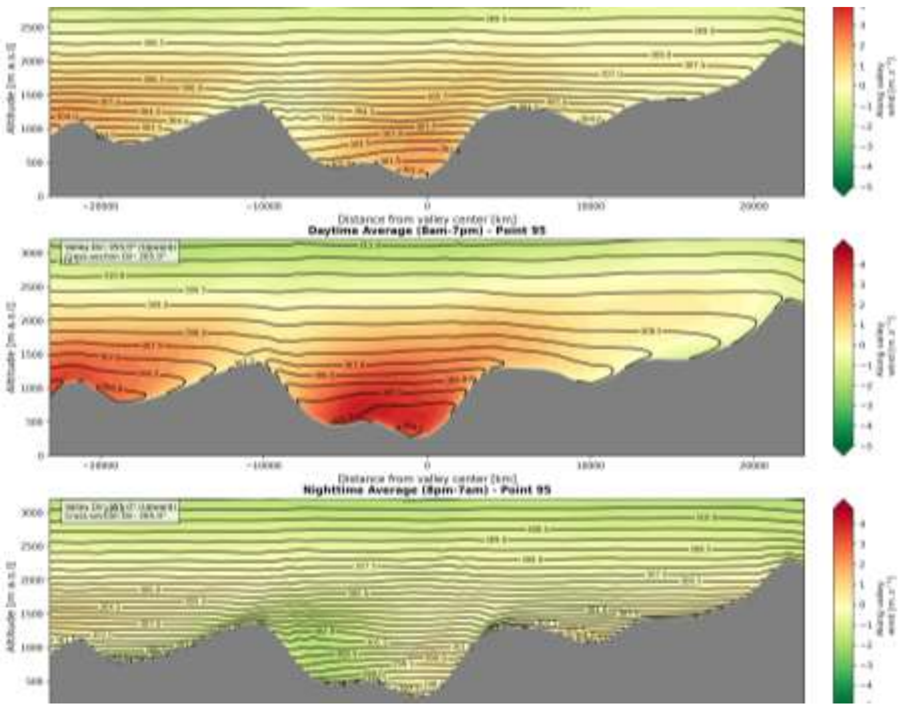

Figure 43. WRF model: Vertical cross sections at the south of Bolzano of the along valley wind (color bar) and the iso potential temperatures (contour lines) during the entire heatwave of August 2023 (top) and for daytime (middle) and nighttime (bottom) only.

Future Heatwave Projection with UrbClim

The UrbClim urban climate model was used to simulate future climate scenarios under the high-emission SSP5-8.5 pathway. Results show a projected increase in the number of heatwave days per year, providing valuable input for long-term planning. The model offers high spatial resolution (typically 100 m) and fast computational performance, making it suitable for long term and very local climate and future projection simulations.

Following a multi-scale and multi-method approach, satellite data could serve as model input or calibration background, while mobile data can validate spatial trends at finer resolution. The output of UrbClim also supports the identification of critical areas for neighbourhood-scale microclimate modelling.

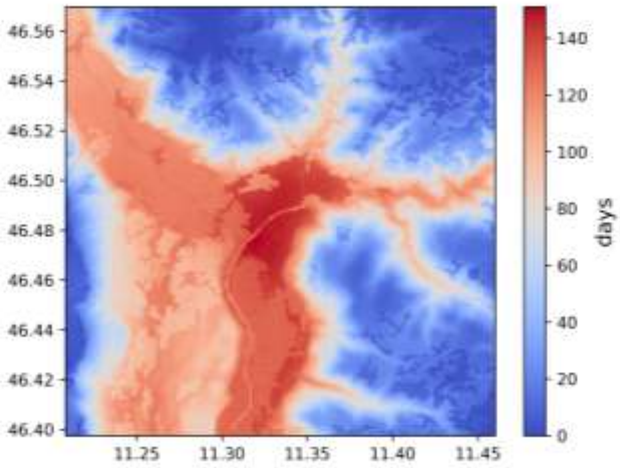

Figure 44. UrbClim Model: Expected number of days per year of heat wave in the future (SSP5 8.5 projection).

Satellite-Based Urban Heat Island Assessment

Land Surface Temperature (LST) data derived from satellite imagery was used to assess spatial UHI patterns across Bolzano. By integrating data from multiple satellite missions - MODIS, which offers high temporal resolution (daily), and Landsat 8–9, which provides high spatial resolution (100 m, resampled to 30 m) - it was possible to generate detailed and continuous temperature maps. This approach enables consistent monitoring over time and across space, offering a reliable means to capture urban thermal dynamics during critical periods such as heatwaves.

Satellite-derived LST data allowed for the identification of thermal hotspots and vulnerable urban zones, supporting the prioritization of intervention areas in urban planning and adaptation strategies. Remote sensing provides a consistent long-term view of temperature variation across diverse urban settings and is particularly useful for initializing and validating urban-scale climate models.

However, it is important to acknowledge certain limitations. LST represents the radiative temperature of the surface and is distinct from the near-surface air temperature typically associated with public heat warnings. Therefore, this phenomenon is accurately termed the Surface Urban Heat Island effect. LST cannot be directly used for thermal comfort analysis or building energy modelling without additional correction or modelling steps. Furthermore, satellite observations are subject to cloud cover limitations, and overpass times (e.g., ~11:00 - 12:00 local time for Landsat) may not capture daily extremes or nighttime conditions relevant for heat stress studies.

Despite these limitations, satellite remote sensing remains a powerful tool for urban climate assessment, providing spatially explicit, repeatable, and scalable data that would be difficult or impossible to collect through in-situ observations alone helping to detect priority zones for model calibration and scenario testing.

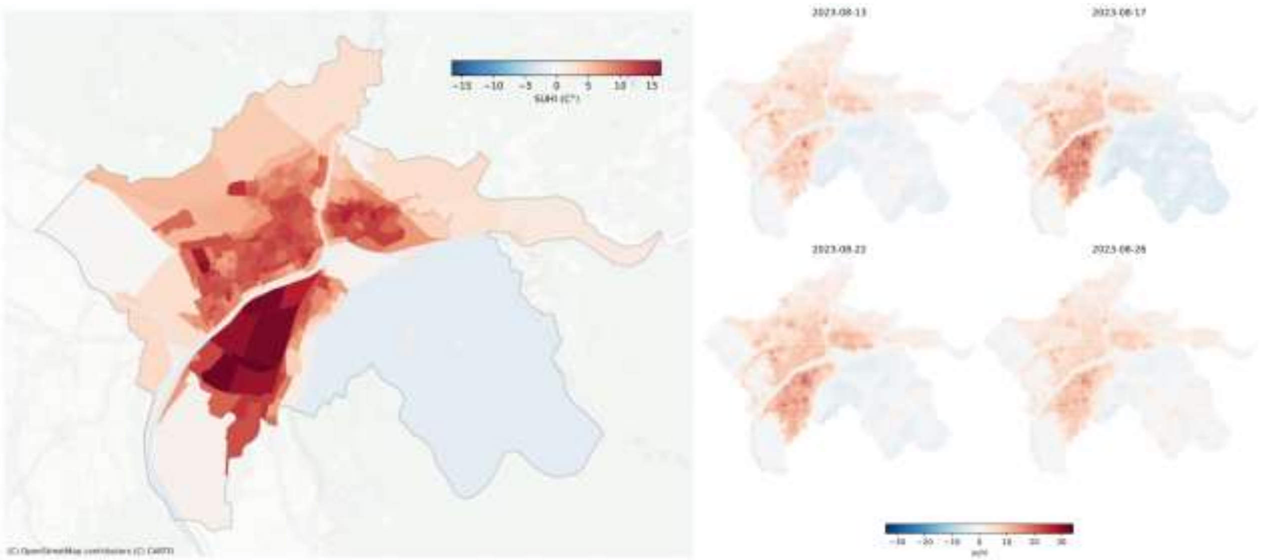

Figure 45. Surface Urban Heat Island (SHUI) intensity from satellite-derived LST for Bolzano metropolitan area. On the left, average SUHI effect during the heatwave of August 2023. On the right, temporal evolution of the SHUI through the heatwave period (13-26 August 2023). Hot spots and vulnerable zones are clearly visible, especially in low-vegetation/high-density areas.

Neighbourhood-Scale Simulations for Nature-Based Solutions (NbS)

ENVI-met microclimate simulations were conducted in the *Casette Inglesi* neighborhood, a mixed-use urban area. A workflow has been developed to assess the contribution of NbS to heat mitigation at neighborhood scale.

As pilot site of the RETURN project, *Casette Inglesi* was expected to provide insights for heat wave mitigation and enhancing the quality of both indoor and outdoor spaces. *Casette Inglesi* is a social housing complex built in 1985-1987 and located in the *Don Bosco* district. It presents itself as an introverted village composed of houses of a maximum of four levels, defined as clustered courtyard houses by the designers, organized in small internal courtyards that serve as entrances to the apartments. The term "Casette Inglesi," meaning "English houses," either references the nationality of the architects or evokes a design aesthetic inspired by British architecture.

For this area several greening scenarios were modelled, including increased tree coverage and NbS implementation (e.g. indirect green walls). These simulations offer high-resolution insights into pedestrian-level thermal comfort and serve as tools to test nature-based design alternatives.

To evaluate the effectiveness of NbS for heat mitigation at the neighbourhood scale, the approach began by assessing ground-based and building-integrated NbS separately. Based on these results, selected measures were combined into integrated design scenarios. Microclimate simulations were then used to quantify the impact of each scenario, showing a reduction of the Universal Thermal Climate Index (UTCI) by at least one thermal stress level in selected and adjacent open spaces. This structured, simulation-based workflow enables the context-specific design of NbS interventions and supports the implementation of climate-adaptive strategies that enhance outdoor thermal comfort.

The input conditions (air temperature, humidity, radiation) for these simulations could be defined based on UrbClim or WRF outputs, ensuring consistency with broader climatic scenarios. The outcomes of ENVI-met simulations also serve as climate input layers for building energy models at the final scale.

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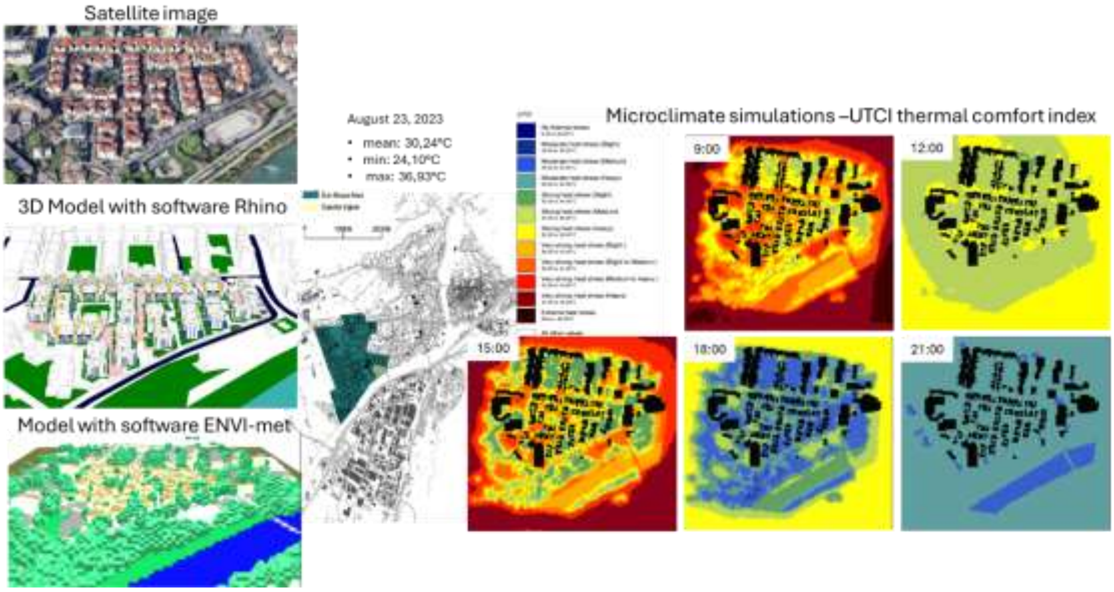

Figure 46. Simulated surface temperatures under different greening scenarios. Maximum temperature reductions of up to 4.5°C were observed under high vegetation density scenarios.

Coupled Urban Microclimate and Building Energy Models

Understanding the dynamic interaction between urban microclimates and indoor thermal environments is critical for accurately assessing building energy performance and designing climate-resilient urban environments. Urban areas are increasingly affected by heatwaves and conventional building energy simulation (BES) tools, when relying on standard weather files, fail to reflect the altered climatic conditions at the building envelope level. Consequently, to assess how external heat stress affects indoor thermal conditions and building energy performance, urban climate outputs (from WRF or UrbClim) and local ENVI-met simulations can be coupled with building energy models (e.g. EnergyPlus). This approach enables a realistic evaluation of thermal comfort, overheating risk, and cooling demand during heatwaves.

Here, the urban microclimate becomes the boundary condition for building physics. For example, reductions in ambient air temperature or increased shading from vegetation directly reduce solar gains and cooling loads. This final level of integration closes the scale loop, moving from regional weather patterns to individual building performance.

The state-of-the-art reveals an increasing number of studies that attempt to integrate localized microclimatic conditions into BES models. Tsoka (2023) proposed a workflow to develop Urban Specific Weather Datasets by adjusting EPW files using ENVI-met outputs, capturing local shading, wind, and thermal effects. The approach demonstrated significant changes in predicted building energy demand, particularly an increase in cooling demand (up to 28.2%) and reduction in heating loads (up to 11.5%) due to localized urban heat island effects. Lauzet et al. (2019) provided a structured classification of coupling techniques into three main categories: one-way chaining (offline), weak coupling (sequential with feedback delay), and strong two-way coupling (real-time or iterative exchange). Their review emphasizes that while chaining is widely adopted due to its simplicity, it inherently lacks feedback mechanisms, particularly in accounting for heat rejection from HVAC systems, which can amplify local microclimate effects.

However, despite growing adoptions, several limitations persist. First, most studies (Tsoka, 2023; Tsoka et al., 2018) rely on offline coupling, where selected climate variables (usually air temperature) are manually modified in EPW files. This approach ignores other vital environmental variables like humidity, longwave radiation, and wind dynamics, which can significantly influence indoor thermal comfort and energy demand. Secondly, ENVI-met outputs, although high-resolution, are typically limited to 1–3-day simulations due to computational constraints, leading to a temporal mismatch with BES models that operate on annual scales (Lauzet et al., 2019), and limiting its ability to assess long-term comfort or seasonal performance. Discrepancies exist between the spatial scales of ENVI-met and conventional building energy simulations as well. The high spatial resolution (0.5–1 m) of ENVI-met also results in significant computational demands.

Furthermore, ENVI-met's capability to assess indoor temperatures and thermal comfort is constrained by several inherent limitations in its numerical modelling. While ENVI-met calculates indoor temperature dynamics based on heat fluxes through walls and roofs, it overlooks key factors influencing a building's thermal balance, such as ventilation, infiltration,

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and internal heat sources. As a result, its predicted indoor temperatures lack validation and may not accurately reflect real conditions. This was also demonstrated in the study by Tsoka (2023), wherein it does not account for internal heat gains, HVAC operation, ventilation, infiltration, or inter-zonal air exchange, all of which are vital for realistic indoor environment prediction, therefore, making it unsuitable as a standalone predictor for indoor conditions. Indoor temperatures predicted by ENVI-met lack validation due to this oversimplification, which undermines its applicability for thermal comfort assessment. Additionally, heat released from building systems to the outdoors and the thermal inertia of interior partitions (walls, ceilings, floors) are omitted.

Moreover, buildings are represented as solid blocks with set envelope properties. Although thermal zoning is allowed, the absence of heat and airflow exchange between zones means that subdividing spaces does not enhance simulation accuracy. In fact, the zone setting imposes constraints on the simulation of indoor temperature. Taking the case of the Casette Inglesi, a neighborhood of Bolzano, the graph below presents the outputs of air temperature at the same location of two models with the same geometry but different zone cutting. The yellow line delineates the model that separates the focusing apartment into different zones, while the green line represents the model that comprises a single zone. In this instance, ENVI-met calculates different zones as enclosed environments without considering heat conductivity. Consequently, the yellow line fluctuates severely in comparison to the green one for the entire apartment. In contrast, EnergyPlus offers a more sophisticated and physically detailed simulation of indoor thermal dynamics. The model explicitly incorporates the mechanisms of heat conduction, convection, and radiation within and between building zones, thereby facilitating more precise predictions of indoor air temperatures by capturing the thermal interactions across walls, floors, and ceilings.

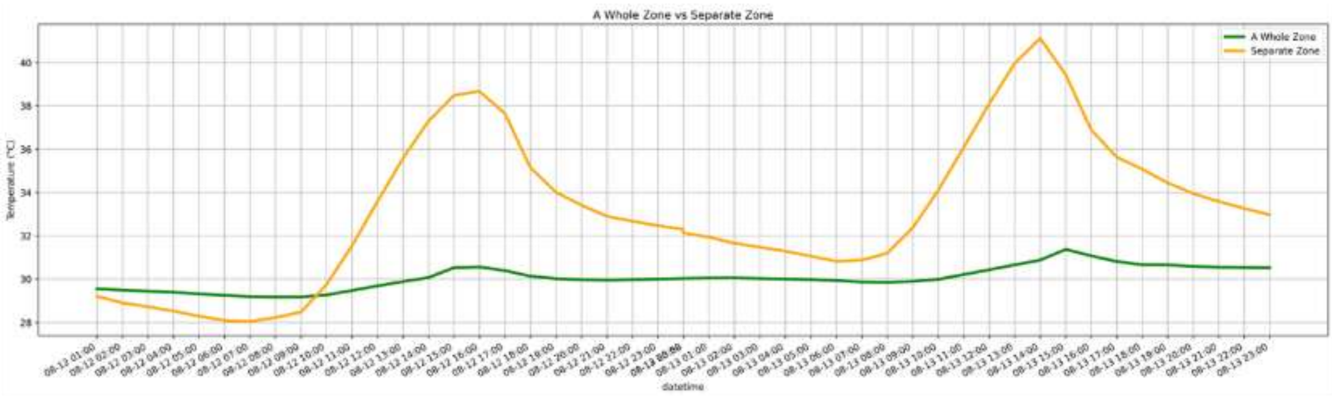

Figure 47. Comparison of indoor air temperature outputs from two ENVI-met models with identical geometries but different zoning schemes.

A further disadvantage of ENVI-met when assessing the indoor environment is that it is dependent on the settings of the building's initial conditions. With regard to the initial building condition inputs, ENVI-met requires the indoor temperature [°C] and the initial building surface temperature [°C], which further stresses on the need for a feedback mechanism from the building energy model to the urban microclimate model. The figure below presents the same model with different initial settings. The red curve represents the initial condition inputs that follow the real condition, which is measured by the meteorological sensor in the case study apartment. During the course of the simulation, which spanned a duration of two days, it was observed that the trajectories of both lines did not intersect at a specific point. In this particular instance, it was deduced that ENVI-met required additional time to establish the initial conditions when the inputs were less precise. In such instances, the utilization of EnergyPlus software can facilitate the provision of precise inputs, particularly in scenarios where the available measured data is limited.

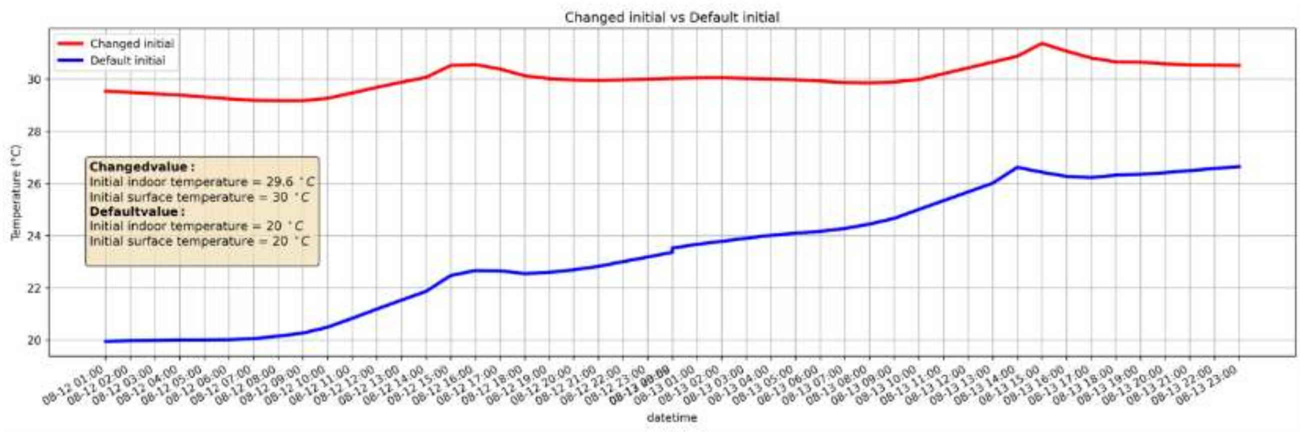

Figure 48. Effect of different initial condition settings on indoor air temperature prediction in ENVI-met.

Despite the constraints mentioned above, ENVI-met offers valuable boundary conditions for building energy models, such as outdoor surface temperatures, solar radiation, wind patterns, and air temperatures near the building envelope. Conversely, building energy simulation tools can supply initial conditions that streamline ENVI-met runs, improving both efficiency and accuracy.

Therefore, in line with this, the current work focuses on establishing a robust coupling framework between ENVI-met and EnergyPlus. In this, the microclimate variables from ENVI-met simulations are extracted and provided as input into the detailed building models developed in EnergyPlus through RHINO-grasshopper via ladybug and honeybee plugins. This framework enables the analysis of indoor thermal performance under localized microclimatic conditions. The approach aims to overcome key barriers in the current state-of-the-art by facilitating a reproducible and climate-sensitive BES workflow with potential extensions toward feedback integration.

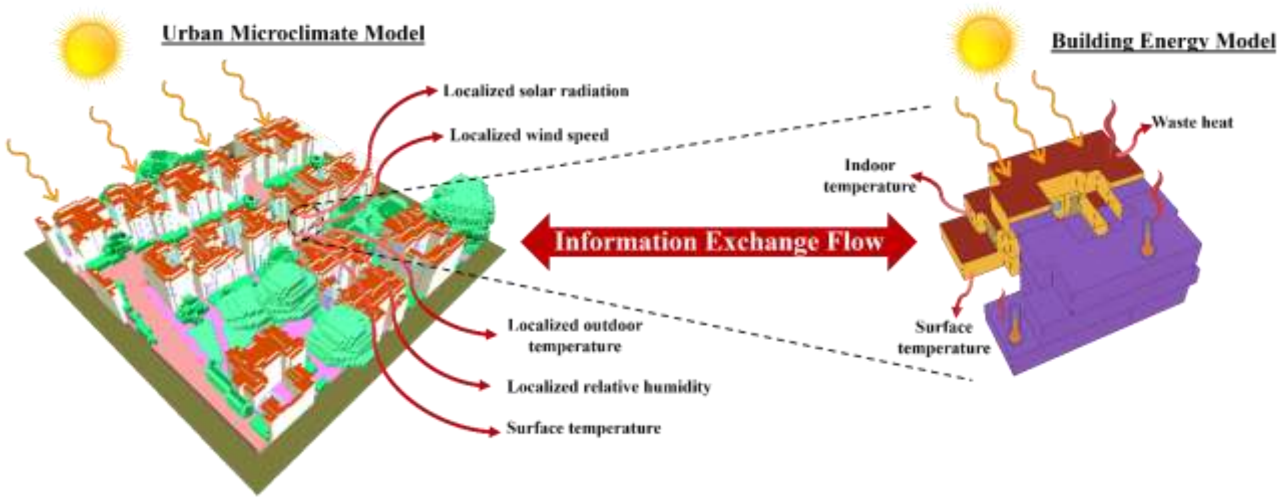

Figure 49. Information exchange flow between the urban mircoclimate and building energy simulation models.

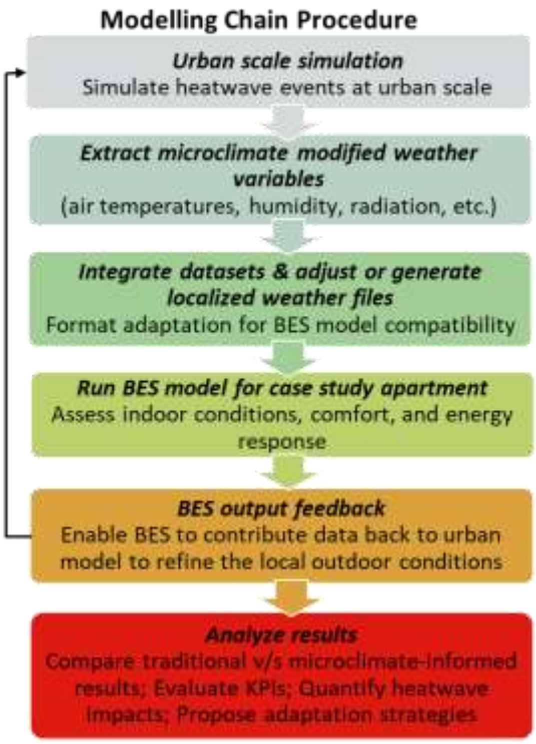

Figure 50. Proposed workflow for microclimate-informed simulation of indoor thermal conditions during heatwaves.

The need for this integrated urban microclimate–building simulation framework is increasingly urgent. As climate change intensifies the frequency and severity of extreme heat events, there is a growing demand for models capable of supporting adaptive building design and climate-responsive urban planning. Such integrated approaches are essential not only for evaluating passive heat mitigation strategies, such as shading, cool materials, and vegetation, but also for quantifying resilience indicators such as duration of thermal discomfort, heat stress exposure, coping capacity, recovery time, to name a few.

Mobile Monitoring with MeteoTrackers

To enhance ground-level thermal observations, mobile sensors (*MeteoTrackers*) were mounted on public transport vehicles. During a full month of monitoring in April 2025, temperature and humidity data were collected across several routes in the city. This high-resolution dataset revealed intra-urban thermal gradients and confirmed localized heat accumulation in densely built areas. These measurements serve as a valuable ground-truth dataset to validate satellite LST patterns and to assess local variability that escapes coarse climate models.

Despite their strengths, mobile sensors come with limitations: measurements are restricted to street networks, and the devices are sensitive to vehicle speed, solar radiation, and sensor shielding. Still, they allow temporal sampling and fine-scale validation that strengthens both UrbClim and ENVI-met simulations at selected hotspots.

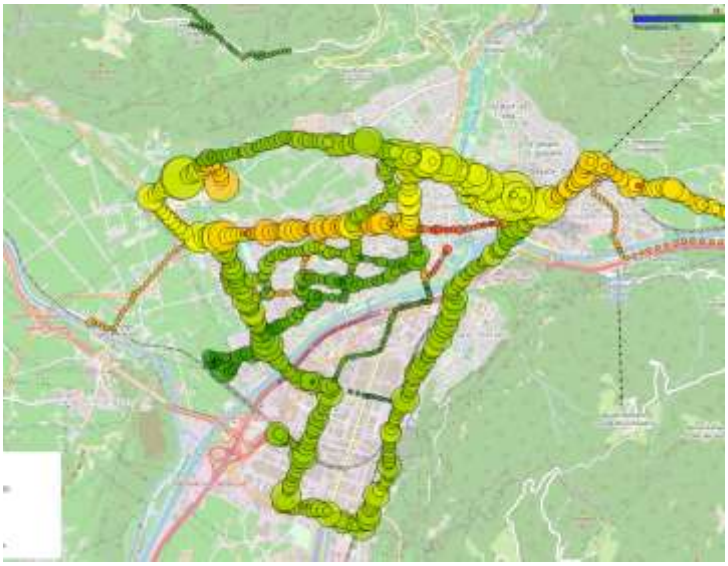

Figure 51. Mobile temperature data from MeteoTrackers: Full month of April example of over one bus. The size of circle represents the amount of data collected whereas the color bar represents the average temperature.

Key Findings and Cross-Scale Integration

The Bolzano case study demonstrates the value of a multi-scale, multi-method approach in understanding and addressing the Urban Heat Island (UHI) phenomenon, providing valuable insights into UHI dynamics and mitigation potentials.

Each layer of analysis contributes complementary insights: satellite-derived land surface temperature maps reveal spatial patterns of heat accumulation at the metropolitan scale; mobile monitoring validates and enhances the resolution of surface-based data; mesoscale climate modelling provides essential context and boundary conditions; urban climate simulations project future heat risks; microclimate models quantify the cooling effects of Nature-based Solutions (NbS) at neighbourhood level; and coupled building energy models link outdoor climate conditions with indoor thermal comfort and energy demand.

These different scales and data types are not isolated efforts but part of an integrated workflow in which outputs from one scale inform inputs or validation for the next. This cross-scale integration improves model reliability, supports site-specific design strategies, and enables the development of replicable methodologies for climate-responsive urban planning. Ultimately, the findings demonstrate how data-driven, scale-sensitive approaches are essential to support resilient, inclusive, and thermally comfortable urban environments.

Furthermore, cross-referencing outputs from different models allows for validation and triangulation of results, improving reliability.

Implications for Design and Policy

Findings from the Bolzano case study can inform both urban design and local policy development. The modelling outcomes are being shared with municipal stakeholders to guide implementation of NBS, revise zoning and planning codes, and develop early-warning systems.

The multi-scale framework offers a powerful toolset for urban designers, planners, and policymakers aiming to implement context-specific climate adaptation strategies. By combining empirical data with model-based projections — including satellite observations, mobile measurements, climate modelling, and building performance simulations — the approach enables informed decision-making on where and how to intervene for maximum environmental and social impact.

This supports a transition from generic, one-size-fits-all planning to targeted strategies grounded in local climate vulnerabilities, spatial dynamics, and performance outcomes. The evidence produced through this workflow can inform zoning regulations, building standards, and investment priorities for both new developments and retrofits of existing urban areas.

From a policy perspective, the methodology aligns with the goals of the European Green Deal and the New European Bauhaus by bridging scientific knowledge with urban aesthetics and social inclusion. By embedding environmental performance, spatial justice, and experiential quality into design and planning processes, this integrated approach supports the creation of cities that are not only more climate-resilient, but also more liveable, equitable, and beautiful.

5.2.3 The GI project at the local level: the case of Meisino Park in the city of Turin

The city of Turin, situated in the western part of the Padana plain, features a complex landscape. The eastern area is hilly, while the city centre is densely built-up, with the Po River and its tributaries (Sangone, Dora and Stura rivers) providing flat terrain. Additionally, the city's proximity to the Alps creates a distinct landscape that presents various challenges, both environmental and social. Indeed, the city of Turin is acknowledged to have hydrogeological risks; over 65% of its surface is artificial, which limits natural drainage significantly. This high percentage, combined with floodplain areas, makes the city susceptible to flooding from both prolonged rainfall and intense downpours. Moreover, Turin faces socio-economic challenges associated with an ageing population, reflected in a ratio of two people aged over 65 for every child under 14 years old. The city is also experiencing deindustrialisation, leading to critical situations that necessitate targeted interventions to enhance resilience against both hazardous events and socio-economic crises. Nevertheless, the city of Turin also has a tight connection with its green areas (Città di Torino, 2020; Giudice, La Riccia, Negrini, Voghera, 2022) and water bodies (project of Torino città d'acque).

Given these as general data, our research focuses on the river context, which encompasses a multifaceted socio-ecological system that provides a comprehensive understanding of different assets, including environmental, ecological, natural, anthropical and social. In particular, we have chosen three different districts (*circoscrizioni*) in the northeastern part of the city: Vanchiglia, Regio Parco and Madonna del Pilone. The choice of these three districts gives the opportunity to examine different territorial and social situations. Furthermore, in the coming years, this part of the city will undergo major transformation processes. To briefly characterize the three districts:

- Vanchiglia is a varied district. It is a transitional area between the historic centre and the more peripheral areas of the city. It is bordered to the south-west by Corso San Maurizio, which marks the boundary with the centre of Turin, and extends to the confluence of the Dora and Po rivers. Part of the district is in continuity with the historic city centre urban fabric, clearly visible up to Corso Regina Margherita. Crossing the river Dora, there is a more peripheral area, characterized not only by obvious traces of its industrial past, but also by extensive green spaces, such as Parco Colletta.
- The Regio Parco district takes its name from a former royal residence and has a strong industrial past. In fact, the royal estate was replaced in 1740 by the Manifattura Tabacchi, a large tobacco factory. Around this proto-industrial complex, a working-class neighbourhood began to grow, which can still be seen today. From the mid-19th century, other manufacturing activities were established in the area, including what is now known as Ex-Fimit. Since the 1980s, several factories, including Manifattura Tabacchi and Fimit, have closed or relocated, leaving empty, abandoned buildings in the city. These changes contributed to the decline of the area.
- Madonna del Pilone is a mainly residential area. It overlooks the Po River and is characterised by an abundance of greenery. To the west, it borders Meisino Park, while to the east, it includes part of the Turin hill.

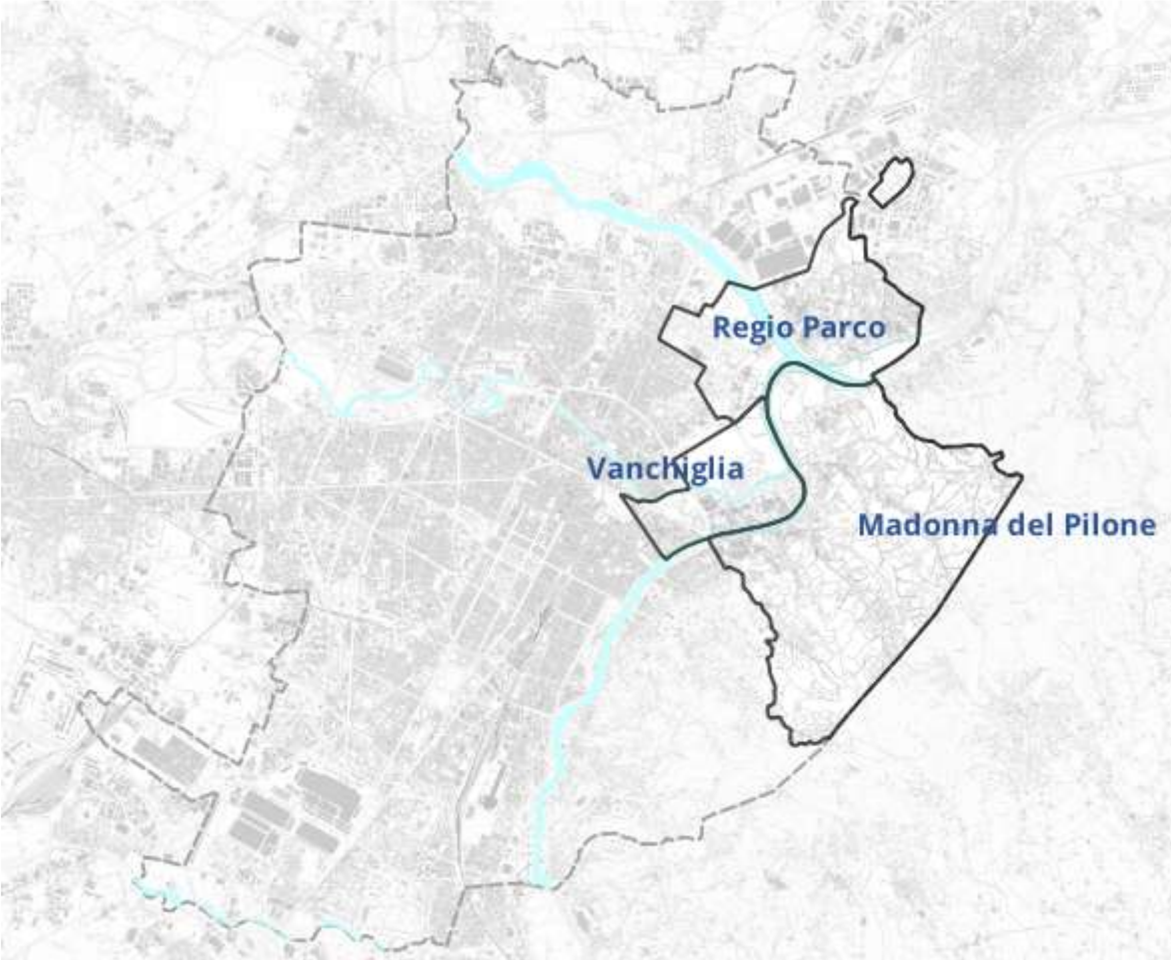

Figure 52. Different district for the study area

The construction of Metro Line no. 2 is set to drive significant transformation within the city. The main objective of this project is to improve mobility and accessibility both at the city level and throughout the metropolitan area. The new metro line will connect the north-eastern part of the city with the south-western part, strengthening the connection between key areas and integrating with the existing public transport system. Moreover, it will provide a general revitalization and regeneration of the northern part of the city. The route of the metro line partly follows the old Gottardo line, known as the "Trincerone", which was originally built to serve the Manifattura Tabacchi and currently acts as a dividing feature within the city. Planned interventions aim to transform this barrier into a vibrant "new boulevard" for the city, featuring public and green spaces, pedestrian and cycling paths, sports facilities, and other community services. The new metro line will have a station called "Cimarosa/Tabacchi" near the Manifattura Tabacchi. This former industrial site has been the subject of a design competition aimed at creating a new cultural hub combining different functions for the city. The site will include a university campus with student accommodation, services and educational facilities, as well as an archive centre with reading rooms, a research centre and storage facilities that will support institutions in Turin, Asti, Biella, Cuneo and Verbania, as well as the General Directorate of Archives of the Ministry of Culture. The site will be accessible to the surrounding neighbourhood that has developed around the factory and will connect to other university campuses and the city through the new metro line and "active" transport infrastructure.

Another major project is underway on the other side of the river, in the Madonna del Pilone district. The "Meisino Sports and Environmental Education Centre" project involves the restoration of the Cascina Malpensata (a former military racecourse) to create a centre for environmental and sports education. The project also includes the construction of light, reversible sports facilities integrated into the park. The interventions will avoid the park's most naturalistic areas. The intervention also includes the improvement of the wooded areas along the right bank of the river, the planting of new trees, the protection of wetlands, the integration of large wooded meadows and the addition of greenery.

The "Torino Cambia" website has collected other smaller-scale transformations, which are listed below, specifically for the districts under study.

Table 5.5 Small-scale transformations for the districts under study

Name	tag	District	State	Description
Valdocco vivibile	verde	7	concluso	Riqualificazione delle aree verdi e dell'arredo urbano nel quartiere Valdocco
Aree gioco a prova di clima	verde; parchi	n.a.	in progetto	Riqualificazione delle aree gioco di quartiere
Centro polifunzionale della protezione civile in via Gladioli 13	verde	5	in progetto	Recupero e riqualificazione di un edificio pubblico comunale e dell'area esterna di pertinenza, per la realizzazione di un centro polifunzionale della protezione civile comunale
Messa a dimora di alberi e arbusti	verde	n.a.	in progetto	Interventi di contrasto al cambiamento climatico
Riassesto idrogeologico sponde fluviali parco Fioccardo e Meisino	verde; parchi	6,7,8	in progetto	Messa in sicurezza delle aree spondali e potenziamento della fruibilità ciclopedonale dei parchi collinari cittadini
Ex Villa Ottolenghi	verde; parchi	7	in cantiere	Riassetto idrogeologico
Parco Leopoardi	verde; parchi	8	in cantiere	Riassetto idrogeologico
Intervento di adattamento per una città più vivibile	verde	7	concluso	Realizzazione di un tetto verde a bassa manutenzione per rinfrescare l'edificio.
Intervento di adattamento per una città più vivibile	verde	5	concluso	Soluzioni verdi e smart per rendere rendere più vivibili le piazze scolastiche
Riqualificazione Corso Belgio	verde	7	concluso	Più verde, più ombra, spazi riorganizzati, accessibilità facilitata e maggiore qualità dello spazio pubblico
Fermate del trasporto puibblico riqualificare	verde	1,2,3,4,5,6,7,8	concluso	Riqualificazione verde di 16 fermate per renderle più vivibili e adattabili ai cambiamenti climatici
Via stradella più vivibile	verde	5	concluso	Riqualificazione verde in via Stradella per una città più vivibile
Superfici permeabili sulla sede tramviaria Nord della Linea 4	verde	6	concluso	Rimozione dell'asfalto e ripristino della permeabilità per migliorare la vivibilità e l'adattamento ai cambiamenti climatici
Accesso parco delle vallette	verde; parchi	5	in cantiere	Riqualificazione dell'accesso est per migliorare la sicurezza e fruizione del parco a piedi e in bicicletta
Parco della Tesoriera	verde; parchi	4	in progetto	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e il giardino storico
Parco Rignon	verde; parchi	2	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e il giardino storico
Strada delle cacce 36	verde	2	in cantiere	Interventi di riqualificazione edifici socio-assistenziali e di aggregazione giovanile
Nuova Biblioteca Via Viterbo	verde	5	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Mausoleo della bela Rosin	verde; parchi	2	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Utoya	verde	4	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Bibilioteca casa della cultura Mozart	verde	6	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini

Biblioteca Alberto Geisser	verde	8	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Don Milano	verde	6	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Rita Atria	verde	6	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Alessandro Passerin	verde	2	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Cesare Pavese	verde	2	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Italo Calvino	verde	7	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Cascina Marchesa	verde	6	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Dietrich BonHoeffer	verde	8	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Francesco Cognasso	verde	5	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Luigi Carlucico e centro civico	verde	3	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Musicale Andrea della Corte	verde; parchi	4	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Biblioteca Villa Amoretti	verde; parchi	2	in cantiere	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
Basso San Donato	verde	4	concluso	Interventi di rigenerazione urbana per potenziare la biblioteca di quartiere e gli spazi urbani vicini
San Secondo	verde	1	concluso	Un quartiere resiliente dove abitare e muoversi in sicurezza
Giardino Peppino Impastato	verde	6	concluso	Riqualificazione del giardino per contrastare gli effetti del cambiamento del clima e offrire esperienze ricreative innovative
Parco di Vittorio	verde	8	concluso	Riqualificazione delle aree verdi e gioco per contrastare gli effetti del cambiamento climatico e offrire più spazi per il gioco
Giardino Madre Teresa di Calcutta	verde	7	concluso	Riqualificazione del giardino per contrastare gli effetti del cambiamento del clima e offrire esperienze ricreative innovative
Giardino Don Gnocchi	verde	5	concluso	Riqualificazione del giardino per contrastare gli effetti del cambiamento del clima e offrire esperienze ricreative innovative
Parco della Pellerina	verde	4	concluso	Riqualificazione delle aree verdi e gioco per contrastare gli effetti del cambiamento climatico e offrire più spazi per il gioco
Giardino San Paolo	verde	3	concluso	Riqualificazione delle aree verdi e gioco per contrastare gli effetti del cambiamento climatico e offrire più spazi per il gioco.

Giardino Nuova Delhi	verde	2	concluso	Riqualificazione delle aree verdi e gioco per contrastare gli effetti del cambiamento climatico e offrire più spazi per il gioco.
Giardini Reali Inferiori	verde	1	concluso	Riqualificazione delle aree verdi e gioco per contrastare gli effetti del cambiamento climatico e offrire più spazi per il gioco
Forestazione Viali	verde	4,7	concluso	Viali alberati più Viali alberati più resilienti
Forestazione dei Parchi Fluviali	verde	2,4,5, 6, 7,8	concluso	Cura e valorizzazione delle sponde dei fiumi
Forestazione della Collina	verde	7, 8	concluso	Cura e valorizzazione dei boschi e dei parchi
Lungo Dora: corridoi verdi	verde	7	concluso	La riqualificazione del lungo fiume da corso Principe Oddone a parco Colletta
Valdocco vivibile - lotto 2	verde	7	in cantiere	Riqualificazione del quartiere Valdocco con spazi pubblici più verdi e sicuri
Pareti verdi in Via Cumina 15	verde	3	concluso	Realizzazione di un sistema antintrusione attraverso pareti verdi verticali
Parco Valentino	verde	8	in cantiere	Restauro del parco storico del Valentino
Centor per l'educazione sportiva e ambientale Meisino	verde	7	in cantiere	Sport ed educazione ambientale nel parco del Meisino
Piste pedonali e ciclabili corso Ferrara e Grosseto	verde	5	in cantiere	Riqualificazione e completamento della pista ciclabile e dei percorsi pedonali
Piste peodnali e c ciclabili alle Vallette	verde	5	in cantiere	Rifacimento e completamento dei percorsi pedonali e ciclabili per favorire la mobilità dolce in sicurezza
Giardino Via delle Verbene	verde; parchi	5	in cantiere	Riqualificazione del giardino pubblico in via delle Verbene
Orti Urbani	orti	2,6,7	in progetto	Messa a dimora di arbusti e siepi di specie autoctone negli orti urbani gestiti dalla Città di Torino
Bonifica Area Ex Cimi Montubi	parchi	6	in progetto	Realizzazione del Parco Urbano Basse di Stura
Bonifica Area Deltasider	parchi	6	in progetto	Bonifica per Parco Urbano Basse di Stura
Attrezzature sportive nelle aree verdi	parchi	varie	concluso	Torino aumenta la sua dotazione di attrezzature sportive all'aperto fruibili da tutti nei parchi e giardini pubblici

Planning processes in the city of Turin

In the past decade, urban and spatial planning in the territorial context of Turin have undergone significant changes to adapt to unexpected crises and international strategies. All the different levels in charge of planning have indeed experienced the necessity to update their plans. The Piedmont Region, within the framework of its regional plans (Piano Territoriale Regionale – PTR and Piano Paesaggistico Regionale – PPR), offers a solid structural and legislative framework for local plans. The PTR, which provides strategic guidelines and indications at a regional scale, is currently being revised to align with the recent regional strategies for sustainable development (Strategia Regionale per lo sviluppo sostenibile released in 2022) and climate change adaptation (Strategia regionale sul cambiamento climatico approved in 2022) and to upgrade its operational effectiveness on a local scale.

Since the first Provincial Territorial Coordination Plan (PTCP) in 1999, the former Province of Turin (converted into a Metropolitan City in 2014) has consistently engaged in extensive territorial planning. This planning activity prioritised soil protection and the limitation of land take, making these goals key objectives alongside the preservation of biodiversity. The Metropolitan City of Turin is currently revising its planning tool (Piano Territoriale Generale Metropolitano – PTGM), continuing emphasising controlling land take, improving slow mobility, and enhancing green and blue infrastructure (Voghera, 2022).

In 2023, the city of Turin began drafting a new land use plan (Piano Regolatore Generale – PRG) with a shared future vision that incorporates feedback from various stakeholders. Furthermore, since rivers are our focus, a tool that comes to our aid is the River Agreement, a voluntary planning and participatory tool used to enhance the resilience and sustainability of river courses (both in terms of water quality and social awareness).

More recently, also the Piedmontese Po River Park has decided to revise its plan to enhance the territorial scenarios for ecological reticularity and local planning with regard to strategic and critical nodes from a landscape perspective.

The GI project of the city of Turin

Green infrastructure is a concept that has recently gained prominence in urban planning studies. Indeed, it is widely acknowledged for its strategic and operational role in conceiving green and open spaces (Meerow & Newell, 2017). Additionally, GI is essential for this research because it provides the opportunity to achieve multifunctional objectives across various fields of study and at different scales (Lovell & Taylor, 2013).

Even in the metropolitan city of Turin, there have been many attempts to operationalize GI into urban planning tools. From 2014 to 2016, the ENEA (Italian National Agency for New Technologies, Energy and Sustainable Development) and the Politecnico di Torino established guidelines for the green system (LGSV) of the provincial territory. Within this framework, a specific methodology was developed for defining the provincial ecological network (LGRE) (Voghera, Negrini, La Riccia, Guarini, 2017; Voghera, A.; La Riccia, L., 2018; Voghera, Giudice, 2019; La Riccia 2023). The goal of this research was to propose an implementation strategy for the provincial ecological network at the local level. The proposed methodology takes a bioecological approach, viewing the landscape as an interconnected system of habitats. It links areas within the Natura 2000 network, including core areas, corridors, and buffer zones, which are essential for enhancing ecological functionality, along with sustainable use areas and potential restoration sites. To effectively evaluate ecological functionality and identify environmental critical issues, various land use types have been assessed against specific ecological and environmental criteria: naturality, relevance for preservation, fragility, extroversion, and irreversibility. These indicators refer to habitats and their functions as complex and interconnected systems. Each of the 97 land use typologies has been assigned ecological and environmental criteria, which collectively characterize these typologies from an ecological perspective. These indicators are categorized into different levels of specificity, ranging from five levels (naturality and extroversion) to three levels (irreversibility).

The value of naturality, which is divided into five levels, is assigned to each land use typology based on its proximity to what would exist in the absence of human disturbance (the climax community). The second value, relevance for conservation, evaluates the importance of various land uses for biodiversity preservation on a scale of four levels. This assessment takes into account not only habitats of communitarian interest but also those necessary for the protection of plant and animal species within the Natura 2000 network. The classification of land uses in relation to their fragility is conducted on four levels. This evaluation assesses how different land use types inherently resist the various pressures exerted by human activities, such as pollution and disturbances. This indicator can measure a system's vulnerability, particularly concerning disaster risk, poverty, food security, and climate change, with a focus on exposure and adaptive capacity. The concept of fragility is primarily related to the intrinsic characteristics of an area. However, for certain land use types, it is crucial to consider fragility that arises from the limited extent of that land use (for example, a specific vegetation type that defines a land use typology). The level of extroversion of a land use type is determined by the intensity, likelihood, or potential for that type to generate pressures on nearby areas. This evaluation includes factors such as pollution, industrial activity, and the possible spread of invasive species, viewed from an integrated perspective. The extroversion levels are divided into five categories: the first includes land use types predominantly comprised of human settlements, while the fifth refers to areas with more natural land use types. The final criterion is irreversibility, which assesses the level of improbability regarding land use changes that could lead to a higher degree of naturality. This criterion is measured on a scale of three levels: the first level represents the most irreversible areas, including sealed land use types such as urban settlements, commercial zones, and industrial areas.

By integrating the first two indicators—naturality and relevance for conservation—we have established a territorial zoning process based on ecological functionality and reticular value. Areas have been categorized into four classes based on their ecological functionality: (1) areas with high ecological functionality, (2) areas with moderate functionality, (3) areas with residual functionality, and (4) areas with null functionality. The first class, encompassing areas with high ecological functionality, is ideal for the development of habitats and species. The second class, while having lower functionality, includes areas that are vital for maintaining connectivity within the ecological network. Areas classified with residual functionality can be partially utilized to expand the network, whereas those in the last class are deemed obstacles to network development. Applying this methodology to specific territories has helped define a widespread reticularity in the involved areas and has highlighted which parts are more sensitive to sudden changes due to human activities. This approach not only identifies natural areas of significant importance for biodiversity conservation but also helps pinpoint priority areas for the expansion of the ecological network.

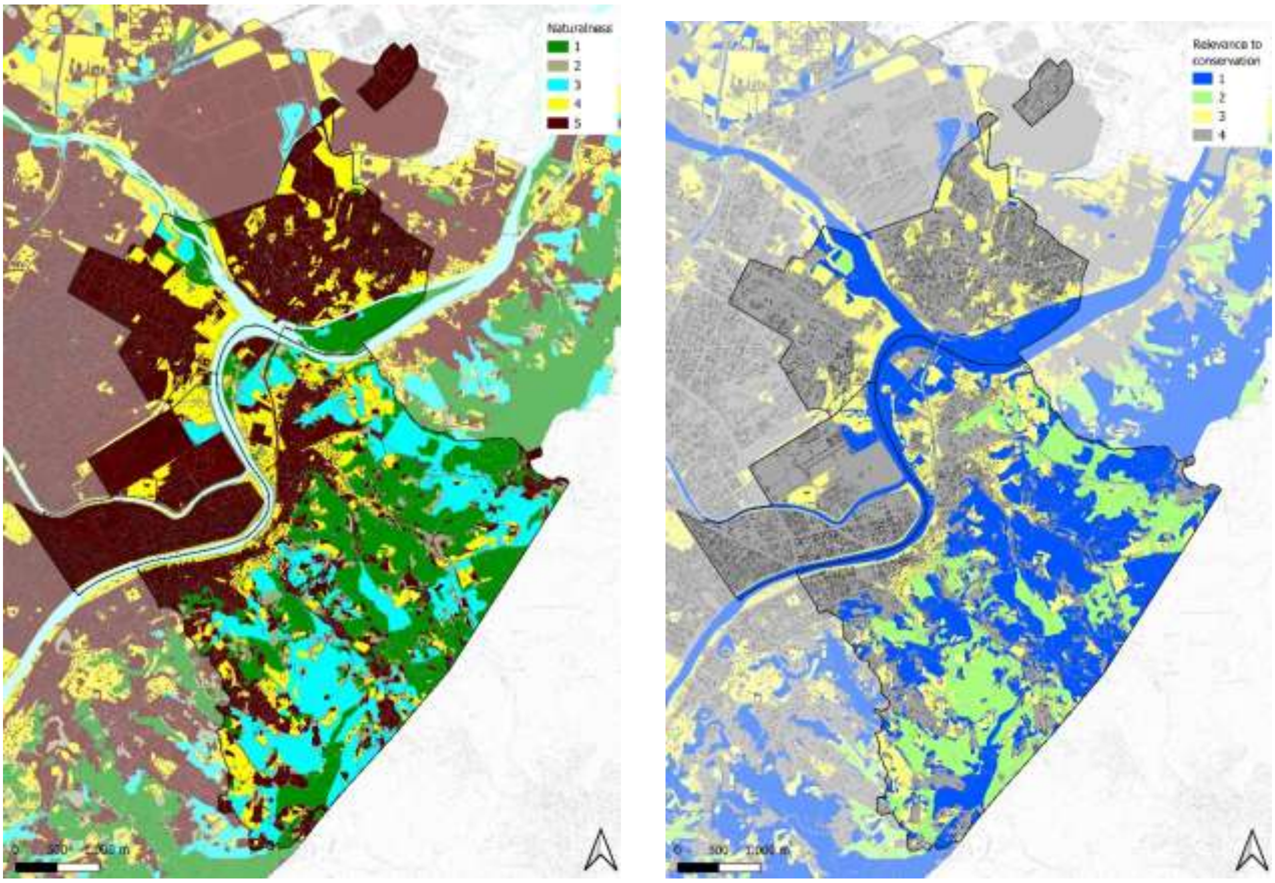

Figure 53. Naturalness and relevance to conservation indicators (output maps).

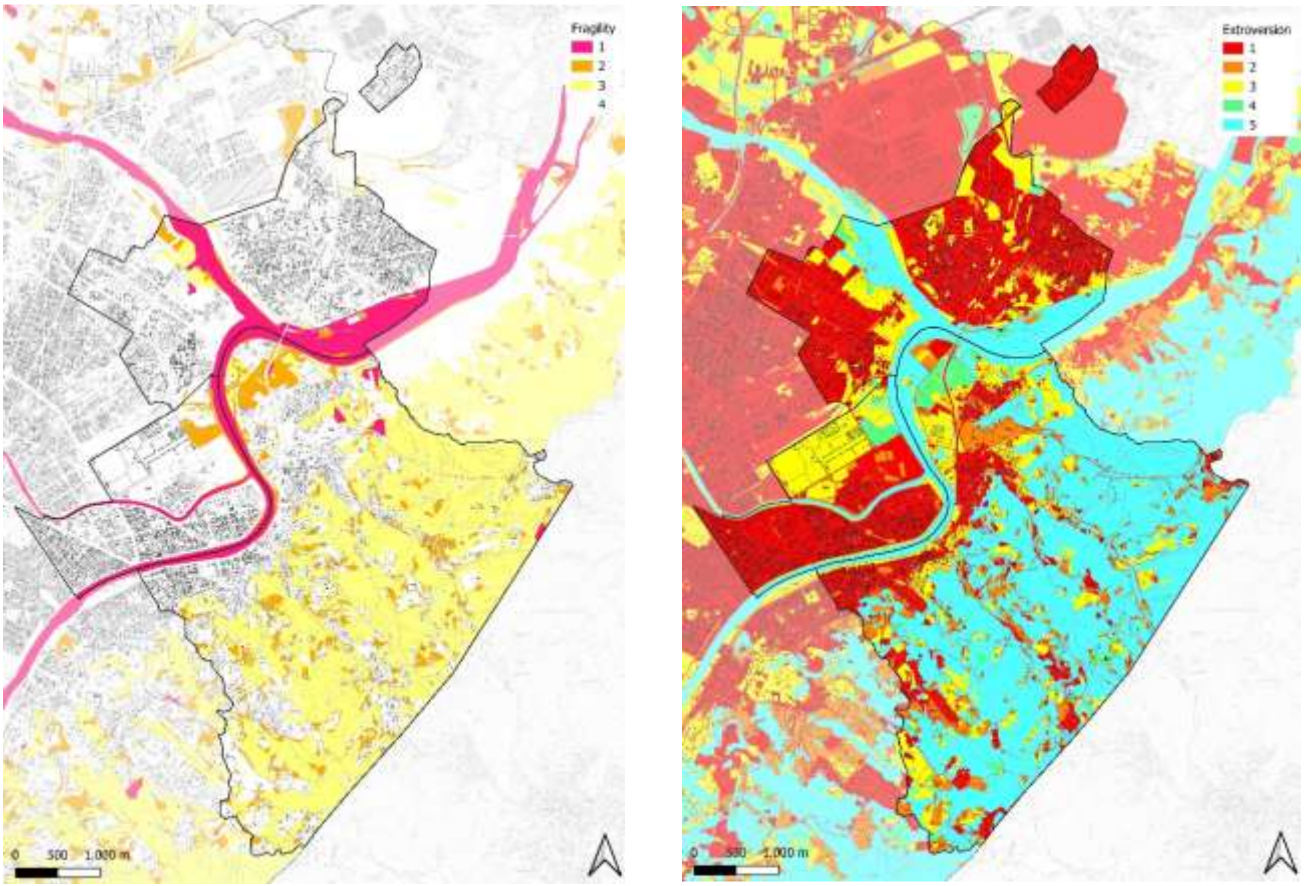

Figure 54. Fragility and exstroversion indicators (output maps).

5.3 Design proposal at District scale

This section presents the application of the experimental design framework for advancing the green transition at the urban district level, building upon the methodological foundations discussed in Section 3.2.5. The experimentations have been carried out on the urban district of Soccavo. In the first paragraph, the proposal integrates – starting from the National Plan for Climate Change Adaptation – regulatory tools, spatial analysis and planning instruments through the Proof of Concept approach to facilitate the transformation of urban districts in eco-districts using a structured taxonomy of design actions, performance indicators and climate change adaptation strategies. Following, Section 5.3.2 expands the scope by addressing the resilience to built-up areas to extreme heat, applying a GIS-based methodology to identify urban hotspots and to design context-specific interventions, such as climate shelters.

5.3.1 Strategic actions for the green transition of urban district in Soccavo (Naples)

This section shows an experimental application of the proposal presented in paragraph 3.2.5: the integration of planning tools in the process of transition from urban district to eco-district through the PoC methodological approach. The proposed method is applied to the Soccavo district in Naples.

Theoretical and normative framework: green transition and adaptation tools

The green transition represents an interdisciplinary process aimed at changing the methods of production, management, planning and consumption, with the aim of reducing environmental impacts and strengthening the resilience of territories. It integrates adaptation and mitigation actions, requiring a profound rethinking of settlement models.

In this scenario, the NPACC, approved in December 2023, is the main Italian technical-political tool to tackle climate impacts. The plan identifies a structured database of actions divided into sectoral areas, related to the physical-environmental, infrastructural, ecosystem and socio-economic components. Each action is accompanied by indicators of effectiveness and progress, which allow it to be evaluated over time.

From a methodological perspective, the taxonomy adopted by the PNACC makes it possible to build a multidisciplinary knowledge matrix useful for the definition of local strategies. This approach makes it possible to harmonize national targets and local actions, bridging the gap between the strategic and the design scale.
The targets can be analyzed as the following:

- Apply and verify the effectiveness of the actions envisaged by the PNACC, using the proposed indicators.
- To build an integrated methodology that can guide the transition of an urban district to an eco-district, making this process monitorable, measurable and replicable.

Case study

The district of Soccavo, located in the western area of the city of Naples, is part of Municipality 9 and has about 48,000 inhabitants on an area of 5.11 km². After the Second World War, the district was the subject of a disorderly and partly illegal building expansion, with significant infrastructural deficiencies and discontinuous management of urban greenery. The territorial context is particularly exposed to natural and anthropogenic hazards, including: volcanic risk (red zone of the Campi Flegrei), hydrogeological risk and landslides, especially in hilly areas, heat waves and pluvial flooding, with direct impacts on urban well-being and quality of life.
From an urban planning point of view, Soccavo has an irregular morphology, with a strong fragmentation of greenery, a partly degraded building fabric and weak mobility, despite the presence of the Circumflegrea railway line. However, the district is in a strategic position close to important urban polarities, such as the university area of Monte Sant'Angelo and the Camaldoli Hill Park, which make it an area with high potential for transformation.
Soccavo's case study was selected based on a targeted analysis of specific risk indicators. Due to the morphology of the hilly park of Pianura and the high impermeability of the urban surfaces, the area is particularly vulnerable to both heat waves and the risk of flooding from intense rainfall (pluvial flooding).
In addition, the building fabric of Soccavo is densely built in some areas, with a lack of open spaces and urban voids, while the large green areas present are not well connected to the inhabited center. This urban configuration can amplify the negative effects of heat waves.
The coexistence and interaction between these two phenomena – intense rainfall and heat waves – contribute to amplified risk conditions. For these reasons, Soccavo has been identified as an emblematic case study of exposure to multiple risks to test the operational effectiveness of the PNACC actions and develop a replicable methodology for the green transition at district scale.

Methodological framework: application of the NPACC structure for the green transition of urban eco-districts

This section is structured as follows. In the first part, there is a quick overview of the different steps of the experimental application, followed in the second part by an analysis, aimed at its application in the knowledge and design phases for the reduction of heatwave-related climate impacts, of the database of actions defined by the NPACC. The third part focuses on the strategic actions and their selection criteria for the green transition of urban district in Soccavo. The last part is devoted to the selection of the performance indicators corresponding to the selected action in the previous step.

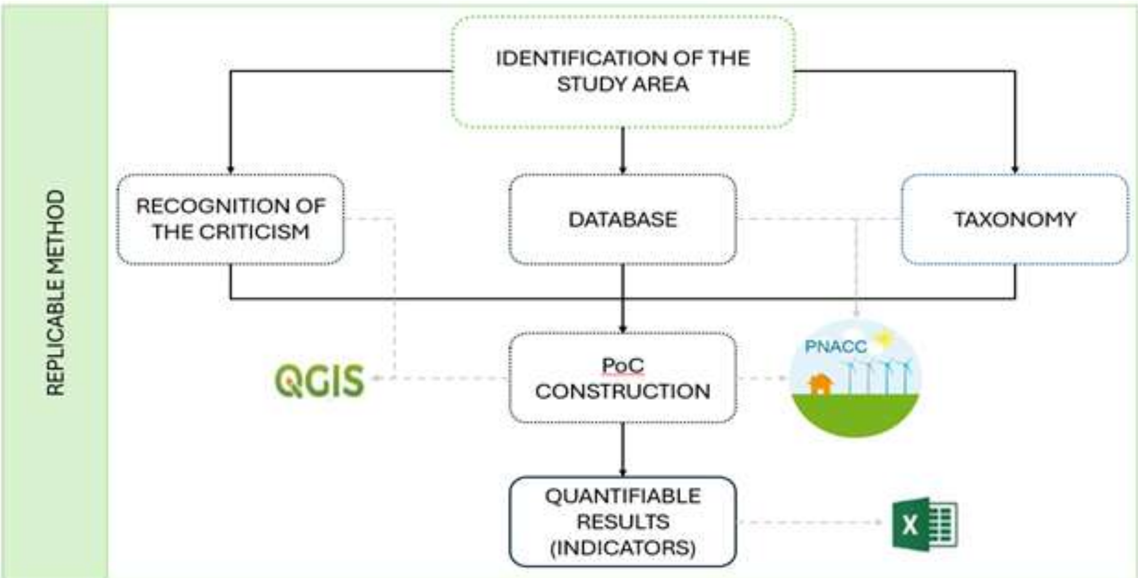

Figure 55. Method's application. Elaboration by A. Citarella, 2024.

Experimental application phases

The NPACC structure has been applied both in the knowledge phase and the design one.

The experimental application on the Soccavo district has been conducted according to the following phases:

- construction of the cognitive framework, through the analysis of risks, risks and territorial potential.
- identification of sectoral areas (grey and green) and related criticalities.
- selection of a set of adaptation actions from the PNACC relevant to the context.
- application of effectiveness and progress indicators.
- development of a strategic framework for the transition to eco-district.

Among the selected actions and tested are:

- the connection of green areas through green infrastructure,
- the recovery and management of rainwater (water squares, retention systems),
- the enhancement of sustainable mobility (bike sharing, cycle and pedestrian paths),
- the enhancement of protected natural areas and the safety of hillsides.

Two types of indicators have been associated with each action:

- effectiveness indicators: they measure effectiveness with respect to the environmental objectives set,
- progress indicators: they assess the degree of implementation of the action with respect to its planning.

Both the selection of the strategic action and the corresponding performance indicators have been derived from the "Database of actions" developed in the framework of the NPACC described in the following section.

Database of actions: structure and taxonomy

The PNACC (National Plan for Adaptation to Climate Change) brings together a set of actions aimed at creating an effective organizational environment at national level and strengthening adaptation capacity.

These sectoral actions are collected in a database, intended to be implemented in the Plans, according to the procedures defined by the local governance structure.

This database of climate change adaptation actions provides a comprehensive overview of the proposed measures, together with their attributes.

For each action, the database specifies:

- the category to which they belong;
- the sector scope (Soft, Green or Grey);
- indicators to monitor both the progress and effectiveness of the action;
- the reference regulatory sources;
- a cost estimate;
- the entities involved in implementation.

With regard to the sector scope, most of the actions shares 274 (76%) are non-structural (Soft). This is followed by ecosystem actions (Green), with 46 actions (13%), and finally infrastructure or technological actions (Grey), equal to 41 (11%).

The analysis of the relationships between the actions shows that agriculture, urban settlements, forests and water resources represent the main nodes of the network of interventions, since numerous actions converge on these sectors that are interconnected with other areas.

In detail:

- Agriculture forms a cluster with desertification, forests, terrestrial ecosystems and water resources;
- Urban settlements are linked to geological, hydrological and hydraulic instability, water resources, transport and coastal areas;
- Water resources interconnect with aquaculture, agriculture, energy, infrastructure, hazardous industries and urban settlements.

These connections highlight the central role of water resources as a connecting element between the sectors of agriculture, urban settlements and energy.

The aim of the research is to demonstrate the applicability of the method, testing it in the context of the Soccavo district.

The first step is to identify the geographical area on which to concretely apply the PNACC DATABASE, structured as follows:

- Actions
- Effectiveness and progress indicators
- Strategy
- Objectives

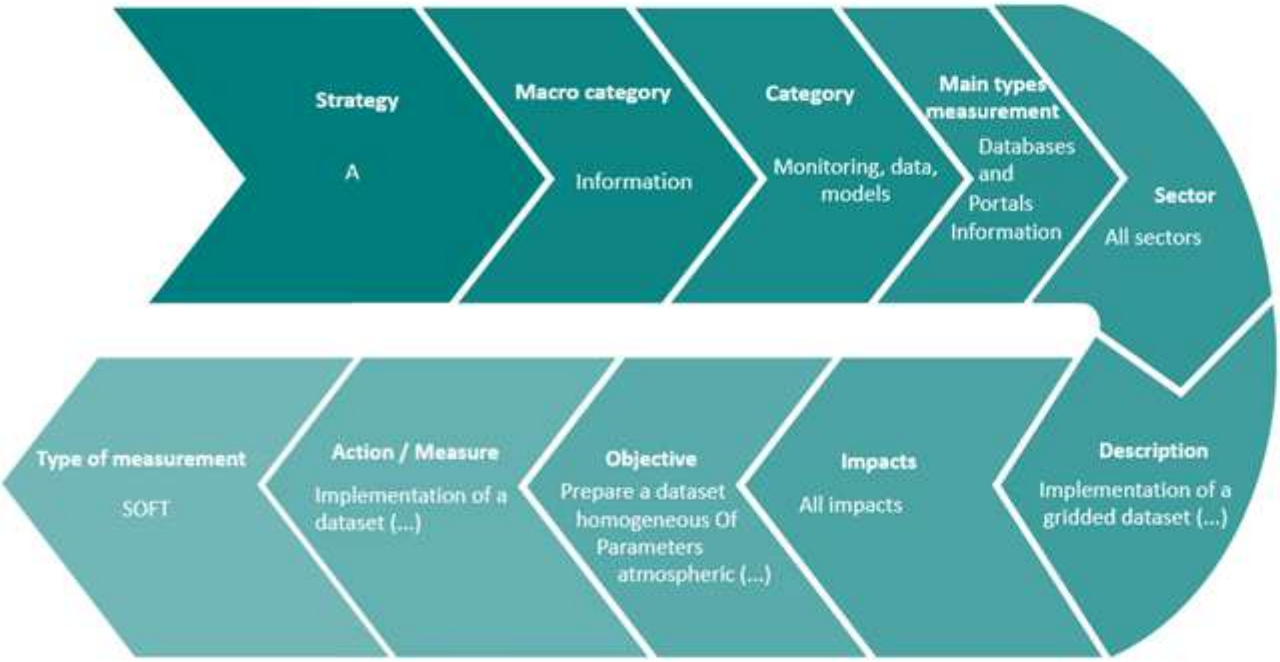

Figure 56. Database PNACC. Elaboration by A.Citarella, 2024.

To facilitate the evaluation process, the 361 actions identified by the PNACC have been organized into homogeneous families, according to a taxonomy that groups their design characteristics. The actions have been divided into macro-categories, each of which represents a type of intervention

Each macro-category has been further divided into specific categories for a more detailed classification.

In addition, actions have been classified into two main types:

- Non-structural (Soft): non-structural actions, which do not involve direct physical or material interventions.
    - These actions are essential to create the conditions favourable to the implementation of concrete interventions, strengthening the capacity for adaptation through information, training, and the construction of a solid institutional, regulatory and organizational context.
    - The macro-categories that fall under the soft typology include information, organizational, and participatory processes, governance.
- Structural (Non-Soft): includes both Green and Grey shares, both characterized by a structural and material component.
    - Green actions propose nature-based solutions, based on the sustainable use of natural and ecosystem resources and services, to mitigate the effects of climate change.
    - Grey actions refer to interventions on plants and infrastructures, and can be divided into subtypes concerning plants, materials and technologies, or physical networks and infrastructures.

The classification adopted is taxonomic: a useful approach to analyze the complexity and environmental criticalities, in order to identify more precisely the most appropriate actions to be taken.

The following table illustrates the structuring and coding of the actions, divided according to the types and categories described above.

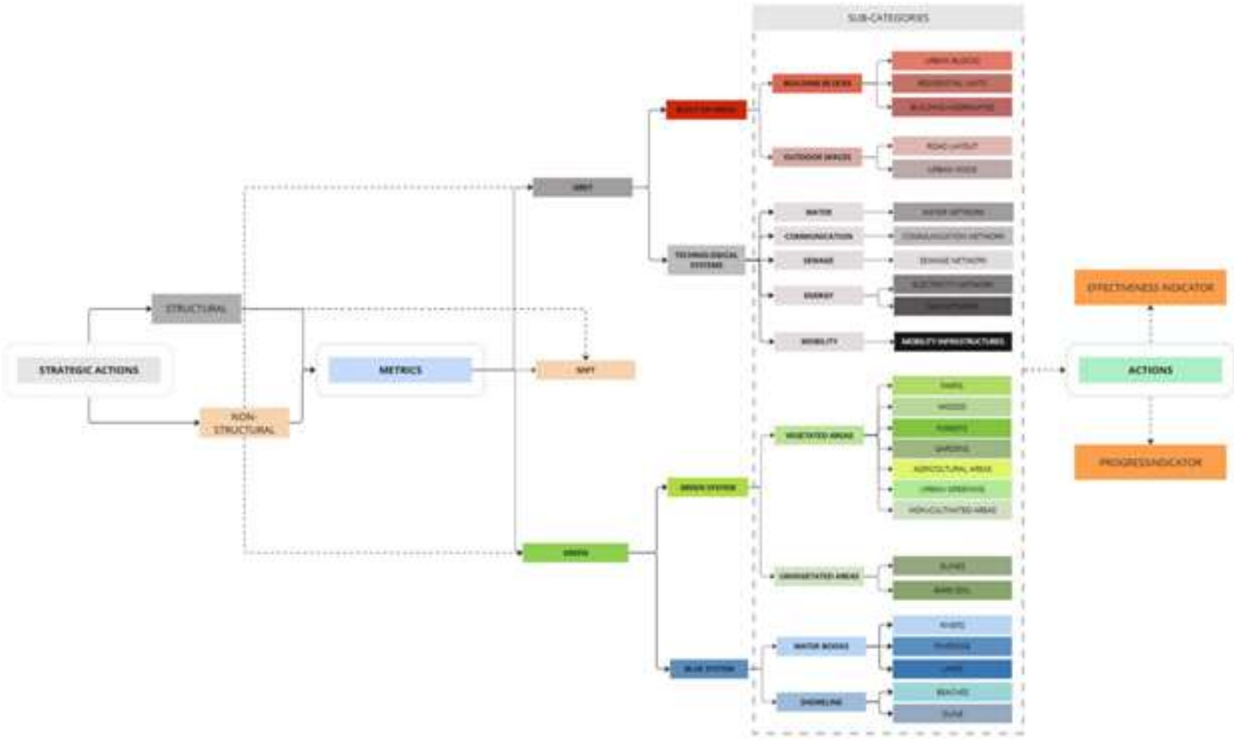

Figure 57. PNACC taxonomy. Elaboration by A. Citarella, A. Sferratore

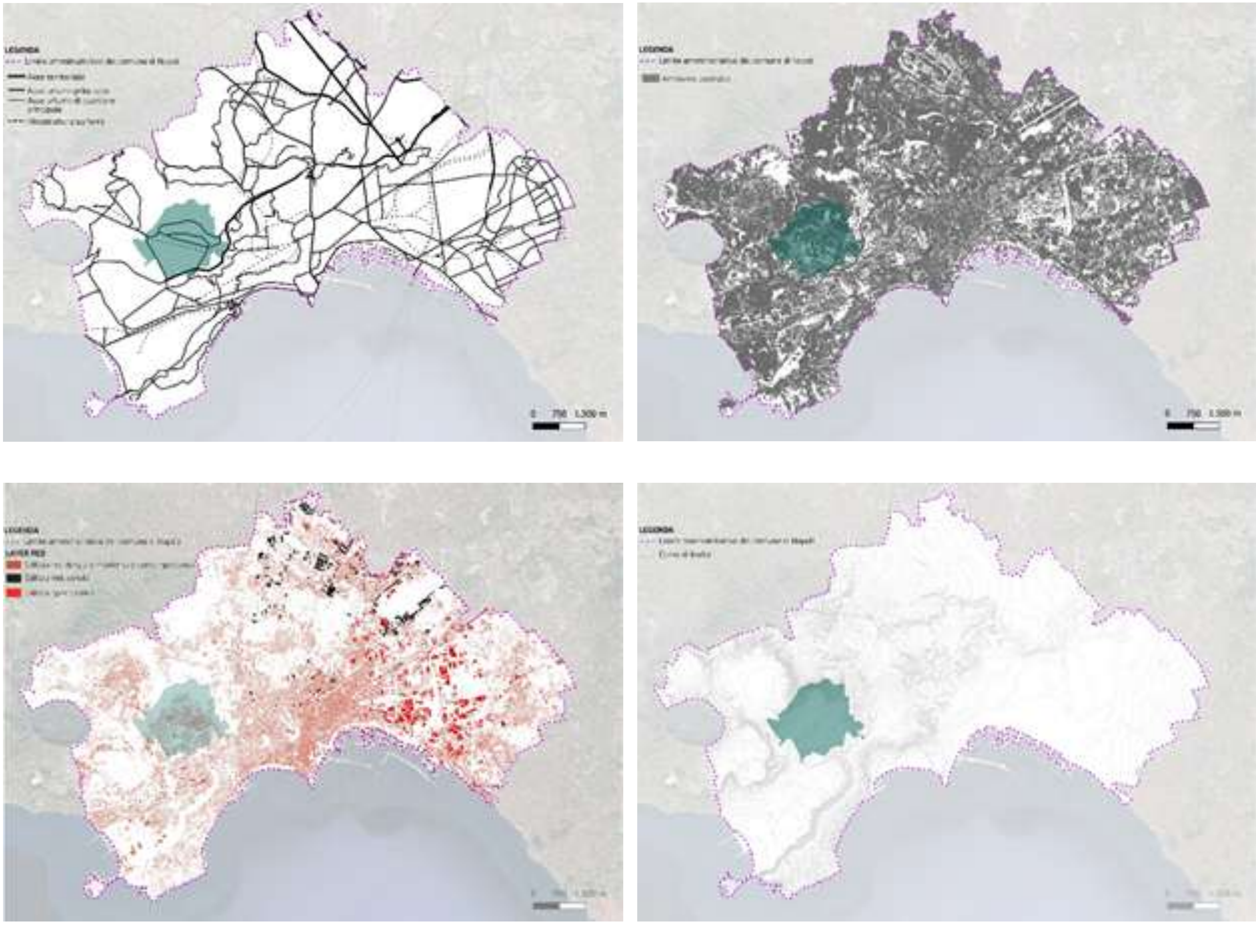

Figure 58. Grey sectoral areas - PNACC taxonomy. Elaboration by A. Citarella, 2024.

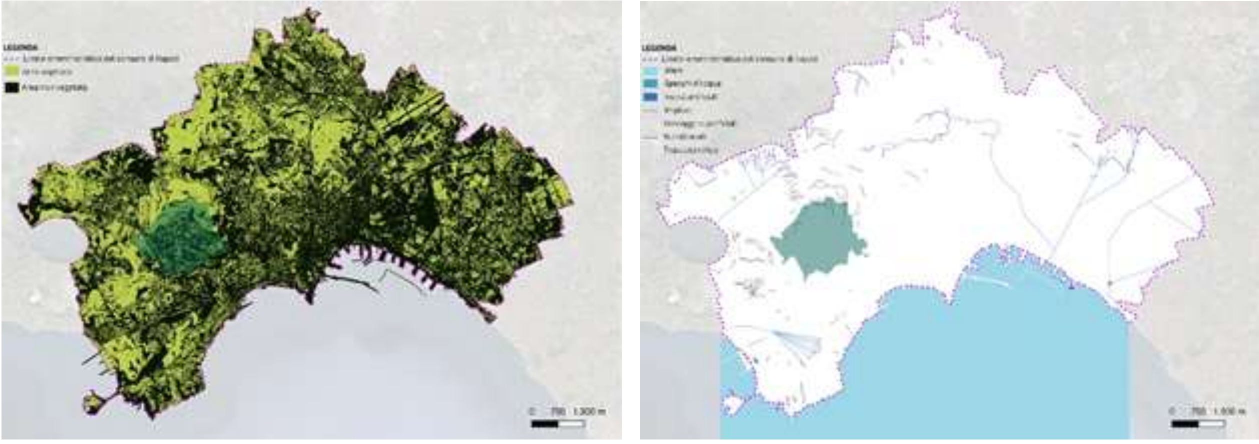

Figure 59. GREEN sectoral areas - PNACC taxonomy. Elaboration by A. Citarella, 2024.

Strategic actions for the green transition of the Soccavo urban district

The selection of the actions to be applied was made on the basis of analyses carried out at district level, favouring those most consistent with the environmental, social and infrastructural characteristics of the reference context, as well as according to the different climate scenarios and risks taken into consideration.

Each action is accompanied by a well-defined operational objective and a monitoring system that allows it to be evaluated in terms of effectiveness and progress, through measurable and verifiable indicators as shown in the table belows.

Table 5.6 Objectives, actions and indicators in accordance to PNACC and relative design actions for the application case of Soccavo. Elaboration by A.Citarella, 2024.

Objective	**Actions**	**Indicators**
Support ecosystem services-based solutions	Increased territorial connectivity – green infrastructure	Effectiveness: Absolute (m_2) and relative (%) increase in public green area Progress: surface area (ha) redeveloped as urban green
Reduce impacts through green infrastructure	Reforestation of urban area and creation of green spaces within cities	Effectiveness: Absolute (m_2) and relative (%) increase in public green area Progress: surface area (ha) redeveloped as urban green
Promote experimental adaptation interventions in peri-urban areas, suburbs, historic centers and public spaces (improvement of the efficiency of the water supply system)	Experimental interventions for the adaptation of public and private space	Effectiveness: Absolute (m_2) and relative (%) increase in public green area Progress: surface area (ha) redeveloped as urban green
Increasing resilience in the forest sector and the maintenance of ecosystem services by promoting sustainable forest planning and management	Planting and maintenance of agroforestry systems	Effectiveness: abosolute (ha) and relative (%) increase in the land coverend by the protected regiment (Natura 2000) Progress: number of interventions in the field of green infrastructure, territorial area (ha) falling under the protected areas regime (Natura 2000)

Increase or change the speed and volume of water runoff	Redevelopment of watercourses in consideration of the maintenance of vital flows and ecological quality in situations of changes in future thermos-pluviometric regimes	Effectiveness: improvement of the ecological status of the waters Progress: Surface area (ha or km_2) subjected to interventions
Preventing and mitigating the effects of extreme events with non-invasive interventions, mitigating environmental impacts and increasing the resilience of hazardous activities	Adaptation measures through non-invasive interventions on watercourses, also based on the principles of naturalistic engineering and sustainable land use practice, aimed at preventing and mitigating the effects of extreme events due to climate change	Effectiveness: improvement of the ecological status of the waters Progress: surface area (ha or km_2) subjected to interventions: mapping of flood/ flood forecasting and warning systems
Improving the efficiency of water infrastructure	Increased connectivity of water infrastructure Maintenance of the multi-function water network	Effectiveness: increased availability of water resources Progress: extension of interconnected networks; overall length of the network
Integrate climate change risks into planning and design towards resilience and adaptation	Evaluate possible revisions of planning and/or design criteria	Effectiveness: scaling up the adaptation relevant project Progress: number of programmes considering adaptation to climate change
	Evaluate synergy and co-benefits of sustainable mobility (mitigation and adaptation)	Effectiveness: decreased transport delays Progress: number of products recognized as typical in response to climate change
Promote and increase better managements of energy demand for heating and cooling	Adaptation of existing buildings	Effectiveness: decrease in the number of days the systems are open Progress: number of plants with low environmental impact techniques; number of structures and or km of support infrastructures and fire protections
Promote experimental adaptation interventions in peri-urban areas and public spaces (improvement of the efficiency of the water supply system; improvement of thermal comfort and quality of living)	Experimental interventions of adaptation at building scale	Effectiveness: reduction of the number of buildings in energy class F and G Progress: extension of municipalities, suburbs, historic centers involved in projects.

Once the urban context and its critical issues have been identified, it is possible to build a framework of strategic actions for climate adaptation. The strategies put in place in the district of Soccavo are identified to achieve the predefined goal of the eco-district.

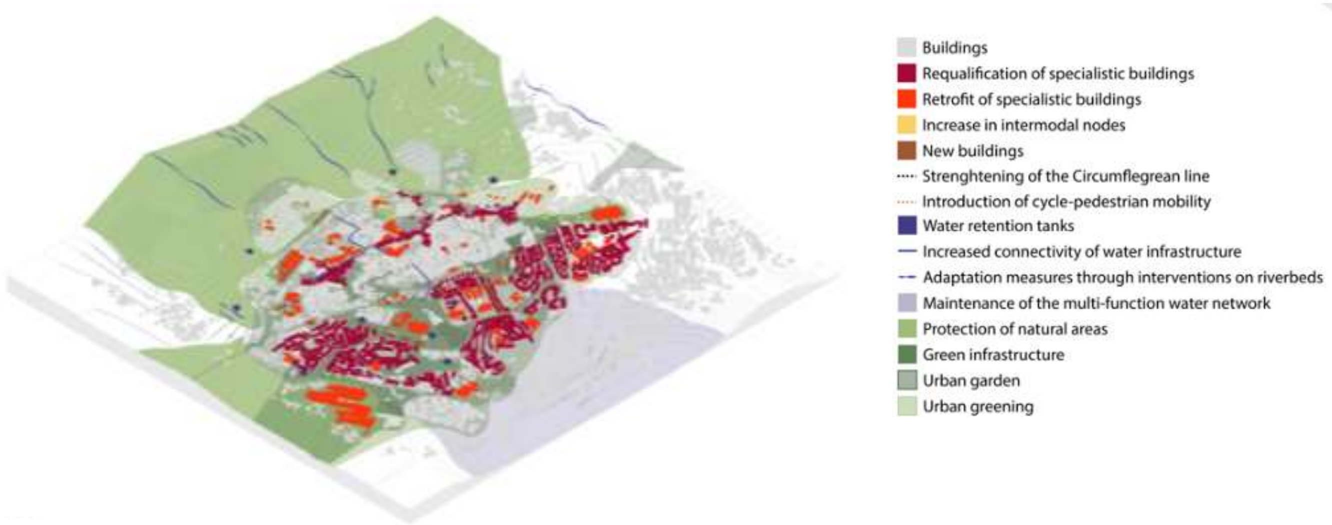

Figure 60. Framework of strategic actions for climate adaptation of the Soccavo urban district. Elaboration by A.Citarella's and G. Gagliano, 2025.

Performance indicators selection and evaluation

The list of indicators suggested for the evaluation of the progress and effectiveness of the adaptation actions of this NAPCC has been built starting from the indications of the same experts who selected the sectoral actions included in the database. The tables indicating the "Progress Indicators" and "Effectiveness Indicators" of the Database must be adapted to the territorial context.

In the tested experimental application on the district of Soccavo, once the actions have been identified, a predefined model is structured, in which each action corresponds to a set of specific indicators. These indicators are quantified through percentage values that determine their relative weight, thus contributing to an objective evaluation of the intervention.

This structure makes it possible to concretely measure the effectiveness of actions with respect to their ability to affect the territory.

The experimentation of the model makes it possible to verify its reliability and applicability, offering an operational tool useful for evaluation and decision-making support in climate adaptation processes. In this way, a functional cognitive framework is built, capable of orienting strategies based on the specific needs and vulnerabilities of the local context.

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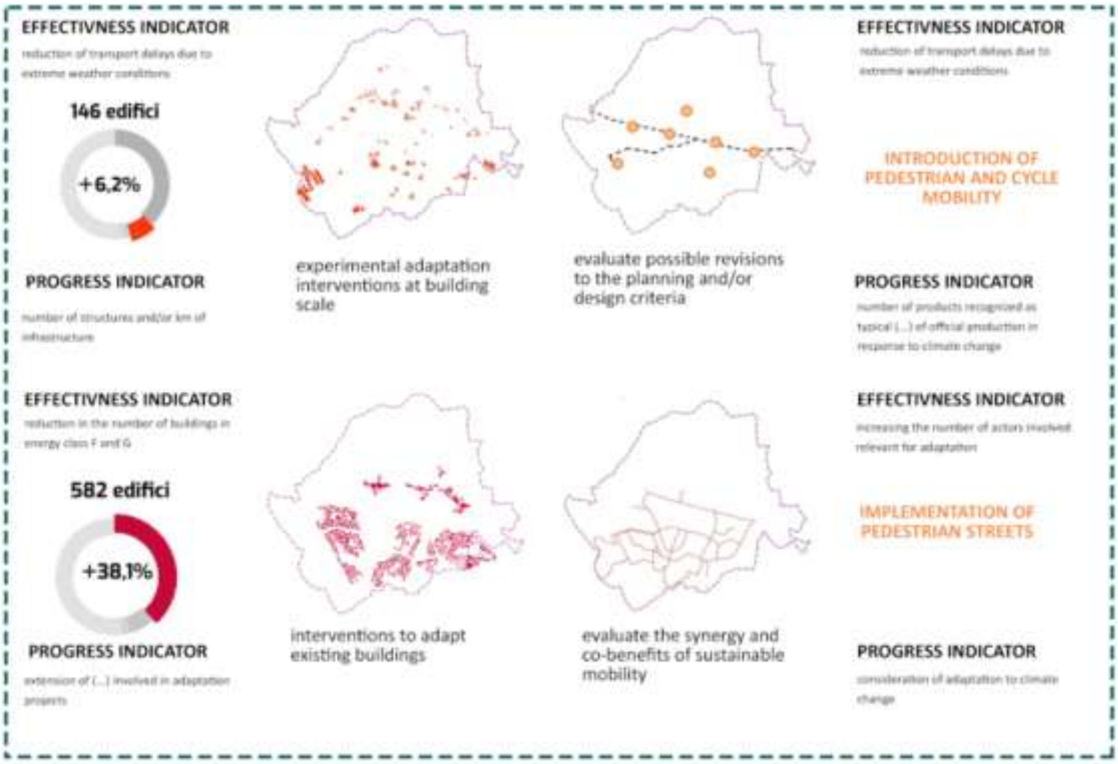

Figure 61. Grey actions monitoring indicators. Elaboration by A. Citarella.

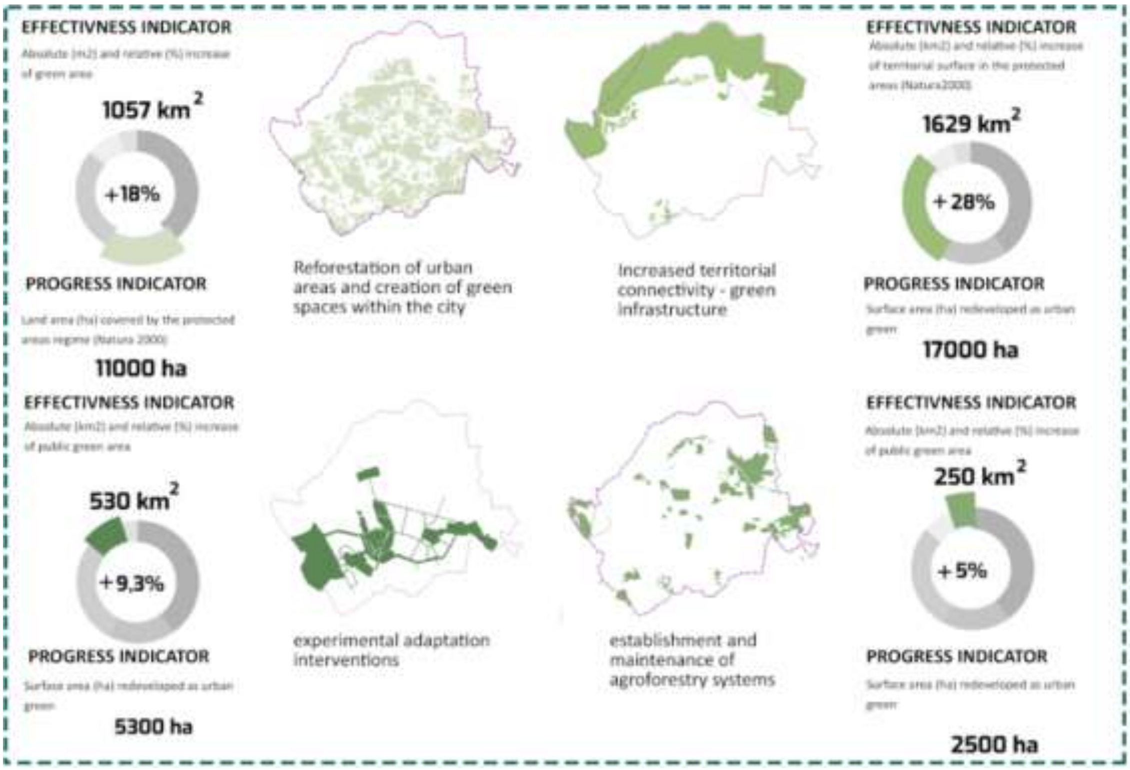

Figure 62. Green actions monitoring indicators. Elaboration by A. Citarella, 2024.

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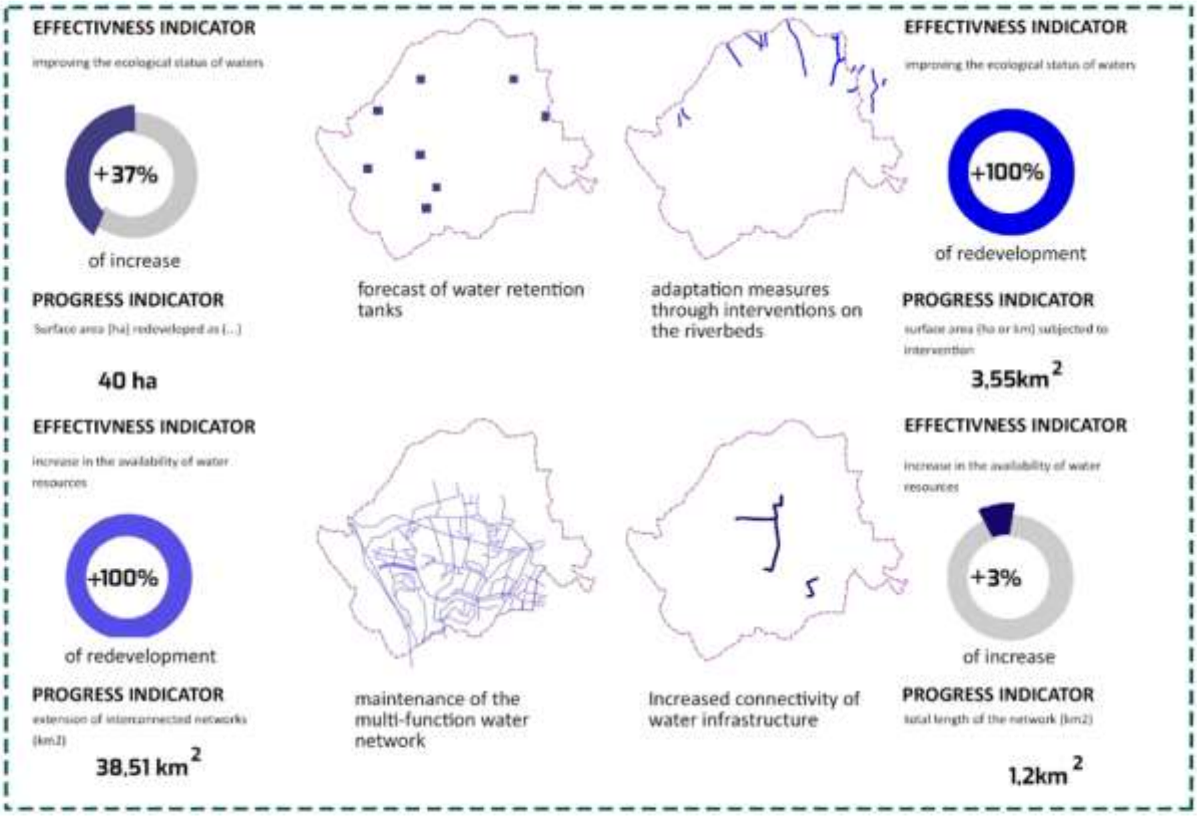


Figure 63. Green actions monitoring indicators. Elaboration by A. Citarella, 2024.

Results and conclusions
The application of the system of indicators made it possible to monitor the status of implementation of the project actions, providing a useful knowledge base for decisions. It was possible to:

- quantify the environmental effectiveness of the proposed actions,
- verify the consistency between strategic objectives and operational interventions,
- hypothesize scenarios of replicability in other metropolitan districts with similar characteristics.

The method developed therefore makes it possible to approach the green transition as a progressive, measurable and adaptable process, in which the district scale represents the optimal level to activate sustainable transformations.
The research, therefore, proposes an innovative methodological contribution for the green transition of urban contexts, integrating normative tools, territorial data and design processes. The proposed approach, based on a cyclical structure like that of the Proof of Concept, allows strategies to be tested and progressively redefined, fostering a process of continuous innovation.

5.3.2 Heatwave resilience of built-up areas: the case of Soccavo (Naples)

The climate emergency and rising global temperatures pose major challenges worldwide. As reported in recent IPCC reports, heatwaves, especially at the national level, are an increasing phenomenon in terms of intensity, frequency and duration, and the situation becomes more critical in cities with high urban density as a consequence of the heat island effect, with significant impacts on fragile populations and urban settlements themselves. It is therefore necessary to adopt innovative climate adaptation and mitigation strategies and actions to contribute to the design of resilient urban and metropolitan settlements.

In particular, the metropolitan city of Naples, presents a complex and articulated conformation of urban fabrics, which show different degrees of vulnerability with consequent different capacities to respond to climatic impacts. In the foothills of the western area of the city lies the district of Soccavo, whose responses to climatic impacts due to the constituent characteristics of its physical component have been studied through environmental analyses processed in a GIS environment by means of the util.

The proposed preliminary methodology is based on assessing the vulnerability of urban physical systems impacted by heatwaves. The indices and indicators proposed consider the open space subsystem and are derived from scientific literature (Macnee et al, 2016; Disher et al.,2021; D'Ambrosio et al., 2023).

Subsequently, we continue by superimposing the vulnerability maps, with the aim of identifying the hotspot areas from which it is then possible to develop adaptation, mitigation and impact reduction strategies and actions for integrated urban resilience.

Among the innovative solutions and actions that can be introduced for heatwave adaptation and mitigation, one effective measure is the climate shelter. Shelter was defined by the Oxford English Dictionary as “a structure affording protection from the weather or danger; a place of refuge or safety”, however, research considers shelter to be a complex element at the center of a socio-technical system that integrates environmental, economic, technical and socio-cultural components and becomes an integrated social ecological technological system. A multifunctional, inclusive, high-performance environmental place, capable of receiving the weak population in case of need and emergency, but also capable of performing ordinary functions and based on (IFRC, 2021):

- Climate protection;
- Security and personal protection;
- Survival against illness and disease;
- Support for the community;
- Self-sufficiency;
- Minimizing negative impacts on the environment and the local economy.

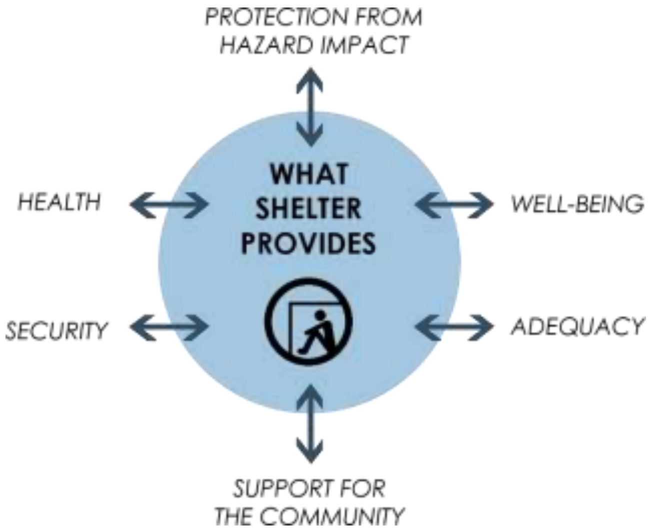


Figure 64. Shelter requirements. Elaboration starting from Sphere Handbook (2018)

Climate shelters, instead, are essential urban infrastructures to support adaptation to extreme weather conditions (Amorim-Maia et al., 2023), providing safe and temperate indoor and outdoor spaces, designed or adapted, in which residents can take refuge during episodes of extreme temperatures.

Prolonged exposure to high temperatures is associated with increased morbidity and mortality, especially among vulnerable populations such as the elderly, children and people with chronic diseases. Climate shelters offer an essential intervention to reduce heat exposure and prevent adverse health effects. These spaces not only provide immediate cooling, but can also serve as social centers and distribution points for resources such as drinking water.

In particular, climate shelters can be compared to critical urban infrastructures (Amorim-Maia et al., 2023), which are systems consisting of networks, installations and everyday spaces created by humans to provide essential services, protection, safety and comfort within urban and metropolitan settlements. They shape urban landscapes because, in order to ensure their distribution across the territory and accessibility by the population, an intervention in the city is required.

The design of climate shelters can take place through the development of a methodology that starts with the identification of public spaces (indoor/outdoor) that can fulfil the role of climate shelter. In particular, outdoor public spaces such as green areas and shaded open spaces, or for indoor can include public buildings such as libraries, community centers and schools where people can find shelter during heatwaves. The basic requirements for the realisation of a climate shelter through a multidisciplinary approach include:

- Accessibility of the site
- User comfort
- Indoor/outdoor thermal comfort
- Sustainability

Some public services and spaces could be equipped with air-conditioning systems or appropriate outdoor temperature mitigation solutions and constitute public refuges, through a change of timetables (extending them beyond the traditional closing time into the evening hours) and access rules. For example, schools and their related spaces, libraries, civic centres, playgrounds and urban parks. Some experiments in Barcelona, Paris, Madrid and in some US cities are already going in this direction, while they are almost totally absent in the Italian context. Another aspect to be considered is the improvement of mobility and pedestrian accessibility to these services, guaranteeing adequate thermal comfort along the route that allows people to reach the shelters from their homes via a pedestrian route of no more than 15 minutes. Urban contexts are often characterised by a predominance of impermeable surfaces without trees and shade, with summer temperature levels that may discourage frail persons from leaving their homes to reach shelters, unless located in close proximity.

Internationally, it has been identified that schools have great potential (Plazas et al., 2024) as climate shelters, for example, the Barcelona city council conducted an extensive action to select schools that had the right characteristics for the target set. In particular, guidelines were identified (Cartalis, 2020) for the conversion of schools into climate shelters through the implementation of solutions divided into three areas:

- Blue measures: related to the optimal use of water, such as the introduction of water parks/playgrounds or multifunctional fountains in schoolyards to improve the thermal comfort of users;
- Green measures: involve the adaptation of predominantly paved play areas by reintroducing tree-lined areas and green facades, thus restoring these spaces and creating shaded areas;
- Grey measures: mainly concern passive and bioclimatic solutions that improve the thermal sensation of playgrounds, play spaces and school buildings by incorporating shading elements (Plazas et al., 2024).

To the requirements and characteristics identified, a series of parameters and performance indicators can be associated that would allow the effectiveness of such an urban strategy to be verified. Indicators such as the indoor temperature that must remain below 26°C, the NDVI that must be greater than 0.4, or UTCI and PMV for verifying indoor and outdoor thermal comfort can be considered.

Requirements		Parameters	Performance indicators
Site accessibility	1	Free entrance	Yes/No
	2	Reachable in 15 min on foot	Yes/No
User well-being	3	Access to drinking water	Yes/No
	4	Access to toilets	Yes/No
Indoor/outdoor thermal comfort	5	Average indoor temperature	$T \leq 26°C$
	6	Overall comfort conditions	$0 \leq PMV \leq 1.5$
	7	Opaque envelope phase shift	$(14h \leq S \leq 10h)$
	8	External wall thermal transmittance	$U \leq 0,33\ W/m^2K$
	9	Vegetation index	$0,2 \leq NDVI \leq 0,4$
	10	Permeable surface	$> 0,4$ ha
Sustainability	11	Energy self-sufficiency from renewables	Yes/No

Figure 65. Requirements, parameters and performance indicator. Elaboration of Silvia Cimmino

From the study of the methodology 'PLANNER - Platform for the management of natural hazards in urbanised environments', POR 2014-2020 developed by the research group of the Department of Architecture of the University of Naples Federico II, in which the census sections are classified by building type by assessing resilience levels through the superimposition of vulnerability maps of urban subsystems and maps of hazard and impact scenarios, in order to select the most effective actions in reducing heat wave impacts. The choice of the optimal climate-proof action is made by selecting them from a database of climate-proof technical solutions for the built environment that guarantee the greatest reduction in the level of CO_2 emissions of buildings and increase indoor comfort, through a classification algorithm of census sections according to recurring building types (D'Ambrosio et al., 2023). The resilience effectiveness of the selected climate-proofing solutions is measured by generating a new impact scenario map, called climate resilience map.

Building on this methodological approach and the data collected, an initial testing phase of the design proposal at district scale of the climate shelter was carried out on the Soccavo district.

The experimentation focused on the definition of strategies and actions for adaptation and mitigation of the impacts due to the heatwave, starting from the identification of the most vulnerable areas and therefore priorities for intervention.

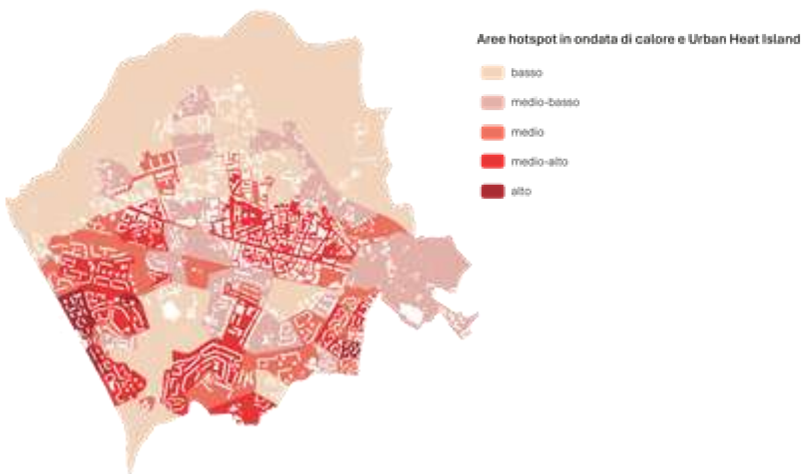
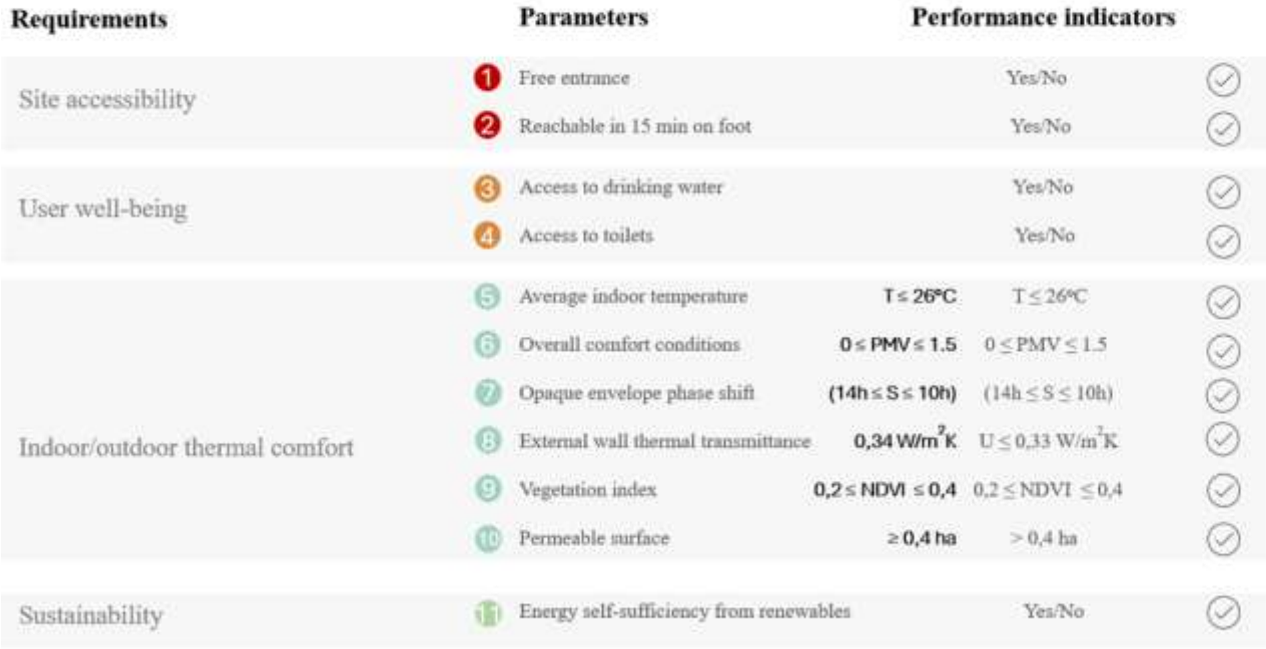


Figure 66. Individuation of heatwave hotspot area of Soccavo district. Elaboration of Silvia Cimmino

In particular, the test focused on a specific area, selected through the study of the most impacted hotspot areas related to the census sections defined by ISTAT 2011 data. Adaptation and mitigation strategies and actions have been defined in the area, verifying their effectiveness through indices and indicators calculated ex-ante and ex-post:



Requirements	Parameters		Performance indicators
Site accessibility	1 Free entrance		Yes/No
	2 Reachable in 15 min on foot		Yes/No
User well-being	3 Access to drinking water		Yes/No
	4 Access to toilets		Yes/No
Indoor/outdoor thermal comfort	5 Average indoor temperature	T ≤ 26°C	T ≤ 26°C
	6 Overall comfort conditions	0 ≤ PMV ≤ 1.5	0 ≤ PMV ≤ 1.5
	7 Opaque envelope phase shift	(14h ≤ S ≤ 10h)	(14h ≤ S ≤ 10h)
	8 External wall thermal transmittance	0,34 W/m²K	U ≤ 0,33 W/m²K
	9 Vegetation index	0,2 ≤ NDVI ≤ 0,4	0,2 ≤ NDVI ≤ 0,4
	10 Permeable surface	≥ 0,4 ha	> 0,4 ha
Sustainability	11 Energy self-sufficiency from renewables		Yes/No

Figure 67. Indicators values assessment. Elaboration of Silvia Cimmino

The systematization of solutions according to a progressive upgrade approach can allow the achievement of integrated urban resilience both at the building-block scale and of the entire district, acting first on short-term and easy-to-implement solutions such as the conversion of an existing building to a climate shelter, if then equipped with energy autonomy, such a refuge would allow that block to increase its capacity to cope with a climate event extreme. Extended reasoning for all blocks in the district would increase their long-term resilience.

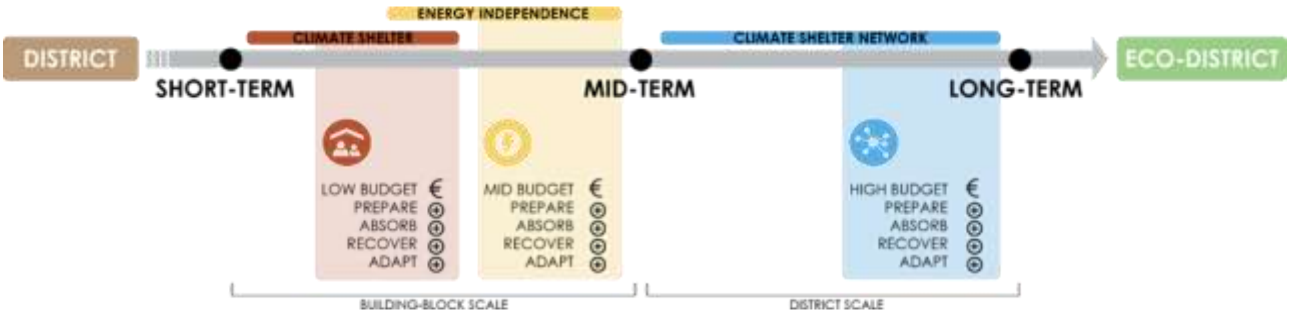


Figure 68. Progressive upgrade of strategies and solution for green transition of district into eco-district.

The proposed simplified GIS-based framework based on open-source data, can be used by decision-makers as a decision support tool to improve the climate-resilient design of urban outdoor spaces but need for further experimentation and integrations. In particular, as the workflow is preliminary work based on open-source data, it may not fully capture the complexity of heatwave impacts, particularly in urban areas with more complex variables, therefore a possible development is the verification of effectiveness, with respect to the time dimension of risk management (preparedness, absorption, recovery/response and adaptation). This proves to be an effective strategy for mitigating the effects of climate change in urban areas that can be applied in urban and metropolitan settlements subject to recurring heatwaves, thus also improving the living conditions of the population.

5.4 Design proposal at Building blocks scale

This section explores the role of active and passive design strategies in retrofitting the built environment as a critical step toward the green transition of urban eco-districts. Drawing on European and national regulatory frameworks – such as the Energy Performance of Buildings Directive (EPBD) and the National Recovery and Resilience Plan – the section focus on the synergistic application of passive bioclimatic solutions and active technological systems – such as photovoltaic installations and building management technologies - with the attention to the architectural, morphological and constructive characteristics of buildings.

5.4.1 Active and passive interventions for building retrofit

Urban settlements, characterized by high population density, presence of infrastructure, economic activities and artistic heritage, are at the heart of climate change challenges and play a key role in governance for the transition to climate neutrality. In fact, cities are responsible for 65 percent of energy consumption and 70 percent of CO2 emissions and with a population concentration of 75 percent, which continues to grow (UN Habitat, 2023). Precisely because of the potential for integration between different sectors of activity, cities are the main field in which to make interrelated strategies for environmental sustainability coexist, aimed at the decarbonization of energy, transport and, above all, buildings (European Commission, 2020).
Indeed, processes of transformation of the built environment and the construction sector continue to play a major role in the contemporary critical scenario. While the building sector contributes the most to the consumption of energy, raw materials and greenhouse gas emissions, at the same time, urbanized contexts are directly and indirectly affected by the climate crisis (Mussinelli, 2023).

Therefore, construction represents one of the areas where efforts need to be intensified. The lines of action in the construction sector turn out to be the basis of new development models for reducing pollutant emissions in order to limit the impacts generated by environmental, natural and anthropogenic risks on the environment, to improve the quality of life and the security of energy and food supplies. In this context, a key step is determined by the renovation of existing buildings and a new design approach for new buildings. It is well known that most of Italy's housing stock was built before the regulations on energy efficiency standards for the building sector came into force and currently pours in critical energy, bioclimatic and comfort conditions compared to current standards. Building retrofit, therefore, represents a unique challenge and opportunity for the implementation of practices aimed at achieving carbon neutrality and green economy goals.

European Union guidelines (Directives 2010/31/EU and 2012/27/EU) highlight the need to apply integrated modes of intervention aimed at rationalizing consumption, the appropriate use of energy produced from renewable energy sources, and the use of innovative technologies, components, and materials that guarantee high energy-environmental performance throughout the building's life cycle. The new Energy Performance of Building Directive (EPBD), approved by the European Parliament, introduces more stringent targets for new buildings and the renovation of existing ones, in line with the "Renovation Wave for Europe" strategies. In fact, the directive expands the calculation of energy consumption and climate-changing gas emissions to include not only the use phase of buildings but also the processes, materials and elements that comprise them throughout their life cycle, with the intention of defining a detailed strategy to improve overall performance by 2050 (Claudi and Thiebat, 2023).

At the national scale, it is pointed out from the National Recovery and Resilience Plan (NRP) that the ecological transition requires a significant reduction in climate-changing gas emissions, with a focus on improving energy efficiency and achieving energy savings in end uses in the entire construction sector. The need to apply integrated modes of intervention aimed at rationalization of consumption, appropriate use of energy produced from renewable energy sources, and use of innovative technologies, components and materials that ensure high energy-environmental performance is emphasized.

In this context, there is an increase in demand for near-zero energy buildings (NZEBs), which is leading to a conceptual transformation of buildings as they are no longer considered simple autonomous units that take and consume energy but are increasingly active elements of the energy network by producing, storing, and supplying energy (Moser and Maturi, 2022). The new transformative characters of the building stock are contributing to a more rapid application of active and passive design strategies and solutions in order to reduce energy losses that take advantage of building characteristics, promote the encouragement of the use of integrated plant systems to support energy supply from renewable sources, in order to achieve adequate comfort levels and minimize impacts. This requires a comprehensive assessment of the building-plant system, a multidisciplinary approach to design, and a selection of technical and architectural solutions that are synergistic and integrated. In this perspective, the application of active and passive strategies on existing and new buildings represents a dual axis, which is fundamental to the achievement of the set energy and climate goals.

To reduce energy needs without compromising housing conditions, it is not enough to focus solely on the transition to clean energy; for the purpose of decarbonizing cities and urban districts, it is essential to integrate not only energy-efficient active systems but also passive bioclimatic strategies into both new and existing architecture (Tucci, 2023). “Passive” design is a strategic approach that, depending on the climatic context of the project, adopts different strategies with the goal of minimizing the consumption of fossil fuels required for heating, cooling, and lighting a building. Passive building, in fact, refers to building bodies whose winter and summer comfort conditions are achieved through envelope characteristics and air conditioning systems that do not require the use of conventional energy sources. In this sense, the main passive strategies refer to microclimatic control and context, in order to take advantage of radiation and solar energy and promote natural ventilation, through the implementation of the building's intrinsic characteristics.

Knowledge and evaluation of climatic and environmental factors, type-morphological and technical-constructive characters are essential elements for the construction of low-energy buildings. Among microclimatic factors, it is necessary to know solar radiation, windiness, and temperature values in summer and winter regimes. With regard to environmental aspects, it is essential to analyze the orientation of the building in order to govern its thermal control. A correct orientation, in fact, turns out to be fundamental for the use of the fronts for the pre-disposition of solar devices, such as greenhouses or storage systems, and the capture of radiation in the fronts exposed to the south, and for the optimization of insulation and thermal inertia at the fronts most exposed to the north. The analysis of orientation, together with the correct arrangement of openings and interior spaces, also offers the possibility of exploiting natural ventilation for summer cooling and to improve the healthiness of spaces. With regard to the type-morological aspects, the geometry and shape of the building must be taken into account in order to optimize the energy performance of the envelope and significantly reduce its heat loss, consistent with the context in which it fits.
The technical-constructive aspects, on the other hand, are based on the choice of energy-efficient materials and solutions. In this sense, passive strategies have as their main process to transform the “skin” of the building that is presented as a sensitive and active interface, which is evolving through continuous design experiments into a fundamental element for sustainable and eco-efficient architecture (Tucci, 2018). The building envelope is increasingly a place for research and application of technical and design solutions, synthesizing many of the technological, performance, functional, and aesthetic challenges that characterize contemporary architectural design. There is a need to identify systems and technical solutions capable of ensuring different long-lasting uses, with the necessary flexibility, dynamism and adaptability to changing external interface conditions and internal demanding conditions, while maintaining an appropriate balance between the levels of insulation and thermal inertia of opaque closures. In fact, current experiments are focusing on curtain walls with adaptive features, capable of responding efficiently to dynamic and complex conditions throughout the entire life cycle of the building envelope. An envelope designed in this way can transform, improve and reduce inputs in terms of heat, acoustics and lighting, enabling greater capabilities to control and manage indoor comfort conditions.
However, the adoption of passive systems alone, with respect to the increasingly frequent extreme climatic conditions, does not fully meet the regulatory and performance requirements of current standards. Therefore, it is necessary to implement buildings with the application of active solutions involving the use and integration of advanced technological systems for power generation, reducing the building's energy requirements.

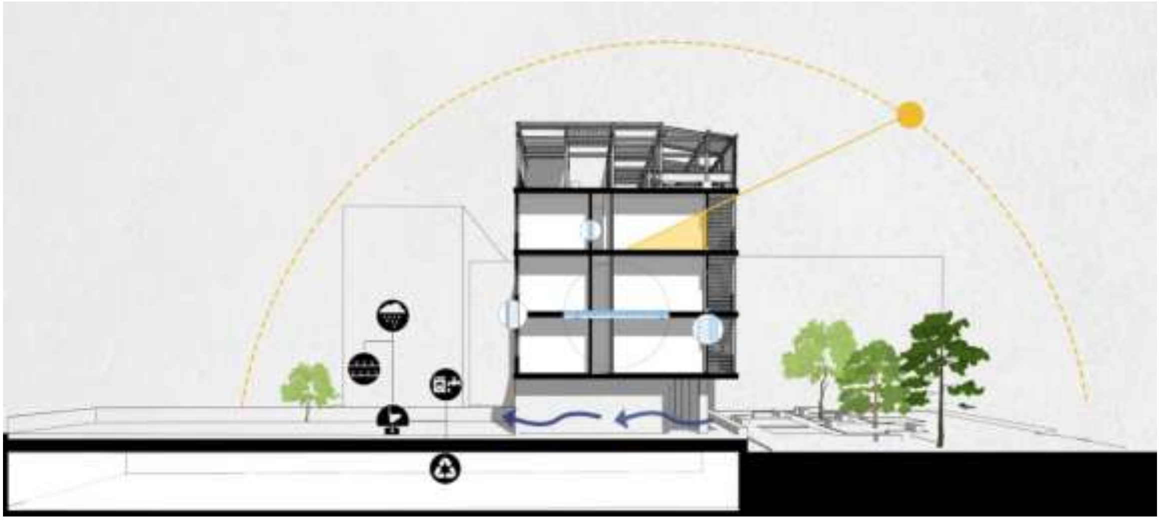


Figure 69. Bioclimatic section for the integration of active and passive strategies at building scale. Elaboration of Giaquinto, Giugliano, Franco, 2021

These include the use of high-efficiency systems, renewable energy production systems such as photovoltaic systems, solar panels, heat pumps and micro-wind, and monitoring technologies (Building Management Systems - BMS). In contrast to passive solutions, active ones can adapt to different climatic contexts and varying usage scenarios. Among these, the most popular solution is for power generation from photovoltaic systems, incentivizing the development of strategies aimed at on-site renewable energy generation to optimize energy demand. In this context, integrated photovoltaics, fully responds to innovative ways of interpreting renewable energy and sustainability and could be a more innovative and dynamic element in replacing fossil fuels with renewable sources (D'Ambrosio et al., 2021). Indeed, both new and existing buildings offer extensive surfaces on which photovoltaic systems can be integrated or applied based on design criteria that are also consistent with sustainability strategies.

In conclusion, an integrated approach that combines passive (to optimize the building's inherent efficiency) and active (to provide flexibility, control, and energy production) strategies is essential. It is well known that the exclusive use of one strategy over the other will not achieve the regulatory standards currently imposed. This synergy is essential to minimize the environmental impact determined by the construction sector while maximizing comfort and housing quality.

6 Conceptual guidelines towards resilient and regenerative urban settlements

6.1 Conceptual framework and reference scenario

According to Collins dictionary, guidelines are a standard or principle by which to make a judgment or determine a policy or course of action. Instead, a set of conceptual guidelines can be seen as an analytical tool for understanding key concepts and variables related to a specific topic and how they relate to each other. Through such general framework it is possible to elaborate appropriate recommendations, general rules or principle to handle specific conditions. Recommendations help the user of the guideline to make informed decisions on whether to undertake specific interventions and on where and when to do so, also supporting the user to select and prioritize across a range of potential interventions.

In the framework of urban integrated resilience, conceptual guidelines can provide a structured framework to support the transition resilient and regenerative of urban district into eco-district. According to WHO

Handbook for Guideline Development published by World Health Organization in 2014, it is crucial to consider what type of guideline will best fit the intended purpose, as this will determine the methods, resources and time frame for development, finalization and dissemination (WHO, 2014). The guidelines comprise a broad spectrum of products that vary mainly in terms of the following features:

- purpose;
- scope or key challenges;
- audience;
- organizations or entities developing the guideline;
- reference scale of the recommendations;
- timeline.

To identify key features, methods and standards for guideline development, five internationally recognized documents have been compared (Table 1) as related to guide national to local resilience actions and referred to different audience (from EU member states to local governments and professionals). Evidence from the review underlines the adoption of the following principles:

- the process of developing guidelines need to be multidisciplinary and include all relevant expertise and perspectives, including input from stakeholders;
- the processes and methods used in each step of guideline development aim to minimize the risk of bias in the recommendations;
- recommendations are based on a systematic and comprehensive assessment of the balance of a policy's or intervention's potential benefits and harms and explicit consideration of other relevant factors;
- the evidence used to develop the guidelines is publicly available;
- recommendations can be implemented in, and adapted to, local settings and contexts;
- guidelines should be tailored to a specific audience. In this case, the audiences may include urban planners, designers and policymakers, urban program managers, the general public and other stakeholders;
- the document should be structured in sections (introduction, key features and key steps for the elaboration/update of the plan) with sum-up and good practices/example, also supporting the main text with user-friendly boxes;
- the guidelines should contain explanatory workflows of drafting phases and associated activities, as well as specific indications or tools for monitoring the successful application of strategies and actions.

Tabella 6.1. A summary of the analyzed documents.

Document	Developer	Year of publication
Guidelines on members on member states adaptation strategies and plans	EC (European Commission)	2023
Definizione di linee guida nazionali per la verifica climatica nei programmi 2021-2027	DPC (Dipartimento di politiche per la coesione) + JASPERS (Joint Assistance to Support Projects in European Regions)	2023
Guidelines for Sustainable Reconstruciton and urban regeneration in the MENA region	UN-Habitat, Worl Green Building Council	2021
Local Governments pocket guide to resilience	UN-Habitat	2015
Guidelines for Resilience Systems Analysis	OECD	2014
National adaptation plans. Technical guidelines for the national adaptation plan processes	UN (United Nations)	2012

In compliance with such principles, the following sections articulate the guideline conceptual framework, reference scenario and structure as organized around key themes, sub-themes, and operational focus areas. Through such elements, a roadmap has been defined to transform urban districts into resilient and regenerative eco-districts. They outline the critical dimensions to be addressed — from governance and energy to biodiversity, mobility, and circular resource management — and offer a coherent framework for action that is both strategic and context-sensitive.

In order to provide a simplified and accessible tool to further support decision makers at the design stage, the DV has been implemented with an annex (Guidelines Handbook annex) in which the guidelines are presented in the form of an informative book, following the case studies analyzed in the literature and shown in Table 6.1. The annex addresses schematically the issues reported here and provides best-cases according to the principles of regeneration and resilience of urban settlements articulated in the previous sections.

6.2 Guideline's themes, sub-themes, focus areas

In order to effectively operationalize the transition toward resilient and regenerative eco-districts, a structured set of Guidelines themes, sub-themes, and focus areas has been defined. This framework functions as a comprehensive and flexible roadmap capable of guiding the planning, design, and management of complex urban transformations. At its core lies the overarching theme of the green transition, which encapsulates the fundamental shift towards sustainability, decarbonization, and ecological regeneration in urban contexts. Within this vision, two pivotal sub-themes emerge: urban resilience and regenerative processes. These elements offer both the conceptual foundations and the operational mechanisms necessary to articulate the objectives of the green transition at the local, district and territorial scale.

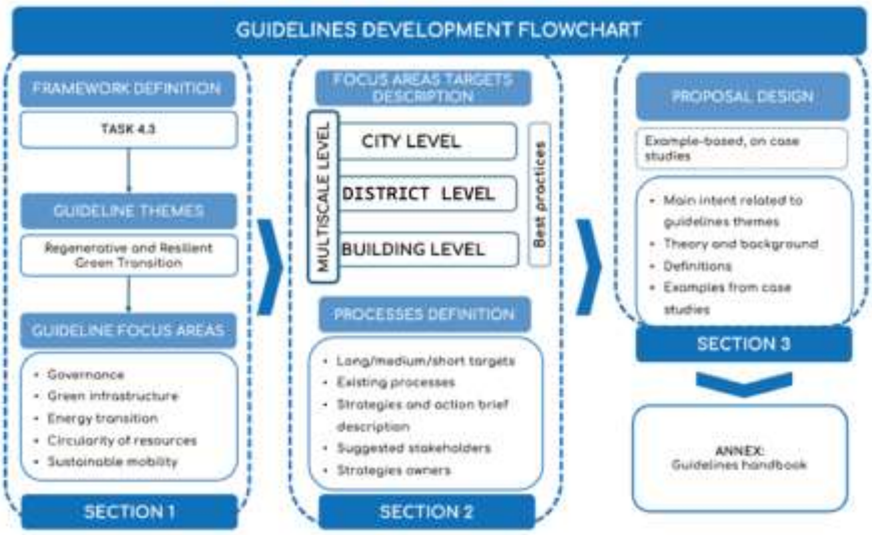


Figure 70. Concept guidelines flowchart.

In this framework, urban resilience is not limited to the capacity to resist or absorb shocks. It expands to encompass adaptability and transformation — the ability of a district to evolve in response to stressors while maintaining its essential functions and enhancing its internal coherence. As stated in paragraph 2.3.3, resilience becomes an organizing principle for designing systems that are both robust and flexible, capable of dealing with uncertainty and complex risks such as climate change, economic volatility, or social fragmentation. In parallel, regenerative processes move beyond the goal of minimizing damage, aiming instead to restore, replenish, and enhance the urban ecosystem. They prioritize the recovery of degraded environmental assets, the reinvigoration of social capital, and the emergence of local economies based on ecological and human-centered value.

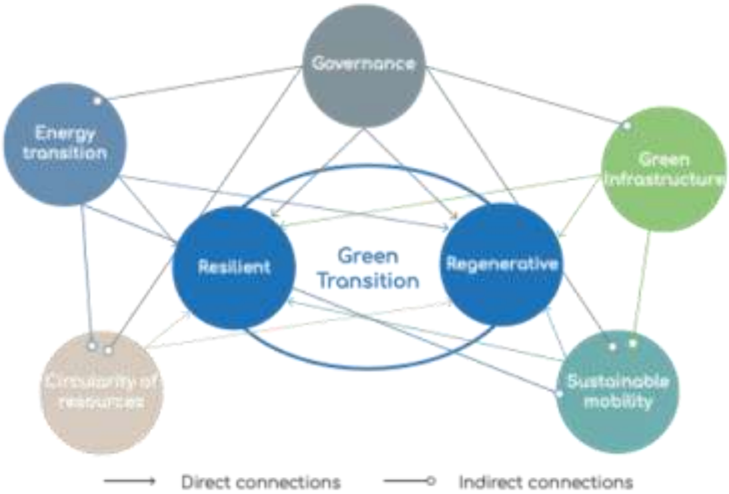


Figure 71. Themes, sub-themes and focus areas.

To translate these principles into action, the contents have been articulated through a series of strategic focus areas, each addressing a critical domain of urban transformation while remaining tightly interconnected with the others in a systemic approach.

The first focus area concerns governance, which provides the institutional and procedural foundation for implementing the green transition. Governance in eco-districts must be capable of integrating the perspectives and contributions of a wide array of actors — including local institutions, private stakeholders, grassroots organizations, and residents — through participatory planning, transparent decision-making, and multi-level coordination. Such governance frameworks create the conditions for shared ownership of the transition process and foster long-term accountability and legitimacy.

The second focus area regards green infrastructure, which functions as the ecological backbone of the urban environment. It must be understood as an integrated network of ecosystems that deliver a wide range of services: climate regulation, air purification, water retention and filtration, biodiversity corridors, and social amenities. In eco-districts, the design of green infrastructure should follow multifunctional and cross-scalar logic, ensure ecological connectivity and enhance both environmental and human health.

The third focus area concerns the energy transition, which is both a technical imperative and a driver of urban regeneration. Within eco-districts, this transition must materialize through the diffusion of energy-efficient buildings, the widespread use of renewable energy sources, and the creation of decentralized, intelligent energy networks. Beyond technological aspects, the energy transition also requires cultural and behavioral changes, promoting collective energy production and consumption models that reinforce local resilience and social equity.

The fourth focus area addresses circular resource management, a paradigm that challenges the traditional linear model of resource extraction, use, and disposal. Within eco-districts, the circular economy must permeate all stages of the urban life cycle, from the design of buildings and infrastructure to their everyday operation and eventual reuse. This implies rethinking material flows, fostering the use of sustainable and recyclable construction materials, implementing closed-loop water systems including rainwater harvesting and greywater reuse, and promoting waste prevention and local valorization of organic matter.

The final focus area refers to sustainable mobility, which plays a decisive role in shaping urban accessibility, reducing environmental footprints, and enhancing spatial equity. This involves promoting active mobility through safe and attractive pedestrian and cycling infrastructure, ensuring access to efficient and low-emission public transport, and supporting shared mobility solutions that respond to diverse user needs. Sustainable mobility is not only about reducing emissions; it is also about creating urban spaces that are more livable, inclusive, and connected, where the quality of everyday movement contributes to social cohesion and environmental awareness.

Taken together, these five focus areas provide a holistic and actionable framework for advancing the green transition in eco-districts. They embody the interdependence of ecological, social, and technological dimensions, and enable the implementation of structured strategies.

6.3 Focus areas targets description

6.3.1 Urban and metropolitan level

In relation to the overall profile of urban and metropolitan settlements (henceforth referred to as “U&MSs”), the identification of the Conceptual guidelines toward resilient and regenerative urban settlements in this chapter (henceforth referred to as “CGLs”) is based on the recognition of the conceptual category of green infrastructure (henceforth referred to as “GIs”) as spatial systems that generate a permanent and long-lasting, hence sustainable, supply of ecosystem services. GIs form the basis for resilient and regenerative metropolitan and urban settlements. It is worth recalling here the general definition of GI proposed in the Subsection 5.2 Design proposal at Territorial/urban scale, Paragraph 5.2.1 Urban green infrastructure, ecosystem services supply and ecological corridors: the FUA of Cagliari: “[A] strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings” [1, p. 3], and, “The work done over the last 25 years to establish and consolidate the network means that the backbone of the EU’s GI is already in place. It is a reservoir of biodiversity that can be drawn upon to repopulate and revitalize degraded environments and catalyze the development of GI. This will also help reduce the fragmentation of the ecosystems, improving the connectivity between sites in the Natura 2000 network and thus achieving the objectives of Article 10 of the Habitats Directive” (European Commission, 2013, p. 7). Hence, the proposed definition for urban GI, which implements that of the European Commission, given above, as follows: “[A] network composed of natural and semi-natural elements designed with the aim of increasing its ESs supply, in which green spaces, open spaces and water bodies are recognized and included. These elements are located in built-up areas and also in correspondence with non-permeable soils, thus completely artificial.”
These CGLs identify some spatial planning processes geared toward the production of resilient and regenerative urban settlements based on the taxonomy of GIs developed in the Deliverable 5.2.1 Risk-Oriented Taxonomy and Ontology of Urban Subsystems and Functional Models, produced as part of the Spoke 5 “TS1 - Urban and metropolitan settlements” di RETURN, WP 5.2 “Multi-risk-oriented modeling of urban systems,” Task 5.2.1 “Holistic understanding and dynamic modeling of urban and metropolitan systems.” In Table 10 of this Deliverable, GIs are classified according to the extract given in Table 6.2, where the first column shows the categories of GIs and the second column the design elements that constitute them.

Table 6.2 Green infrastructure taxonomy as per Table 10, Deliverable 5.2.1

Green infrastructure category	Design elements of GIs
Green Buildings	Balcony green
	Green ground
	Green vertical structure
	Green roof
	Green pavement
	Green Noise barriers
	Rain barrel
	Perforated pipe
	Permeable pavement
Green-Grey Area *Urban green areas connected to grey infrastructure*	Ecological corridor
	School ground
	Green street
	Railroad bank
	Green playground/school ground
	Green parking
	Riverbank greens
Urban and Peri-urban Agricultural Land	Agri sites
	Allotment
	Community allotment
	Grassland
	Arable land
Urban Green Area	Park
	Green sports area
	Urban garden
	Urban forest
Natural or Semi-Natural Green Area	Wastelands
	Bare soil
	Shoreline
	Dune system

The policy implications presented and discussed in Subsection 3.2.4 of Section 3.3 Strategic Environmental Assessment and climate change adaptation are associated to the taxonomy reported in Table 6.2, leading to the identification, in important illustrative terms, of three CGLs-oriented spatial planning processes for the production of resilient and regenerative urban settlements: *afforestation, de-sealing and greening*.

The CGLs are identified with the contents of the sheet given in Table 6.3 "Guidelines sheet," which are analytically discussed below.

Table 6.3 Guidelines sheet

TITLE			
Xxx			
PROCESS DEFINITION			
SCALE			
□ Metropolitan/Urban level	□ Neighborhood level	□ Building block level	□ Other
HAZARD CONSIDERED			
• Xxx			
BENEFITS AND CO-BENEFITS			
Benefits: • Xxx		Co-benefits: • Xxx	
INTEGRATION WITH OTHER CLIMATE PROOF SOLUTIONS			
• Xxx			
BRIEF DESCRIPTION			

Objectives Xxx *Scale* Xxx *Benefits / co-benefits* Xxx
STAKEHOLDERS
Xxx
GUIDELINES
DESIGN IMPLEMENTATION
Environmental considerations Xxx *Technical considerations* Xxx
REFERENCES
1. Xxx
BEST PRACTICES
Best practice 1 *Project* Xxx *Location* Xxx *Description* Xxx *Source* Xxx
Best practice 2 XXXXX
RESEARCH UNIT AND AUTHOR/S

Title: one of the spatial planning processes for the production of resilient and regenerative urban settlements: *afforestation, de-sealing and greening*.

Scale: this item refers to the scale at which the spatial planning process can be applied, including the metropolitan/urban, neighborhood or building-block contexts.

Hazard considered: this item refers to the List of hazards by "Hazard Information Profiles: Supplement to UNDRR-ISC Hazard Definition & Classification Review - Technical Report", available at https://www.undrr.org/media/73913/download?startDownload=20241030.

Benefits and co-benefits: this item refers to multiple ways the spatial planning processes can deliver social, economic, and environmental benefits and co-benefits. Co-benefits are those benefits that are considered least relevant. Examples of benefits and co-benefits may include human health improvement, cultural enhancement, biodiversity protection and increase, flooding risk reduction, heat stress reduction and so on.

Integration with other CGLs-oriented spatial planning processes for the production of resilient and regenerative urban settlements: this item refers to spatial planning processes related to the categories of climate-proof solutions reported in the taxonomy developed in Deliverable 5.2.1 Risk-Oriented Taxonomy and Ontology of Urban Subsystems and Functional Models.

Brief description: this item refers to the description of the following elements: i. goals; ii. scale; iii. benefits and co-benefits.

Stakeholders: this item refers to the description of stakeholders involved in the process and measures that can be implemented to foster these policies.

Design implementation: this item refers to factors to be considered when determining the suitability of the CGLs-oriented spatial planning processes for the production of resilient and regenerative urban settlements to a specific location within or near a metropolitan or urban context. The relevant considerations for assessing the feasibility and implementation of such processes are categorized into the following: environmental (location, climate, hydrology, soil characteristics, etc.) factors, and technical (synergies with grey infrastructures, preferred land use, the size of the required area, etc.) factors.

References: this item refers to the list of a few essential references related to the section "Brief description".

Best practices: this item refers to the description and discussion of a few relevant examples from already-implemented projects which build on CGLs-oriented spatial planning processes for the production of resilient and regenerative urban settlements. For each of the targeted projects, this item should include: title, location and implementation period, synthetic description, sources and websites where gathering detailed information, and a few images.

6.3.1.1 Processes definition

Afforestation

According to the definition provided by FAO (2016, p. 2) "Urban forests can be defined as networks or systems comprising all woodlands, groups of trees, and individual trees located in urban and peri-urban areas; they include, therefore, forests, street trees, trees in parks and gardens, and trees in derelict corners".
In relation to the Taxonomy developed within the Deliverable 2.1, afforestation concerns Green Infrastructure, and in particular, urban green areas. Moreover, afforestation can be applied to different scales from metropolitan area to neighboring scale. As a consequence, afforestation has positive effects in relation to various hazards, such as heatwaves, flooding, landslide, and air and soil pollution. The main benefits concern flood risk reduction, heat stress risk reduction and human health, carbon storage and sequestration and improve biodiversity. For example, forests are effective in retaining stormwater, thereby decreasing the rapid runoff that flows over streets and public spaces and overwhelms sewer systems, which helps minimize structural

damage to properties and infrastructure (Salbitano et al. 2016). Moreover, trees mitigate heat in urban areas. Indeed, forested areas decrease solar radiation by offering shade and lowering air temperatures through evapotranspiration (EPA n.d.). In relation to human health, urban forests provide numerous physical, emotional, and mental health benefits to local communities in various ways, such as enhancing immune responses (Kuo 2015), improving focus and attention (Kaplan 1995), and speeding up recovery from illnesses (Ulrich et al. 1991). In relation to carbon storage and sequestration, urban forests store and sequester carbon in both vegetation and soil, contributing to climate change mitigation. The amount of carbon stored per hectare varies significantly due to factors such as climate, soil conditions, and forest management practices (World Bank, 2021). In addition, forests and woodlands support a diverse array of terrestrial and aquatic biodiversity (World Bank, 2021). Afforestation provides several co-benefits, such as tourism and recreation and resource production. Afforestation policies should be conducted by metropolitan and regional administrations though incentives for farmers.

A more detailed description of afforestation can be found in section 6.3.2.1 where the different characteristics are explained through textual and figurative parts within a sheet.

De-sealing

De-sealing interventions involve the removal or replacement of impermeable surfaces such as asphalt, concrete, and compacted soils with permeable materials, vegetated areas, or natural substrates. This process aims to restore soil permeability and improve the environmental quality of both urban and non-urban areas. In urban contexts, de-sealing reduces surface runoff, enhances stormwater infiltration, and mitigates the urban heat island effect by promoting evapotranspiration and increasing vegetative cover. In non-urban and peri-urban settings, de-sealing contributes to restoring natural hydrological functions, supporting biodiversity, and improving ecosystem services such as water retention, soil health, and carbon storage.

From a climate change perspective, de-sealing is a key nature-based solution that supports both mitigation and adaptation strategies. Mitigation is achieved through increased carbon sequestration in soils and vegetation, reduced energy consumption for cooling due to urban greening, and improved air quality. Adaptation benefits include reduced flood risk during extreme precipitation events, enhanced resilience to droughts, and increased capacity to buffer the effects of temperature extremes. Additionally, de-sealing improves groundwater recharge and reduces the transport of pollutants into surface waters, thus contributing to better water quality.

Effective de-sealing requires careful planning and context-specific approaches. Urban interventions may include transforming paved plazas, streets, or parking lots into green corridors, bioswales, or permeable pavements. In agricultural or natural areas, it may involve the removal of obsolete infrastructure or compacted surfaces, allowing for natural vegetation to recover. Stakeholder involvement, regulatory support, and integration with urban and regional planning are essential to ensure long-term success. Monitoring and evaluation frameworks should accompany implementation to measure hydrological, ecological, and social impacts. Ultimately, de-sealing contributes to building more resilient, healthy, and liveable environments in the face of accelerating climate change.

A more detailed description of afforestation can be found in section 6.3.2.1 where the different characteristics are explained through textual and figurative parts within a sheet.

Greening

Preserving, expanding, and enhancing greenery interventions is a fundamental component of environmentally responsible urban planning. Natural elements like vegetated zones of varying sizes, permeable surfaces, and interconnected green pathways play a crucial role in helping urban environments respond to climate-related challenges. These green features contribute to temperature regulation, cleaner air, increased shade, and mitigation of the urban heat island phenomenon. Additionally, permeable, non-paved surfaces can absorb rainfall, slow down stormwater flow, reduce the volume directed into drainage networks, and limit both stormwater runoff and wastewater discharge, thus supporting flood control strategies in cities.

Open green spaces differ widely in size and ownership status, encompassing both publicly accessible parks and privately held plots, from small community green patches to expansive metropolitan parks linked to broader ecosystems. Due to these differences, such areas offer diverse ecological and social benefits. Green corridors, linear stretches of plant life such as trees, shrubs, or grasses, typically serve to interconnect green zones throughout the city, forming an integrated web of natural infrastructure within the urban fabric. Green corridors serve to connect urban green areas, conserve wildlife habitats, and often encompass critical urban environments for key animal species. These linear green features facilitate the movement, survival, and reproduction of living organisms within the city. In urban areas where natural spaces are scattered and poorly connected, due to the lack or inadequacy of such corridors, the landscape loses much of its ability to manage flood risks through natural water absorption and slowing of runoff.

In many urban settings, impermeable surfaces like concrete and asphalt greatly outnumber permeable, biologically active zones that can absorb, retain, and cycle water. This imbalance overwhelms stormwater systems and sewers, which are often not equipped to handle the rising volume of precipitation. The resulting strain can lead to destructive urban flooding and contamination of rivers and waterways. To address this, cities can invest in developing additional green corridors and integrate them into a larger network of urban green infrastructure. This approach helps to alleviate pressure on drainage systems and provides a sustainable means of protecting cities from water-related hazards and pollution. As recognition of the ecological and urban value of green corridors increases, many cities are actively working to create networks of linked green areas. These efforts include both expansive projects and localized improvements within neighbourhoods and individual buildings. Riparian zones, green spaces alongside rivers and streams, are particularly prominent in many urban environments. They play a critical role in enabling species to move across landscapes, especially in response to climate shifts, and offer cooler microenvironments that help buffer the effects of rising temperatures. At a smaller scale, cities are introducing features such as vegetated streets, tree-lined boulevards, and urban gardens. These elements act as miniature corridors or ecological "stepping stones," enhancing biodiversity and supporting essential ecosystem functions within densely built areas.

A more detailed description of greening can be found in section 6.3.1.2 where the different characteristics are explained through textual and figurative parts within a sheet.

6.3.1.2 Guidelines

Afforestation

The implementation of urban afforestation policies requires certain environmental and technical precautions. First of all, from the environmental viewpoint, new urban forests can be established worldwide (FAO, 2021). However, in arid regions, afforestation efforts require particular care to avoid depleting water tables and decreasing soil recharge rates, especially in dry seasons. Newly planted trees thrive in substrates with high mineral and structural quality. Key factors include soil type and composition, depth, acidity, and level of compaction. Sandy and loamy soils are generally better suited for new forests, as they provide excellent infiltration and soil aeration. In contrast, soils high in clay content or heavily compacted are less conducive to supporting new root growth (Kadam et al., 2020). On the other hand, from the technical viewpoint, the preparation for urban forest sites may include weed control, soil cultivation, fertilization, and improvements to soil structure (Le et al., 2012). In areas with minimal vegetation, fast-growing nurse crops may be planted first to support subsequent growth of preferred species (FAO, 2021). Suitable locations for urban forests are degraded natural areas, alluvial zones near water bodies, eroding slopes, non-productive agricultural land, and former industrial plantations (FAO, 2021). Planting on degraded sites requires robust, well-watered nursery plants, especially near urban infrastructure, where specific planning factors—such as tree size, pruning, and root management—must be considered. Urban afforestation is a policy that is implemented in several countries. A best practice is represented by the Project "Freetown the Tree Town Campaign, 2020–23" in Freetown, Sierra Leone, where the City Council launched a campaign to plant one million trees by 2020.

A more detailed description of afforestation can be found in Table 6.4 where the different characteristics are explained through textual and figurative parts within a sheet.

Table 6.4 Design proposal sheet related to afforestation

<table>
<tr><td colspan="4">TITLE</td></tr>
<tr><td colspan="4">Afforestation</td></tr>
<tr><td colspan="4">PROCESS DEFINITION</td></tr>
<tr><td colspan="4">SCALE</td></tr>
<tr><td>☑ Metropolitan level/Urban level</td><td>Neighborhood level</td><td>☐ Building block level</td><td>☐ Other</td></tr>
<tr><td colspan="4">HAZARD CONSIDERED</td></tr>
<tr><td colspan="4">• Heatwave
• Surface water flooding
• Rock slide and mud flow
• Polluted air</td></tr>
<tr><td colspan="4">BENEFITS AND CO-BENEFITS</td></tr>
<tr><td colspan="2">Benefits:
• Flood risk reduction
• Heat stress risk reduction
• Human health
• Carbon storage and sequestration
• Biodiversity</td><td colspan="2">Co-benefits:
• Tourism and recreation
• Resource production</td></tr>
<tr><td colspan="4">INTEGRATION WITH OTHER CLIMATE PROOF SOLUTIONS</td></tr>
<tr><td colspan="4">• Park
• Street trees
• Urban garden</td></tr>
<tr><td colspan="4">BRIEF DESCRIPTION</td></tr>
<tr><td colspan="4"><u>Objectives</u>
According to the definition provided by FAO (2016, p. 2) “Urban forests can be defined as networks or systems comprising all woodlands, groups of trees, and individual trees located in urban and peri-urban areas; they include, therefore, forests, street trees, trees in parks and gardens, and trees in derelict corners”.
<u>Scale</u>
Urban forest can be applied to different scale from metropolitan area to neighboring scale.
<u>Benefits / co-benefits</u>
Flood risk reduction: Forests are effective in retaining stormwater, thereby decreasing the rapid runoff that flows over streets and public spaces and overwhelms sewer systems, which helps minimize structural damage to properties and infrastructure (Salbitano et al. 2016).
Heat stress risk reduction: Trees mitigate heat in urban areas. Indeed, forested areas decrease solar radiation by offering shade and lowering air temperatures through evapotranspiration (EPA n.d.).</td></tr>
</table>

Human health: Urban forests provide numerous physical, emotional, and mental health benefits to local communities in various ways, such as enhancing immune responses (Kuo 2015), improving focus and attention (Kaplan 1995), and speeding up recovery from illnesses (Ulrich et al. 1991).

Carbon storage and sequestration: Urban forests store and sequester carbon in both vegetation and soil, contributing to climate change mitigation. The amount of carbon stored per hectare varies significantly due to factors such as climate, soil conditions, and forest management practices (World Bank, 2021).

Biodiversity: Forests and woodlands support a diverse array of terrestrial and aquatic biodiversity (World Bank, 2021).

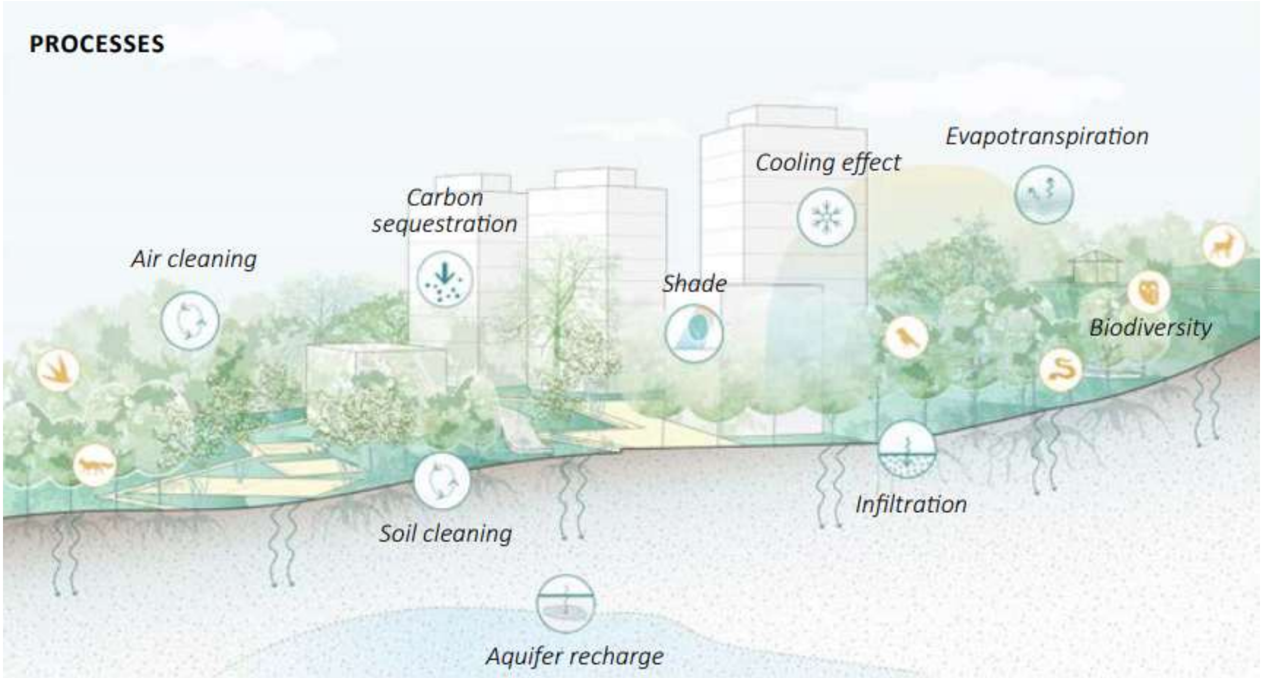


Figure 72 - Main processes supported by urban forests (World Bank, 2021, p. 43).

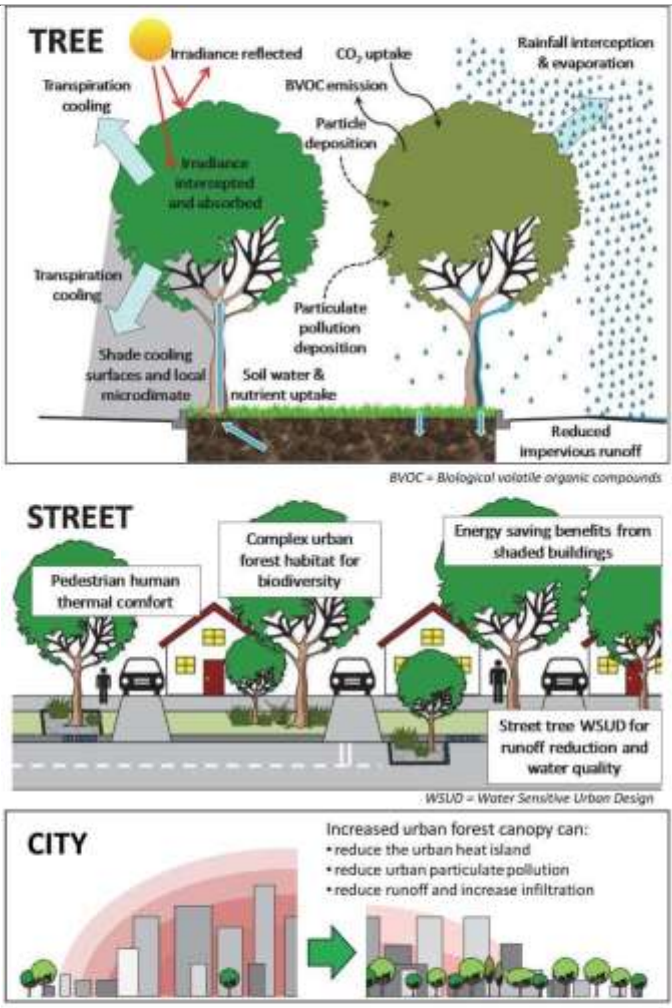


Figure 73 - Urban forest ecosystem service and function: at the tree, street, land city scale (Livesley et al., 2016)

STAKEHOLDERS

Afforestation policies should be conducted by metropolitan and regional administrations. Afforestation should be encouraged through incentives for farmers who currently earn low income from agriculture, encouraging them to transition into forest farming. These incentives are expected to be particularly effective in rural areas where land is categorized as pastures and mosaic croplands. However, it is unlikely that farmers of arable land and permanent crops would be drawn to these incentive programs (Hyytiainen et al., 2008). Conversely, expanding afforestation in rural areas where agriculture generates higher revenue requires careful consideration by public planning authorities. This is because the financial resources necessary to make such incentives appealing may be prohibitively high, and shifting away from traditional agriculture could potentially harm the social, economic, and environmental stability of these rural communities (Behan et al., 2006). In this context, public administration at local, regional, and national levels has a crucial role to play, as it must balance the extent of afforestation with feasible investment levels to support these land-cover transformations, especially in areas dominated by extensive agriculture (Zavalloni et al., 2019).

GUIDELINES
DESIGN IMPLEMENTATION

Environmental considerations

New urban forests can be established anywhere in the world (FAO 2021). However, in dry climates, afforestation must be carried out with extra caution to prevent lowering water tables and reducing soil recharge rates, especially during the dry season.

New trees need a substrate with high mineral and structural quality. Important factors include the type and composition of the soil, its depth, acidity, and degree of compaction. Sandy and loamy soils are more suitable for new forests due to their strong infiltration capacity and good soil aeration. In contrast, soils with a high clay content and compacted soils are much less favorable for the establishment of new roots (Kadam et al. 2020).

Technical considerations

Site preparation may involve weed suppression and removal, potential cultivation and fertilization, and enhancement of soil structure and composition (Le et al. 2012). In areas lacking established vegetation, it may be necessary to plant nurse crops of fast-growing species before introducing preferred species (FAO 2021).

Suitable land uses for urban forests include degraded natural forest areas, alluvial sites along streams, rivers, and water bodies, steep slopes at risk of erosion and landslides, non-productive agricultural sites, and formerly productive industrial wood plantations (FAO 2021). Planting on deforested or degraded sites requires sturdy nursery plants that are well-watered before planting (FAO 2021). In urban settings, especially where urban forests are intended for human use and near gray infrastructure, additional considerations are necessary. These include seedling or tree sizes, pre-planting formative pruning and root management, proximity to gray infrastructure, and identifying other growth and planting parameters to ensure a sustainable planting initiative.

Newly established forests should generally consist of a mix of local tree and understory species. Forests should not be established on untransformed land that already supports indigenous vegetation, as these areas contribute to the conservation of non-forest species and ecosystems. When establishing forests, using a mix of species that mimics the natural forest habitat of the region is important. Such forests are typically more productive, resilient, and provide higher levels of ecosystem services (Le et al. 2012).

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BEST PRACTICES

Best practice 1

Project

Freetown the Tree Town Campaign, 2020–23

Location

Freetown, Sierra Leone

Source image: https://www.betterplace.org/en/projects/82290-tree-plantingcampaign-in-sierra-leone

Description

Trees have given way to buildings in and around the capital Freetown, a grim testament to Sierra Leone's ongoing deforestation and environmental degradation. The Freetown City Council has launched a campaign to plant one million trees by 2020. In addition to diverse indigenous tree species with large canopies and strong roots, trees on private land and in communities include mango trees to provide additional community benefits from fruit harvesting. Educational workshops, community-based stewardship, planting and cultivation models are building ownership and value of the campaign at the community level.

Source

Freetown City Council

https://www.betterplace.org/en/projects/82290-tree-plantingcampaign-in-sierra-leone

Best practice 2

Project

Shandong Ecological Afforestation Project, 2010–2016

Location

Shandong, China

Source image: https://www.worldbank.org/en/results/2017/07/26/china-afforestation-project-in-shandong-improves-environment-and-farmers-incomes

Description

In Shandong Province, local authorities with the support of the World Bank launched a program to restore vegetation in severely eroded mountainous regions by planting trees and shrubs on slopes with minimal soil depth. This effort primarily aimed to safeguard farmland, boost agricultural yields, and reinforce the stability of a recently formed alluvial plain situated near the Yellow River's estuary. Vegetative cover was also developed alongside transportation routes, irrigation channels, and in zones set aside for forestation. The project sought to enhance the administrative and operational abilities of both regional and provincial governments. Those involved in the initiative were provided with expert guidance, trained in methods for tracking and assessing progress, and engaged in educational visits and exchange programs.

Source

The World Bank

https://www.worldbank.org/en/results/2017/07/26/china-afforestation-project-in-shandong-improves-environment-and-farmers-incomes

RESEARCH UNIT AND AUTHOR/S

De-sealing

Soil sealing refers to the permanent coverage of land by impermeable materials like asphalt or concrete, disrupting natural soil functions (FAO & ITPS, 2015). De-sealing involves removing these layers to restore soil infiltration, enhance environmental services, and improve ecological functions. These interventions vary in scale from metropolitan to local levels. Benefits include flood risk mitigation through improved groundwater recharge, reduction of urban heat island effects by increasing vegetation and surface permeability, carbon sequestration via restored organic soil carbon, and biodiversity support by revitalizing soil microbial communities (FAO, 2022; European Commission, 2012). Successful implementation depends on coordinated governance involving municipal, regional, and national authorities, alongside scientific institutions and community groups to ensure context-sensitive planning and social acceptance. Technical requirements include assessing impermeable surface characteristics, soil hydraulic properties, groundwater conditions, and urban infrastructure constraints. Design considerations focus on surface grading, slope optimization, and selection of appropriate permeable materials or native vegetation adapted to local climates and land uses. In peri-urban and rural contexts, soil decompaction and erosion control are critical. Continuous monitoring of soil health, hydrology, and vegetation success ensures long-term sustainability. An interdisciplinary approach is essential to balance technical feasibility, environmental functionality, and resilience. A more detailed description of afforestation can be found in Table 6.5 where the different characteristics are explained through textual and figurative parts within a sheet.

Table 6.5 Design proposal sheet related to de-sealing

<table>
<tr><td colspan="4">TITLE</td></tr>
<tr><td colspan="4">De-sealing</td></tr>
<tr><td colspan="4">PROCESS DEFINITION</td></tr>
<tr><td colspan="4">SCALE</td></tr>
<tr><td>☑ Metropolitan level/Urban level</td><td>Neighborhood level</td><td>□ Building block level</td><td>□ Other</td></tr>
<tr><td colspan="4">HAZARD CONSIDERED</td></tr>
<tr><td colspan="4">Heatwave
Surface water flooding</td></tr>
<tr><td colspan="4">BENEFITS AND CO-BENEFITS</td></tr>
<tr><td colspan="2">Benefits:
Flood risk reduction
Heat stress risk reduction
Carbon storage and sequestration
Biodiversity</td><td colspan="2">Co-benefits:
Resource production
Human health</td></tr>
<tr><td colspan="4">INTEGRATION WITH OTHER CLIMATE PROOF SOLUTIONS</td></tr>
<tr><td colspan="4">Park
Street trees
Urban garden</td></tr>
<tr><td colspan="4">BRIEF DESCRIPTION</td></tr>
<tr><td colspan="4"><u>Objectives</u>
According to the definition provided by FAO and ITPS (2015, p. 2) “Soil sealing means the permanent covering of an area of land and its soil by impermeable artificial material such as asphalt or concrete, for example through buildings and roads”. De-sealing interventions concern the elimination of the impermeable upper layer in order to enhance soil infiltration, boost environmental functionality, and improve the ability of the land to deliver ecological benefits.
<u>Scale</u>
De-sealing interventions can be applied to different scales from metropolitan area to neighboring scale.
<u>Benefits / co-benefits</u></td></tr>
</table>

Flood risk reduction: Exposed soil surfaces offer a natural route for rainwater to infiltrate into underground aquifers, aiding in flood mitigation. This approach is gaining significance as episodes of heavy rainfall become more common, likely as a consequence of shifting climate patterns. (FAO, 2022).

Heat stress risk reduction: The loss of vegetation in cities due to soil sealing reduces evapotranspiration. Dark urban surfaces like asphalt and concrete absorb more solar energy, and combined with heat from air conditioning and traffic, intensify urban temperatures (Commissione Europea, 2012).. De-sealing interventions contribute significantly to reducing the "urban heat island" effect.

Carbon storage and sequestration: Soils covered by impervious surfaces typically have minimal amounts of organic carbon, which means they hold significant potential for carbon capture and can support efforts toward climate neutrality in urban areas. Unsealed, permeable soils are capable of storing carbon and plays a role in reducing greenhouse gas emissions (FAO, 2022).

Biodiversity: Soil sealing negatively affects both surface and underground biodiversity. Around a quarter of all known species live in the soil, including essential microorganisms. These organisms support organic matter decomposition, nutrient cycling, and carbon storage. They also improve soil structure and permeability, sustaining ecosystems above and below ground. (Commissione Europea, 2012).

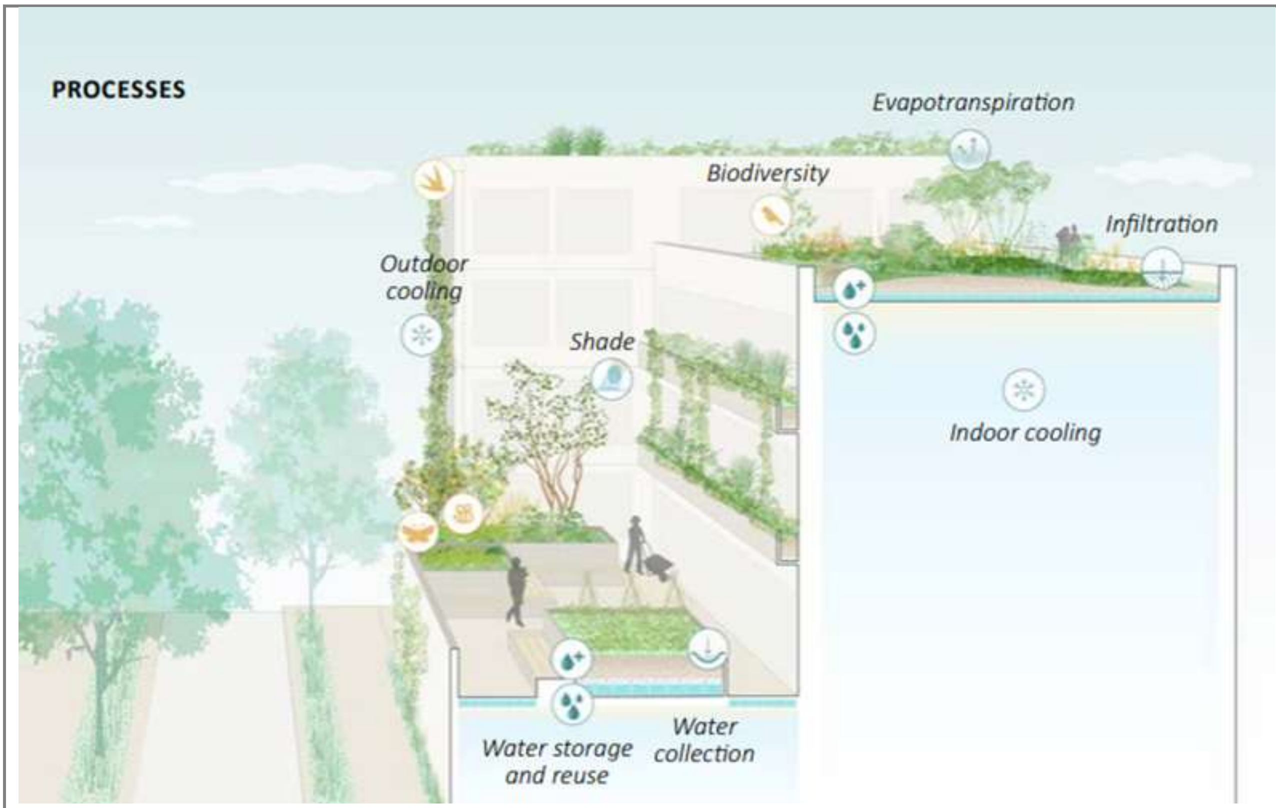

Figure 74. Main processes supported by green building solutions (World Bank, 2021, p. 85).

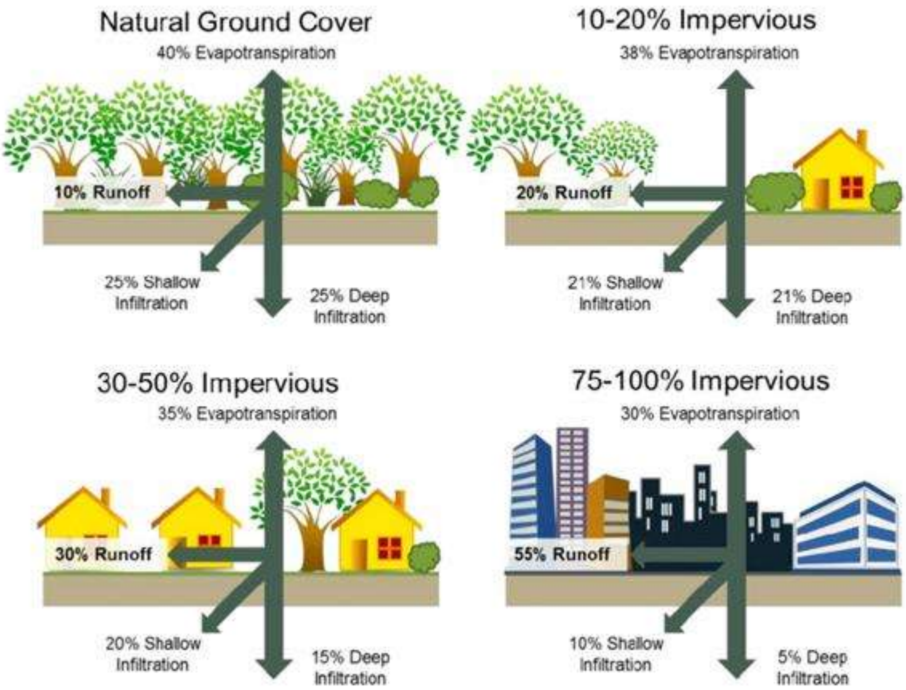

Figure 75. Consequences of sealed urban surfaces on overland water discharge and subsurface water absorption (Holt et al., 2018, p. 18)

STAKEHOLDERS

The successful execution of surface de-sealing measures relies on the active involvement of diverse institutional actors operating at multiple administrative scales. In densely built environments, municipal governments and urban planning departments are key agents, as they oversee spatial development, public infrastructure, and climate resilience frameworks. These entities are uniquely equipped to incorporate de-sealing actions into urban regeneration projects, land-use regulations, and green infrastructure planning. At broader territorial levels, regional and national authorities are responsible for establishing policy instruments, financial incentives, and normative standards that facilitate and coordinate local-level actions. In non-urban and rural territories, responsibility often falls to environmental management bodies, agricultural landowners, and conservation organizations, particularly in areas requiring ecological rehabilitation or hydrological restoration. Universities and scientific institutions provide essential support through applied research, modeling, and evaluation of environmental and socio-economic outcomes. Moreover, non-governmental organizations and community groups play a critical role in fostering awareness, mobilizing local participation, and ensuring the social acceptability of interventions. A cross-sectoral, integrative governance approach is therefore fundamental for delivering effective, context-sensitive, and durable de-sealing outcomes.

GUIDELINES

DESIGN IMPLEMENTATION

Environmental considerations

Interventions involving the removal of impermeable surface layers confer substantial ecological advantages but necessitate strategic planning to circumvent inadvertent environmental disturbances. The reinstatement of soil porosity facilitates enhanced aquifer replenishment, sustains intrinsic hydrological regimes, and mitigates surface water runoff as well as urban flood occurrences. Augmented soil infiltration capacity diminishes the conveyance of contaminants to aquatic systems, thereby promoting improved aquatic ecosystem health. Within metropolitan landscapes, the expansion of vegetative cover alleviates the urban heat island phenomenon, augments atmospheric air quality, and fosters carbon dioxide sequestration. Nonetheless, meticulous oversight is imperative to avert soil degradation, pollutant release during de-sealing processes, and the proliferation of non-native invasive flora. The restoration of indigenous plant species aids in reinforcing habitat connectivity and biodiversity conservation but requires adaptation to site-specific ecological parameters. In transitional peri-urban and rural contexts, such measures must be harmonized with broader landscape preservation objectives and minimize perturbations to extant biotic communities. Ongoing environmental surveillance should evaluate soil physicochemical properties, hydrological equilibrium, and overall ecosystem resilience to guarantee the enduring viability of the rehabilitated substrates.

Technical considerations

The execution of de-sealing initiatives mandates a comprehensive evaluation of site-specific geophysical and environmental parameters. Crucial technical considerations encompass the detailed assessment of extant impermeable substrates, soil hydraulic conductivity, subsurface stratigraphy, and groundwater dynamics. Within urban environments, particular attention must be given to subterranean utilities, stormwater conveyance infrastructure, and the structural integrity of adjacent constructions. Precise surface contouring and gradient engineering are imperative to optimize percolation rates while preventing hydrological stagnation or soil erosion. The choice of suitable permeable substrates or vegetative species should be informed by regional climatological conditions, land utilization patterns, and available maintenance resources. In peri-urban and rural landscapes, restoration objectives often necessitate soil decompaction techniques, the establishment of endemic flora, and the implementation of sediment retention strategies. Integrated monitoring frameworks are critical to continuously assess hydraulic efficiency, edaphic health, and vegetative establishment success. Adopting an interdisciplinary methodology is vital to harmonize technical practicability, ecological functionality, and the durability of the intervention over time.

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BEST PRACTICES

Best practice 1

Project

Redesign the Nibelungenplatz in Tulln

Location

Tulln, Austria

Source image: https://www.cipra.org/en/projects/grc

Description

The choice to unseal Nibelungenplatz in Tulln was driven by the goal of turning the former parking area into an urban green space in order to create a natural retreat within the heart of the city. Emphasis is placed on developing multifunctional, water-permeable zones to enhance soil infiltration and promote a more nature-based layout. Typical strategies include using porous paving materials and planting vegetation, which help reestablish healthy soil conditions by boosting water absorption, retention, and restoring ecological soil functions.

Source

Kühleitner, D., Kuncio, P., Praun, M., Jarosch, J., Adolf, H., Ebster, M., Planitzer, A., Pastorelli, F. and Veselko, S.B. 2023. Handbook. Ground: Breaking. Unsealing to improve soil, climate and biodiversity. CIPRA International & CIPRA France

(https://www.cipra.org/en/projects/ground-breaking)

Best practice 2

Project

LIFE Project "SOS4Life"

Location

Forlì, Italy

Source image: https://www.cipra.org/en/projects/ground-breaking)

Description

The project aimed to redevelop the space in front of the San Domenico Museums, previously occupied by an elevated parking lot, and convert it into a public green space. As part of the transformation, 6,500 m² of pavement were dismantled, 3,700 m³ of concrete were removed and disposed of, and 6,500 m³ of soil were added, including 1,650 m³ of topsoil. The impervious surface was replaced with vegetation and infrastructure supporting urban greenery, increasing the share of permeable land from 6% to 74%.

Source

Kühleitner, D., Kuncio, P., Praun, M., Jarosch, J., Adolf, H., Ebster, M., Planitzer, A., Pastorelli, F. and Veselko, S.B. 2023. Handbook. Ground: Breaking. Unsealing to improve soil, climate and biodiversity. CIPRA International & CIPRA France

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(https://www.sos4life.it/progetto/)

RESEARCH UNIT AND AUTHOR/S

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SCALE			
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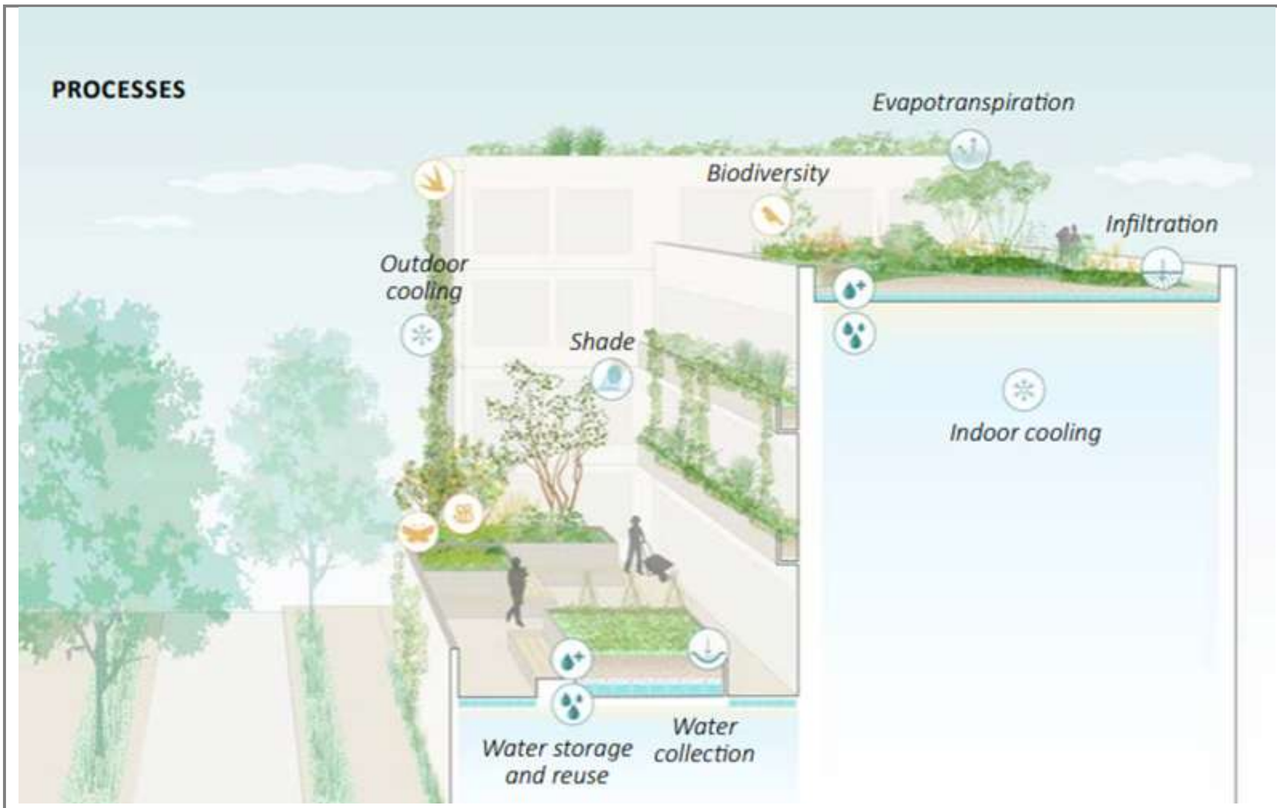

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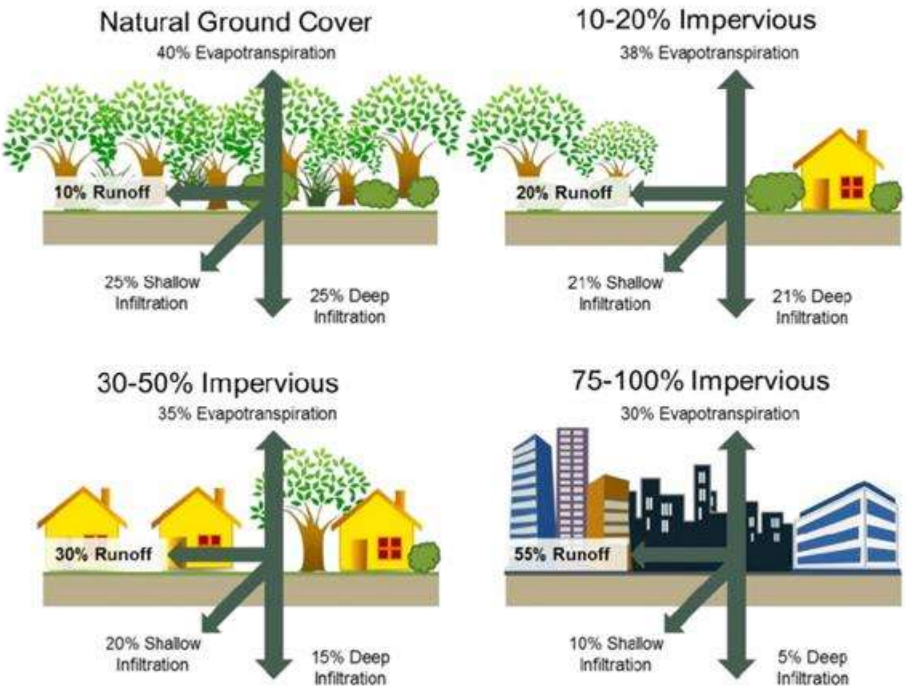

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GUIDELINES

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BEST PRACTICES

Best practice 1

Project

Redesign the Nibelungenplatz in Tulln

Location

Tulln, Austria

Source image: https://www.cipra.org/en/projects/grou

Description

The choice to unseal Nibelungenplatz in Tulln was driven by the goal of turning the former parking area into an urban green space in order to create a natural retreat within the heart of the city. Emphasis is placed on developing multifunctional, water-permeable zones to enhance soil infiltration and promote a more nature-based layout. Typical strategies include using porous paving materials and planting vegetation, which help reestablish healthy soil conditions by boosting water absorption, retention, and restoring ecological soil functions.

Source

Kühleitner, D., Kuncio, P., Praun, M., Jarosch, J., Adolf, H., Ebster, M., Planitzer, A., Pastorelli, F. and Veselko, S.B. 2023. Handbook. Ground: Breaking. Unsealing to improve soil, climate and biodiversity. CIPRA International & CIPRA France

(https://www.cipra.org/en/projects/ground-breaking)

Best practice 2

Project

LIFE Project “SOS4Life”

Location

Forlì, Italy

Source image: (https://www.cipra.org/en/projects/ground-breaking)

Description

The project aimed to redevelop the space in front of the San Domenico Museums, previously occupied by an elevated parking lot, and convert it into a public green space. As part of the transformation, 6,500 m² of pavement were dismantled, 3,700 m³ of concrete were removed and disposed of, and 6,500 m³ of soil were added, including 1,650 m³ of topsoil. The impervious surface was replaced with vegetation and infrastructure supporting urban greenery, increasing the share of permeable land from 6% to 74%.

Source

Kühleitner, D., Kuncio, P., Praun, M., Jarosch, J., Adolf, H., Ebster, M., Planitzer, A., Pastorelli, F. and Veselko, S.B. 2023. Handbook. Ground: Breaking. Unsealing to improve soil, climate and biodiversity. CIPRA International & CIPRA France

(https://www.cipra.org/en/projects/ground-breaking)

(https://www.sos4life.it/progetto/)

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Table 6.5 Design proposal sheet related to de-sealing

Greening

Vegetation interventions, including open green spaces and corridors, are vital across diverse climatic zones due to their multifaceted environmental functions. Their stormwater management benefits are especially pronounced in regions with frequent intense rainfall, whereas shading and temperature regulation are critical in arid and hot climates. Sustainable maintenance of open green spaces in dry areas requires careful water resource management to avoid groundwater depletion and ensure adequate soil moisture. Plant species selection for green corridors should be guided by local hardiness zones, soil types, sunlight, precipitation, and frost patterns, complemented by historical ecological data. Optimal stormwater regulation demands synergistic selection of soils and plants: soils must balance infiltration capacity with nutrient retention, avoiding erosion-prone loose soils and impermeable clays. Incorporation of open water bodies can augment management in clay-dominated or high-water table areas (Gehrels et al., 2016).
In open green spaces, vegetation choice prioritizes native, resilient species that support climate mitigation, water absorption, pollution control, aesthetics, and biodiversity. Park sizes vary; small neighbourhood parks offer localized recreation, medium district parks serve multiple communities with diverse activities, and large city parks accommodate broader populations (City of Gold Coast, 2018). Universal design principles must

ensure accessibility and social inclusivity, while design strategies mitigate vandalism and crime through spatial configuration, lighting, and surveillance.

Green corridors require species that optimize carbon sequestration, heat reduction, and wildlife habitat provision. Urban trees along infrastructure need ample root volume and unpaved space for water infiltration and pollutant filtration. Adequate spacing and clearance from utilities, both overhead and underground, are essential to prevent damage and ensure long-term health (Gilman, 1994).

A more detailed description of greening can be found in Table 6.6 where the different characteristics are explained through textual and figurative parts within a sheet.

Table 6.6 Design proposal sheet related to greening.

TITLE			
Greening			
PROCESS DEFINITION			
SCALE			
☑ Metropolitan level/Urban level	Neighborhood level	□ Building block level	□ Other
HAZARD CONSIDERED			
• Heatwave • Surface water flooding • Polluted air			
BENEFITS AND CO-BENEFITS			
Benefits: • Flood risk reduction • Heat stress risk reduction • Human health • Carbon storage and sequestration • Biodiversity	Co-benefits: • Tourism and recreation • Cultural		
INTEGRATION WITH OTHER CLIMATE PROOF SOLUTIONS			
• Afforestation • De-sealing			
BRIEF DESCRIPTION			
Objectives Urban greenery interventions refer to the strategic planning, design, implementation, and management of vegetated spaces within city environments, aimed at enhancing ecological, social, and climatic functions. These interventions encompass a variety of elements, including open green spaces such as parks, community gardens, and natural reserves, as well as linear green corridors that connect fragmented habitats and facilitate biodiversity movement. The primary objectives of greenery interventions are to improve urban ecosystem services, such as air purification, temperature regulation, stormwater management, and carbon sequestration, while also providing recreational opportunities and promoting mental and physical well-being among urban residents. *Scale*			

Greenery can be applied to different scales from metropolitan area to neighboring scale.

Benefits / co-benefits

Flood risk reduction: Integrating greenery into a cohesive green infrastructure network enhances stormwater management by absorbing, storing, and slowing runoff, thereby reducing storm impacts and protecting urban infrastructure (Gehrels et al., 2016).

Heat stress risk reduction: Greenery mitigate heat stress through shade and evapotranspiration (Gehrels et al., 2016), improving thermal comfort, reducing heat-related illnesses (Howe and Boden, 2007), enhancing productivity (Seppanen et al., 2004), and cooling buildings.

Human health: Greenery enhances mental and physical health by lowering pollution and heat, reducing respiratory issues and heat-related mortality, enabling outdoor activity, and offering psychological relief from urban stress (Kaplan and Kaplan, 1982).

Carbon storage and sequestration: Greenery sequester carbon in vegetation and soil, storing up to 130 tCO_2/ha (75% below ground) in temperate zones (Lindén et al., 2020). Sequestration rates vary by vegetation type, ranging from 0.5–5 tCO_2/ha/year in grasslands to higher in forests

Biodiversity: Greenery safeguard vital habitats and supports biodiversity. Integrating key biodiversity areas into a connected network of green patches and corridors enhances habitat quality and species movement (De la Barrerra et al., 2016).

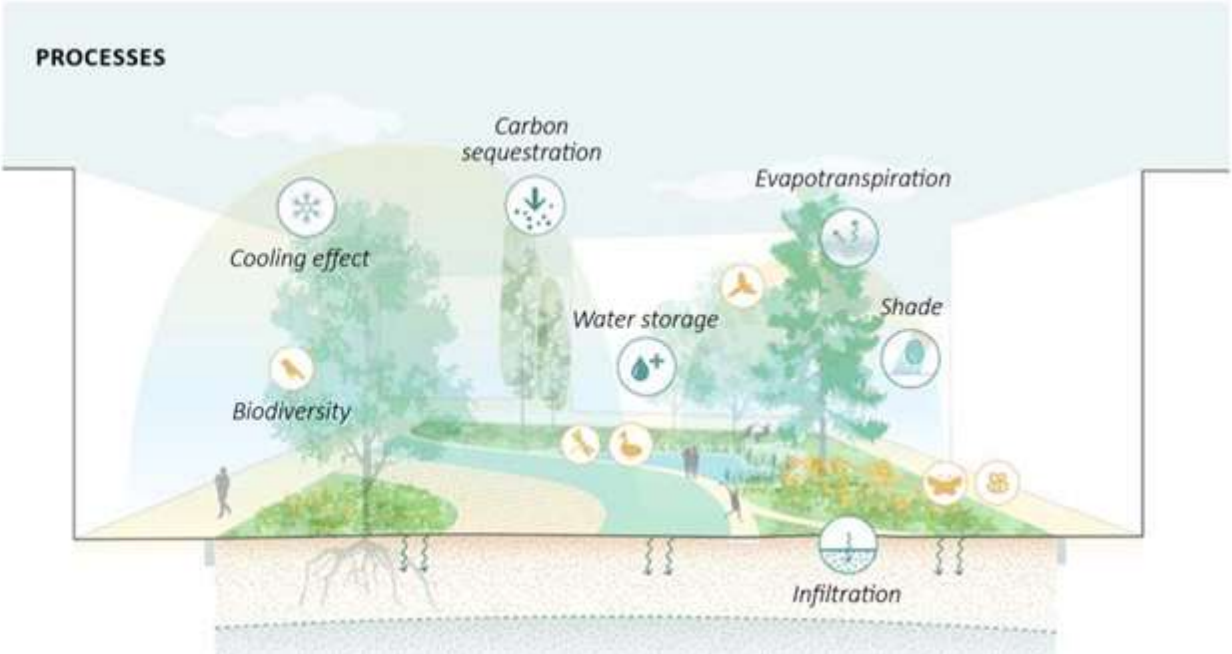

Figure 78. Main processes supported by green spaces (World Bank, 2021, p. 99).

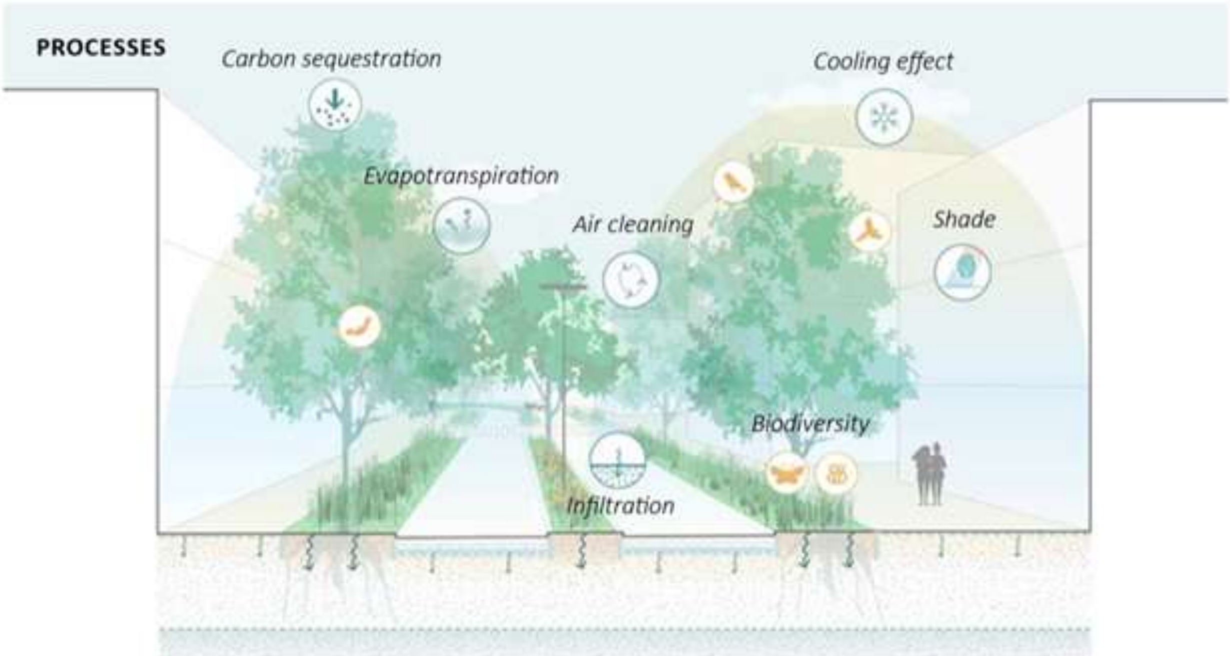

Figure 79. Main processes supported by green corridors (World Bank, 2021, p. 99).

STAKEHOLDERS

Urban greenery initiatives, including the development of open green spaces and green corridors, can be implemented by a diverse range of stakeholders. Local governments and municipal planning departments typically play a central role in policy-making, land allocation, and coordination of projects. Urban planners, landscape architects, and environmental agencies contribute technical expertise to design effective and resilient green infrastructure. Community organizations and non-governmental organizations (NGOs) are crucial in advocating for green space preservation, facilitating community engagement, and supporting maintenance activities. Private sector actors, such as developers and businesses, can integrate greenery through green roofs, pocket parks, and corridor enhancements in their projects.

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To expand green interventions, stakeholders may adopt strategies such as incorporating green infrastructure into urban master plans and zoning regulations, prioritizing the use of native, drought-resistant vegetation, and promoting multifunctional green spaces that address climate adaptation, biodiversity, and social wellbeing. Public-private partnerships and incentive programs can mobilize resources and encourage private investment. Additionally, fostering community participation through educational programs and volunteer initiatives enhances stewardship and ensures long-term sustainability. Monitoring and adaptive management frameworks are essential to assess effectiveness and inform ongoing improvements.

GUIDELINES
DESIGN IMPLEMENTATION

Environmental considerations

Vegetation, encompassing both open green spaces and green corridors, holds significant value across all climatic zones. Their role in managing stormwater is especially pronounced in regions experiencing frequent intense rainfall. Conversely, their capacity to provide shading and temperature moderation is most critical in arid and hot environments. Maintaining year-round green spaces in dry areas demands careful management to prevent depletion of groundwater reserves, reduction in soil water recharge, and to ensure adequate hydration for plant survival. Selection of species for green corridors must consider local hardiness zones, soil characteristics, sunlight exposure, precipitation patterns, frost occurrence, and other environmental factors influencing plant viability. Gathering regional data on historically successful tree species, prevalent plant diseases, and notable climatic shifts is essential for informed decision-making. In semi-arid and arid contexts, particular attention should be paid to irrigation requirements, water resource impacts, and effects on groundwater and soil moisture before establishing green corridors.

For optimal stormwater regulation, soil and vegetation choices should be integrated. Soils must possess sufficient density, infiltration capacity, and depth to support healthy plant growth. While loose soils are susceptible to erosion, heavy clay soils impede water absorption and may exacerbate runoff. An ideal soil composition balances permeability to allow water infiltration with nutrient retention to sustain vegetation. Areas dominated by clay soils or high groundwater levels benefit from incorporating open water features to enhance stormwater management (Gehrels et al., 2016).

Technical considerations

In relation to open green spaces, the selection of vegetation is influenced by factors such as local climate, sunlight exposure, soil properties, and water availability, with a preference for hardy native species. Additional criteria include the plants' roles in climate regulation, water management, pollutant absorption, aesthetic contribution, and support for urban biodiversity. Parks vary in size and function according to their urban context and resilience goals. Small local parks (250-4,000 m²) serve nearby residents within a 400-meter radius, offering limited recreation. Medium district parks (2-4 hectares) cater to multiple neighborhoods within 400-800 meters, supporting diverse informal activities and community amenities. Large city parks (10-20 hectares) attract visitors from 1-5 km and beyond, meeting broader recreational demands (City of Gold Coast, 2018). Design and refurbishment of parks should adhere to universal design principles to ensure accessibility for all ages and abilities. Equitable access requires accommodating diverse social and ethnic communities, enabling cultural engagement and enjoyment of nature. Implementing evidence-based design strategies helps prevent vandalism and crime. Effective environmental design includes strategic planting, spatial layout, lighting, and signage to enhance visibility and natural surveillance.

In relation to green corridors, plant species should be carefully chosen to maximize ecological and social benefits. This includes selecting trees that enhance carbon storage and mitigate urban heat, as well as species that contribute to aesthetics or provide essential habitat and nourishment for wildlife. Urban trees planted alongside linear infrastructure like roads require sufficient three-dimensional growing space to establish healthy root systems. Tree pits with grates must preserve adequate unpaved soil around the base to facilitate water infiltration and minimize contamination from debris and pollutants. Key considerations include root depth, canopy height and spread, and spacing between trees (Center for Watershed Protection, 2012). Ideally, root zones should encompass approximately 12 cubic meters with a minimum soil depth of 1.5 meters, although urban constraints often limit this (Eisenberg and Polcher, 2018). Furthermore, a buffer of at least 1.8 meters between tree pits and curbs or buildings is necessary to allow root expansion (Center for Watershed Protection, 2012). Trees must be selected and managed to avoid conflicts with overhead power lines and underground utilities, ensuring sufficient clearance is maintained both above and below ground to prevent interference (Gilman, 1994).

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BEST PRACTICES

Best practice 1

Project

The Green Belt of Vitoria-Gasteiz, 1990s to 2008

Location

Vitoria-Gasteiz, Spain

Souce image: https://www.vitoria-gasteiz.org/wb021/was/contenidoAction.do?idioma=en&uid=u_1e8934a8_12e47a4954c__7ffd

Description

The Green Belt comprises a network of peri-urban parks characterized by significant ecological and scenic importance, interconnected through eco-recreational corridors. This green infrastructure emerged from an ambitious environmental rehabilitation initiative launched in the early 1990s around the outskirts of Vitoria-Gasteiz. Its primary aim was to establish an extensive natural area for public enjoyment encircling the city. The Green Belt encompasses a diverse array of habitats, including woodlands, streams, marshes, grasslands, agricultural lands, groves, and hedgerows, all coexisting within a mosaic of natural landscapes. Certain ecosystems within the Belt—such as the rehabilitated wetlands of Salburua and the fluvial landscape of the Zadorra River—have received international acclaim for their exceptional ecological significance.

Source

Vitoria-Gasteiz Municipal Council

https://www.vitoria-gasteiz.org/wb021/was/contenidoAction.do?idioma=en&uid=u_1e8934a8_12e47a4954c__7ffd

Best practice 2

Project

Chulalongkorn Centenary Park, 2012–2017

Location

Bangkok, Thailand

Source image: https://landezine-award.com/chulalongkorn-university-centenary-park/

Description

Established in 2017, Chulalongkorn Centenary Park represents Bangkok's first major intervention in urban green infrastructure, created to address pressing environmental challenges. Located within Chulalongkorn University's campus, the 48,000 m² park—stretching 1.3 kilometers—has introduced vital open space into the city's densely built environment. It features Thailand's largest green roof and incorporates a water management system that filters runoff from adjacent urban zones. The park serves as a model for the ecological and social potential of landscape architecture in highly urbanized contexts, demonstrating how thoughtfully designed green spaces can contribute to both environmental resilience and community well-being.

Source

Landezine International Landscape Award

https://landezine-award.com/chulalongkorn-university-centenary-park/
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6.3.2 Urban districts level targets

This section starts with the intent of developing the proposed strategies at the urban district level, followed by theory and background, and definitions for specific terms. The environmental issue is increasingly central to our nation's political, economic, and social agenda, driving substantial changes for both citizens and businesses. This necessitates adapting lifestyles, production, and consumption to the effects of climate change, as well as complying with the Green Deal. Among the significant opportunities arising from the requirements of green transition plans, urban and territorial regeneration processes play a crucial role. These are composite processes encompassing both 'soft' measures (e.g., information campaigns, development of organisational and participatory methods, governance) and 'green and grey' measures, as established by the National Plan for Climate Change Adaptation (MASE, 2023). The latter are characterised by tangible component and structural interventions, proposing actions for the resilient development of urban districts.

Measures and strategies towards resilient and regenerative urban districts include urban transformation and construction actions in urban areas and building complexes, primarily those characterised by urban, building, environmental or socio-economic degradation, which do not result in land consumption or, in any case, according to criteria that use methodologies and techniques related to environmental sustainability, including through actions to renaturalise consumed soils reversibly with the recovery of lost ecosystem services, through de-impermeabilization and the enhancement of ecological-environmental potential and urban biodiversity (Nava et al., 2024). The main strategies and actions are then introduced, defining processes and realisation phases, followed by a list of suggested stakeholders who are considered essential for enabling the proposals.

Conceptual guidelines toward resilient and regenerative urban settlements in this chapter focus on the recognition of urban climate shelters (henceforth referred to as “UCSs”), as stated in Section 5.3.1, as networks, installations and everyday spaces created by humans to provide essential services, protection, safety and comfort within urban and metropolitan settlements, thus contributing to the resilient and regenerative transition of urban district into eco-districts.

The identification of some urban design processes geared toward the production of resilient and regenerative urban settlements is based on the taxonomy of urban settlements developed in the Deliverable 5.2.1 “Risk-Oriented Taxonomy and Ontology of Urban Subsystems and Functional Models”, produced as part of the Spoke 5 “TS1 - Urban and metropolitan settlements” di RETURN, WP 5.2 “Multi-risk-oriented modelling of urban systems,” Task 5.2.1 “Holistic understanding and dynamic modelling of urban and metropolitan systems”. Since strongly related to power, mobility, and emergency systems, here presented as the potentially most critical elements of the urban system, UCSs may represent a feasible design strategy to increase the capacity of urban districts to cope with climate-adverse events and foster urban resilience. As stated in Section 5.3.1, the systematization of climate-proof solutions according to a progressive upgrade approach can allow the achievement of integrated urban resilience both at the building-block scale and of the entire district, acting first on short-term and easy-to-implement solutions and then, through extended reasoning, for all blocks in the district, increasing their long-term resilience.

The implications presented and discussed in Subsection 5.4.1 of Section 5.3 lead to the identification, in illustrative terms, of a UCSs-oriented design process in terms of requirements, parameters and performance indicator to produce resilient and regenerative urban settlements. The UCs are identified with the contents of the sheet given in Table 6.3 “Guidelines sheet,” which are analytically discussed below.

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Table 6.3 Design proposal sheet related to climate shelter

TITLE					
CLIMATE SHELTER					
SCALE					
□ metropolitan/ urban level	**X** District level	**X** building block level	□ Others		
SECTOR					
X grey	**X** green	□ soft			
HAZARD CONSIDERED					
X heatwave	**X** pluvial flooding	□ drought	□ coastal and fluvial flooding	□ others	□ …
BENEFITS					
X Increase of thermal comfort indoor/outdoor	**X** Reduction of health impacts	**X** Strengthening of heat wave emergency management system	**X** Contribution to the reduction of CO_2 emissions	□	□
CO-BENEFITS					
X Improving the quality of public spaces	**X** Reduction of energy poverty	**X** Reducing the economic impact on the health system	□	□	□
ASSESSMENT AND MONITORING INDICATORS					
X TMRT	**X** PMV	**X** UTCI	**X** NDVI	□ PET	□ …
BRIEF DESCRIPTION					
Urban climate shelter is a public space where citizens can take refuge for long and medium-term periods, adapted to cope with the harsh environmental conditions of their surroundings. Requirements: Site accessibility User well-being Comfort termico indoor/outdoor Sustainability					

	Indoor
	Spaces within buildings, such as libraries, shopping malls, gyms, or public facilities, that offer refuge from the summer heat or winter cold.
	Outdoor
	Playgrounds, urban parks and transport stops are considered potential climate refuges due to their wide distribution in cities. Effective measures include installing pergolas, planting vertical vegetation and using high reflectivity draining pavements. Air pretreatment and water use to cool the space through radiant energy exchange techniques stand out in air-conditioned installations.

BEST PRACTIES

Indoor shelter:

Escola Llorers.

Carrer d'Aragó, 121. L'Eixample, Barcelona

Source image: barcelona.cat

Eleven of the city's schools have become climate shelters thanks to a project funded by the European Commission's Urban Innovative Action (UIA) programme, aimed at “adapting schools to climate change through green, blue and grey” and proposing blue (incorporation of water points), green (shady spaces and vegetation) and grey (actions on buildings to improve their insulation) measures. In these schools, outdoor spaces have been transformed through these green, blue and grey actions. Around 1,000 m2 of natural terrain with vegetation has been restored in the schoolyards, replacing concrete, and 2,213 m2 of new shade spaces have been created with pergolas and awnings. In addition, a total of 74 trees were planted, spread over two entire blocks, and 26 new water points were installed.

The aim is for these spaces to serve not only the school's students, but also all citizens of the surrounding area, who will be able to access the courtyards during non-school periods.

DESIGN IMPLEMENTATION GUIDELINES

Urban climate shelters play a crucial role in achieving the integrated urban resilience of urban and metropolitan settlements as they offer safe spaces for vulnerable population during extreme weather events (e.g. heatwave, flooding). Their main function is to provide temporary shelter for citizens, but their impact is broader, integrating into an urban adaptation and mitigation strategy that contributes to the overall resilience of cities. Especially:

- they must be designed according to sustainable architectural features, such as natural ventilation, thermal insulation, green roofs and stormwater management systems, which reduce environmental impact and improve the city's ability to adapt to climate change;
- they must be designed following the principles of energy sustainability and reduction of CO2 emissions. The integration of renewable energy sources reduces dependence on fossil fuels and reduces cities' contribution to climate change;
- during extreme events they help reduce the load on other critical infrastructure, such as hospitals and emergencies, limiting overcrowding and preventing health crises;
- They can also act as community and social hubs, strengthening social cohesion.

Therefore, to develop a network of climate shelters it is necessary to:

- identify potential climate shelters in the analysis area based on specific hazard and vulnerability indicators related to the impacts of heat waves on the population, supplemented with additional indicators representing the endowment of spaces in the analysis area suitable for climate shelters. The territorial mapping of the indicators makes it possible to identify the potential network and select the indoor and outdoor spaces to be used as climatic refuges, possibly 'thematising' them with respect to the type of services (green areas, cultural spaces, etc.) they introduce into the neighbourhood;
- set the functional-spatial characteristics and technological-environmental performance: it is necessary to determine the characteristics that determine the indoor/outdoor comfort conditions and the functional equiment of the potential spaces, in order to outline their suitability and the interventions needed to include them in the network of neighbourhood climatic shelters.

As an example, Naples' SECAP (Sustainable Energy and Climate Adaptation Plan) outline the following checklist to support the design of climate shelters (SECAP, 2025), regarding:

- indoor spaces, through building envelope efficiency (insulation systems and thermal inertia of the envelope, shading systems), plant efficiency (air conditioning and ventilation systems, energy production from renewable sources), accessibility (free access, absence of architectural barriers;
- outdoor spaces, through vegetation (presence of trees, bushes, horizontal vegetation), paving (presence reflective and permeable paving), water (fountains and water blades, sea access, water vaporizers) shading features (shading elements, shaded areas in the hottest hours)
- indoor/outdoor spaces, through usage flexibility (modular or adaptable furniture and spaces, social spaces for conviviality, resting areas) and functional dotation (first aid goods, availability of drinkable water, emergency systems, provision of children and elderly's areas).

KEYWORDS

Heatwave, energy efficiency, climate shelters,

STAKEHOLDERS

Urban climate shelters (UCS) can be defined as a space that provides features for the adaptation to climate change, providing security from the heat, flood, and droughts, through a multi-hazard approach by using green and blue infrastructures, together with the process of coproduction of local stakeholder. Therefore, by involving citizens,

community, NGOs, at all stages of the process, engaging public and private sector, climate shelters may also address the intersecting environmental and social needs of climate-vulnerable and marginalized residents (Amorim-Maia et al., 2023). These infrastructures of refuge must provide access to nature and protection from extreme heat and cold, while also addressing other social, cultural, and recreational needs. Since shelters' design supports the accommodation of multiple forms of knowledge, cultural norms, and identities in urban transformation (Romero-Lankao et al., 2018), local decision-makers and urban planners should consider such proposal design to identify social-ecological needs and co-create place-based solutions to address intersecting climate vulnerabilities (Amorim-Maia et al., 2023).
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6.3.3 Building block level targets

This section regards the definition of building block level strategies and actions considering the related long-, medium-, and short-term targets, their intent related to guidelines themes, theory and background, and glossary definitions. Relevant existing processes and best practices are therefore reported, as well as suggested stakeholders and strategy owners.

The application of strategic initiatives in the context of climate risk management demands an adaptive approach. This process involves deconstructing high-level ambitions into a coherent set of building-block level strategies and actions, each carefully mapped to short-, medium-, and long-term targets (Weiner et al., 2012). Moreover, the contribution to this topic is articulated by proposing a holistic and participatory methodology for climate-proofing urban environments, emphasizing the role of stakeholder engagement and citizen empowerment in enhancing resilience (Tucci, 2022). These temporal targets are more than just chronological markers - they serve as functional milestones, offering a staged roadmap for iterative progress, learning, and recalibration. In this light, the short-term horizon emphasizes quick-response mechanisms and foundational actions (e.g., vulnerability assessments, early warning system deployment); the medium-term focuses on systems integration and institutional adaptation; while the long-term targets aim at transformational change, such as climate-resilient infrastructure and regenerative land-use strategies (IPCC, 2022).

The need for such stratification is particularly acute in climate governance, where challenges are multidimensional, intersectoral, and often cross-jurisdictional boundaries. Actions must respond not only to biophysical risks (e.g., sea-level rise, heatwaves, extreme precipitation), but also to social vulnerabilities, institutional inertia, and economic trade-offs. Therefore, each building block must be designed with a clearly articulated strategic intent, ensuring its alignment with the guideline themes and overarching values of the initiative - such as sustainability, inclusion, social justice, and systems resilience. This level of articulation facilitates accountability, aids prioritization, and provides a framework for assessing the effectiveness of actions over time (Jasti et al., 2018).

At the building block scale, the translation of strategic intent into tangible interventions requires the adoption of environmentally responsive design solutions and context-specific technological systems. This implies moving beyond passive resilience toward active regeneration - through strategies such as nature-based solutions for microclimate regulation (e.g., green roofs, vegetated façades), adaptive envelope systems, or decentralized energy and water infrastructures. These components contribute to both immediate risk reduction and long-term ecological renewal, embedding climate responsiveness into the physical and operational fabric of urban settlements. In this regard, the building block becomes a key interface between system-level planning and site-specific design, enabling the materialization of resilience and regeneration principles at the scale of daily life. Moreover, the integration of digital platforms (e.g., Building Information Modeling, urban sensing networks) supports real-time monitoring, performance assessment, and adaptive management of interventions, making the strategies both measurable and updatable over time.

Critically, this entire architecture must be grounded in a solid theoretical foundation. Among the most relevant conceptual lenses are: Resilience Thinking, which provides an ecological systems view emphasizing adaptability, transformability, and persistence in the face of disturbance (Folke et al., 2010); Adaptive Pathways Planning, a method that supports flexible long-term planning by identifying decision points, contingency actions, and scenario-based strategies (Haasnoot et al., 2013); and Adaptive Governance, which underscores polycentric, participatory, and learning-oriented institutional arrangements for addressing uncertainty and complexity (Chaffin et al., 2014). These frameworks do not operate in isolation but are instead mutually reinforcing, providing the intellectual scaffolding needed to ensure that strategies are not only coherent but also operational under uncertainty.

To enable consistency and facilitate multi-stakeholder engagement, the establishment of a comprehensive and authoritative glossary is a foundational element of this process. Shared definitions of key terms such as "climate resilience", "transformational adaptation", or "systemic risk" are essential to avoid ambiguity and ensure a common language across technical experts, policymakers, civil society, and community actors. Glossary definitions should be aligned with internationally recognized sources (e.g., IPCC, UNDRR, ISO climate standards), but contextualized to the specific governance and operational environment of the initiative.

Another pillar of this strategic process is the identification and incorporation of existing processes, validated tools, and best practices, which allows organizations to build on established knowledge rather than starting from scratch. This requires a multi-source review combining internal organizational assessments and past program evaluations; comparative policy analysis of adaptation frameworks across cities, regions, or sectors (e.g., national adaptation plans, resilience scorecards); scientific literature and meta-analyses identifying scalable interventions and barriers to implementation (Frantzeskaki et al., 2018; Biesbroek et al., 2013). Exemplary models include community-based adaptation in vulnerable regions (Ensor & Berger, 2009), ecosystem-based approaches to flood mitigation (Kabisch et al., 2017), and digital twin technologies for urban climate simulation. These approaches may be drawn from diverse sectors, including health, infrastructure, biodiversity, finance, and emergency management - underlining the transdisciplinary nature of effective climate risk strategies.

In addition to the temporal articulation of targets, the building block strategies must align with regenerative design principles and circular economy frameworks. This means prioritizing resource loops, material reuse, zero-waste construction methods, and adaptive reuse of the built stock. In the medium to long term, such strategies can lead to the creation of positive urban metabolism, where building blocks do not only mitigate harm but actively contribute to ecosystem services, carbon sequestration, and social cohesion. This shift requires rethinking performance metrics - from reductionist indicators (e.g., energy efficiency) to more systemic ones (e.g., ecological footprint, social value creation, regenerative capacity), grounded in Life Cycle Thinking and territorial metabolism analysis.

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Strategic alignment with international policy frameworks - such as the New Urban Agenda (UN-Habitat, 2016), the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015), and the EU Mission on Climate-Neutral and Smart Cities - offers additional leverage for operationalizing building block strategies within multilevel governance systems. These frameworks encourage the codification of resilience into local regulations, performance-based standards, and urban planning instruments, enhancing institutional capacity to deliver adaptive and regenerative interventions across scales.
Furthermore, attention must be paid to the identification of strategy owners and key stakeholders. These include both institutional actors (e.g., ministries, municipalities, utilities) and non-institutional partners (e.g., academic researchers, civil society networks, private sector innovators). The use of tools such as the RACI matrix (Responsible, Accountable, Consulted, Informed) can clarify governance roles and promote shared ownership of actions. When supported by participatory design processes, this also enhances the legitimacy and effectiveness of the resulting strategies (Moser & Ekstrom, 2010). Crucially, the articulation of building block strategies should emerge through deliberative and participatory processes that empower stakeholders at all levels to co-create the strategic agenda. This includes the development of visioning workshops, scenario planning, and multi-criteria decision-making frameworks. Such participatory governance models help ensure that actions are not only technically sound but also socially acceptable, locally relevant, and politically feasible - factors that are essential for sustaining momentum in climate adaptation over the long term.
Ultimately, building block level strategies must be conceived as dynamic interfaces - capable of integrating knowledge, practice, and governance - to bridge ambition and action in the climate-resilient transformation of urban systems. Their effectiveness depends on iterative evaluation mechanisms, flexible regulatory environments, cross-sector collaboration, and long-term investment frameworks. By rooting these strategies in robust conceptual foundations and translating them into context-specific design actions, it becomes possible to activate a process of urban transformation that is not only resilient to climate risks, but regenerative by design.
In this perspective, interventions on the envelope represent one of the most effective actions for enhancing climate resilience and improving the energy and environmental performance of buildings. The following technical analysis, focused on façades, describes an integrated retrofit solution that combines innovative technologies with multiple benefits. It stands as an exemplary and replicable case of intervention, useful for translating adaptation and mitigation strategies into operational measures within urban regeneration processes

Table 6.4 Design proposal sheet related to envelope retrofit

TITLE				
ENVELOPE RETROFIT – FACADE				
SCALE				
□ metropolitan	□ urban context	□ district	☑ building blocks	
SECTORAL DOMAIN				
X Grey	□ Green	□ soft		
HARD INFRASTUCTURE				
☑ Grey infrastructure ☑ Urban element □ Urban network	☑ Green infrastructure ☑ Green Buildings □ Green-grey area □ Urban and peri-urban □ Urban green area □ Natural or seminatural green area		□ Blue infrastructure □ Blue area □ Blue-green area	

HAZARD CONSIDERED					
☑ heatwave/ coldwave	☑ pluvial flooding	□ drought	□ coastal and fluvial flooding	□ others	□ …
BENEFITS					
☑ Reduced energy consumption	☑ Energy efficiency	☑ UHI reduction	☑ Reduction of CO2 and greenhouse gas emissions	□ …	□ …
CO-BENEFITS					
☑ Improved indoor comfort	☑ economic	☑ ..	□ …	□ …	□ …

BRIEF DESCRIPTION

Objective

The aim of the project is to improve the building's energy and environmental performance by upgrading its envelope, with a particular focus on the roof and facades. The retrofit aims to increase resilience to climate change, reduce energy consumption, mitigate the urban heat island effect, and improve indoor comfort, while contributing to the reduction of greenhouse gas emissions.

1. Facades Insulations:
   - External insulation: reduces thermal bridges and heat loss, improves thermal transmittance, phase shift and attenuation, reduces the building's energy requirements and, consequently, CO2 emissions, improving indoor comfort;
   - Internal insulations: Used when external intervention is not possible due to architectural or historical constraints. This may include the use of low-conductivity internal insulation panels, moisture-regulating materials, and modular systems integrated with finishes. Effectiveness depends on proper control of thermal bridges and internal ventilation to prevent condensation;
   - Cavity wall insulation: This is implemented when the external wall has an empty cavity of at least 50 mm and is filled with insulating material to improve the thermal properties of the wall.
2. Ventilated facade: It is a cladding technique that exploits the ventilation of an air chamber created between the thermal insulation and the external façade panels, which can be made of different materials (bricks, stone, metal, ceramics). It is designed to create a chimney effect caused by the temperature difference between the air in the air chamber and the incoming external air, through natural convection.;

BEST PRACTIES

Description

"The Arroyo", Santa Monica, California. Koning Eizenberg Architects. Certification LEED Platinum



Source image: USGBC.org. The Arroyo | U.S. Green Building Council

This LEED Platinum project uses a combination of passive and active systems to address energy, water, and wellness. High albedo roofs reduce heat island effect reducing cooling demand, while rooftop PV's and solar hot water panels offset energy use. Access hallways are not conditioned. Enhanced air filtration and low VOC materials improve interior air quality. Sunshades reduce solar gain and glare encouraging residents to maximize daylight. Artificial lighting fixtures are all high efficiency. In-ground drought tolerant non-invasive plantings reduce water demand as do high efficiency plumbing fixtures.

STAKEHOLDERS

Envelope retrofit interventions, especially when aimed at enhancing climate resilience, require the coordinated involvement of multiple actors operating at different institutional and spatial scales. These include public authorities, private sector stakeholders, professional experts, community-based organizations, and citizens themselves. Their roles are not merely operational but strategic, as the success of retrofitting depends on context-sensitive planning, legitimacy, and social acceptance.

Such interventions should be understood as part of broader governance processes that link energy transition goals with urban regeneration, risk reduction, and social inclusion. Collaborative governance structures—characterized by knowledge-sharing, mutual learning, and co-production—are key to mobilizing capacities across sectors and aligning retrofit measures with local needs and vulnerabilities (Fudge & Peters, 2009; Bulkeley et al., 2014).

Involving end users and local communities in the early stages of design and decision-making enhances the social effectiveness of technical solutions, ensures equitable access to benefits, and fosters a sense of ownership and stewardship. Retrofit strategies must therefore be integrated into urban planning tools that recognize and respond to place-specific climatic risks, enabling the development of adaptive, low-impact, and culturally attuned solutions (D'Ambrosio et al., 2023).

PROPOSAL DESIGN

DESIGN IMPLEMENTATION GUIDELINES

The 'envelope retrofit' design proposal represents a package of fundamental solutions in the definition of conceptual guidelines. In particular:

- It identifies and defines some of the environmental sustainability and energy efficiency objectives that should be ensured within an integrated urban adaptation, mitigation and resilience project;
- Defines the need to undertake an analysis of existing buildings so that targeted and efficient strategies and solutions can be developed;

- Defines and emphasises the importance of choosing innovative materials and technologies; - Stresses the importance of a post-intervention performance monitoring process, so as to ensure the achievement of efficiency and effectiveness objectives; - Defines the importance of using sustainable materials and advanced technologies that reduce impacts on the environment; - Stresses that upgrading the envelope results in an aesthetic renewal of the building, harmonized with the original aesthetics and the surrounding context; - Stresses the importance of choosing durable solutions and materials that are easy to maintain, reducing operating costs and ensuring the need for low maintenance; - Emphasizes the importance of choosing roofing solutions that do not add to the load bearing structure; - Stresses the importance of using recycled materials to reduce waste and environmental impact.
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6.3.4 Multiscale/ar interaction/approach

A robust and future-oriented approach to climate adaptation within the New European Bauhaus framework necessarily requires the adoption of an integrated multiscale perspective. This approach is not a methodological option but a structural necessity, particularly in light of the complex challenges posed by climate change, such as extreme heat events, the urban heat island effect, and hydrogeological risks (e.g., landslides, flash floods, or soil erosion). These phenomena manifest across spatial gradients and temporal scales that often do not align with traditional planning units or administrative boundaries.

It is important to note that while the New European Bauhaus framework does not explicitly articulate a multiscale approach, it does promote a multilevel governance model that inherently operates across different institutional and territorial layers. The emphasis within NEB is placed on involving a diversity of actors—citizens, local authorities, designers, scientists and policymakers—across various levels of decision-making, which reflects a strong commitment to vertical integration and subsidiarity.

However, the multiscale spatial dimension, while not explicitly defined in NEB foundational texts, is implicitly embedded in many of the initiative's principles and design guidelines. For instance, when the NEB advocates for climate-resilient, inclusive and beautiful living spaces, it refers to transformations that must occur simultaneously at the building scale, the neighbourhood level, and the broader urban or territorial/metropolitan scale—each requiring different strategies, tools and actors.

In this sense, although NEB does not codify a formal multiscale planning methodology, its holistic and systemic ambition presupposes multiscale thinking. The initiative's call for integrated solutions, cross-sector collaboration, and contextualised design inherently aligns with the logic of spatial scaling. Therefore, operationalising NEB principles in climate adaptation and urban resilience planning requires translating its multilevel governance orientation into a consciously multiscale approach, where interventions are tailored to the appropriate spatial unit—be it a street, a valley or an entire urban region.

Indeed, one of the main issues in planning for resilience is that geographical units relevant to climate-related phenomena rarely coincide with the boundaries of administrative jurisdictions such as municipalities, provinces, or regions. Climate risks such as coastal flooding or upstream-downstream hydrological interactions operate according to geomorphological logics—e.g., river basins, mountain valleys, or coastal systems—that are disconnected from the institutional map used for governance. As a result, interventions based solely on fixed administrative boundaries risk being ineffective, fragmented, or even counterproductive.

To address this misalignment, the NEB approach indirectly calls for an integrated multiscale strategy, where scale is determined not by planning conventions but by the level of intervention and the actors responsible for its execution. This means shifting from a rigid interpretation of geographic scale to a more relational and operational perspective, in which the relevance of a scale emerges from the interaction between the nature of the risk, the technical solution proposed and the institutional capacity in place.

In this view, it becomes more appropriate to speak of a multiscale gradient, rather than discrete and disconnected levels. There is no sharp boundary between one spatial or administrative level and another. Rather, there exists a continuous transition across densities, intensities and geomorphological units—such as hydrological basins, ecological corridors, or mountainous catchments—that require differentiated yet interlinked strategies. These "functional geographies" act as the true substrata for understanding, modelling and intervening in climate dynamics.

Within these functional units, it is also essential to differentiate between geographic areas with shared morphological, socio-economic, and ecological characteristics, such as coastal areas, inland territories or peri-urban belts. The multiscale approach becomes particularly meaningful when embedded within these homogeneous units, where interventions can be context-specific yet scalable and transferable.

In this regard, the concept of Functional Urban Areas (FUAs) could become essential. FUAs are defined by the European Union as urban cores and their surrounding commuting zones, representing real patterns of economic, social, environmental, and infrastructural interdependence that transcend administrative boundaries. FUAs can offer a pragmatic and analytical reference framework for climate adaptation, as they often encompass the full range of interactions and dependencies that shape climate vulnerability and resilience—from upstream catchment areas to downstream floodplains, from residential zones to industrial belts.

As such, in relation to the interaction between climate change and society, FUAs could serve both as general containers for the design of adaptation solutions and as units of analysis for understanding how climate risks manifest across space and society. They provide a functional lens through which to identify shared challenges (e.g. air pollution, heat stress, water scarcity) and to coordinate cross-jurisdictional responses. Importantly, FUAs also support the integration of climate models, land-use planning, and infrastructure design, making them critical operational scales for aligning NEB principles with evidence-based urban and regional policy.

Ultimately, while NEB builds on a multilevel governance ethos, it is through the adoption of a multiscale planning perspective—anchored in functional geographies like FUAs—that its transformative potential can be fully realised. Only by doing so can climate adaptation strategies become coherent across scales, effective in addressing the right phenomena at the right level, and legitimate in terms of stakeholder involvement and institutional responsibility.

Crucially, the multiscale dimension is inseparable from the multilevel governance dimension. Governance structures are themselves organized according to jurisdictional scales, where competencies and responsibilities are distributed across municipal, regional, national, and EU levels. These institutional layers interact with the same territory, often overlapping or conflicting. For this reason, governance systems must be re-read through a multiscale and integrated lens, ensuring that actors across levels cooperate within coherent, cross-scalar frameworks.

Lastly, the challenge of modelling climate risks and adaptation scenarios further underscores the need for a multiscale logic. Different models are designed for different spatial and temporal resolutions, and they rely on input data that are themselves referenced to different scales. Without careful integration, this leads to fragmentation in both analysis and policy. Therefore, model interoperability must be pursued so that the output of one scale-specific modelling approach can serve as input for another, allowing for the construction of a chained modelling framework capable of supporting decision-making across domains. This becomes even more complex when crossing from one disciplinary domain to another—for example, from meteorological to hydrological to urban planning domains—each with its own tools, languages, and spatial assumptions.

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8 Annex

The document aims to provide a methodological framework to support the transition of urban districts towards resilient and regenerative eco-districts, summing up interdisciplinary knowledge and translating it into operational tools. Through such a general framework, it is possible to develop appropriate recommendations, general rules or principles for managing specific conditions. The recommendations help users of the Guidelines to make informed decisions about whether to undertake specific interventions and where and when to do so, while also supporting them in selecting and prioritizing among a range of potential interventions. In the context of integrated urban resilience, the Conceptual Guidelines can provide a structured framework to support the resilient and regenerative transition of urban districts into eco-districts.

9 Authors contribution

Even if the Deliverable are unified in their aspects of conception, knowledge framework, methodological approach and experimentation, the contributions have been elaborated as follows:

1. **Introduction** - Valeria D'Ambrosio, Daniele Vettorato
2. **Conceptual frameworks and reference scenario**
   - 2.1. "Green transition for regenerative urban settlements" – UNINA-DiARC Valeria D'Ambrosio, Sara Verde.
     - 2.1.1. "European and national framework for green transition: policy, programs and guidelines" - UNINA-DiARC Valeria D'Ambrosio, Maria Fabrizia Clemente, Chiara Russo, Sara Verde
     - 2.1.2. "From urban Districts to regenerative urban Eco-districts" - UNINA-DiARC Valeria D'Ambrosio, Sabrina Puzone, Sara Verde
   - 2.2. "The New European Bauhaus" - EURAC Daniele Vettorato
     - 2.2.1. "Key concepts" - EURAC Daniele Vettorato
   - 2.3. "Resilience of urban settlements in the framework of green transition" - UNINA-DiARC Maria Fabrizia Clemente, Sabrina Puzone
     - 2.3.1. "Urban Resilience under multi-risk scenarios" - UNINA-DiARC Maria Fabrizia Clemente, Sabrina Puzone
     - 2.3.2. "Review of existing protocols for urban resilience assessment and monitoring" - UNINA-DiARC Maria Fabrizia Clemente, Sabrina Puzone
     - 2.3.3. "From urban resilience to urban integrated resilience" - UNINA-DiARC Maria Fabrizia Clemente, Sabrina Puzone
3. **Planning tools and methods for urban regeneration**
   - 3.1. "Target definition and reference scenario"
     - 3.1.1. "Review of existing planning tools and methods for urban regeneration at national level" - UNINA-DiARC Maria Fabrizia Clemente, Sara Verde
     - 3.1.2. "The gap in planning and design in compliance with NEB" – EURAC Daniele Vettorato
     - 3.1.3. "The gap in planning and design at urban scale" - UNINA-DiARC Antonio Sferratore, Chiara Russo
   - 3.2. "Strategic Environmental Assessment (SEA) and climate change adaptation (CCA)" - UNICA-DICAAR Corrado Zoppi, Sabrina Lai, Federica Leone
     - 3.2.1. "Introduciton and general conceptual layout" - UNICA-DICAAR Corrado Zoppi, Sabrina Lai, Federica Leone
     - 3.2.2. "Integration of the strategic framework of the Nation Plan for Adaptation to Climate Change into Municipal Master Plans (MMPs) through SEA" - UNICA-DICAAR Corrado Zoppi, Sabrina Lai, Federica Leone
     - 3.2.3. "Implementation of the methodological approach into the logical frameworks (LFs) of the Ers of four MMP's" - UNICA-DICAAR Corrado Zoppi, Sabrina Lai, Federica Leone
     - 3.2.4. "Policy implications" - UNICA-DICAAR Corrado Zoppi, Sabrina Lai, Federica Leone
     - 3.2.5. "A proposal of planning tools integration through PoC for the transition of urban districts into urban eco-districts" - UNINA-DiARC Maria Fabrizia Clemente, Antonio Sferratore, Sara Verde
4. **Monitoring and assessment systems through indicators and protocols for urban integrated resilience in the framework of green transition**
   - 4.1. "Indicators and protocols to monitor and assess urban systems" - POLITO Angioletta Voghera, Benedetta Oberti, Giosuè Pier Carlo Bronzino, Valeria Vitulano, Ilaria Cazzola
   - 4.2. "Indexes and indicators for the assessment of adaptation and mitigation capacity to climate change in urban districts" - UNINA-DiARC Maria Fabrizia Clemente, Sara Verde
   - 4.3. "A review of protocols and tools for urban integrated resilience" - UNINA-DiARC Silvia Cimmino, Anna Citarella, Antonio Sferratore
   - 4.4. "NEB dedicated monitoring and assessment framework" – EURAC Daniele Vettorato
   - 4.5. "Circularity" – EURAC Daniele Vettorato