POLITECNICO DI TORINO

MASTER'S DEGREE PROGRAMME IN TERRITORIAL, URBAN, ENVIRONMENTAL AND LANDSCAPE PLANNING

CURRICULUM: PLANNING FOR THE GLOBAL URBAN AGENDA

IMPLEMENTATION OF NATURE-BASED SOLUTIONS (NBS) FOR URBAN HEAT ISLAND (UHI) MITIGATION

RESTORATION OF GREEN BROWNFIELDS IN THE CITY OF MILAN

MASTER APPLICATION THESIS

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A Stefano,

Ubi tu, ibi ego

“Dovunque tu sarai, io sarò lì con te”

ABSTRACT

The objective of this work was to contribute to the recovery of a disused green area in the municipality of Milan, located in one of the most vulnerable areas, through the implementation of nature-based solutions (NBS) to mitigate urban heat island (UHI) problems. After an initial overview of climate change issues and the problems caused by urban heat islands (UHI), an in-depth analysis of NBS solutions was carried out with the aim of understanding which of them were most suitable for the project, but also how they could be economically evaluated. Both the technical implementation and subsequent maintenance of NBSs were considered, as well as the economic return and environmental and social benefits. To identify degraded green spaces in the city of Milan that could benefit from NBS intervention, a vulnerability map was developed based on three macro variables: environment, society and infrastructure. The map was created using QGIS software and the Analytical Hierarchy Process (AHP) technique was used to weight the variables using SuperDecision software. Based on this map, it was possible to select an abandoned area where it was decided to implement urban reforestation as an NBS solution, with the intention of providing cooling benefits for UHI mitigation and also to provide a green area for citizens in a vulnerable context. Once the NBS to be implemented was identified, all the cost items for its implementation were analysed with reference to the 2024 Prezzario of the Lombardy Region. The cost analysis continued with the maintenance items for the years following implementation, calculated for a 20-year period. Finally, to estimate the potential benefits generated by ecosystem services from NBS implementation, a literature review was conducted, followed by a cost-benefit analysis (CBA) to quantify the economic value of these services. This work illustrates the significance of brownfield redevelopment in large urban contexts, such as Milan, integrating solutions such as NBS. It demonstrates how these micro-interventions can potentially benefit the population and the environment by mitigating increasingly urgent problems. Furthermore, it illustrates the importance of a decision support tool, such as the one developed in this thesis, which can identify the areas in which it is most important to intervene and provide information regarding costs and benefits in monetary terms.

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SUMMARY

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PART I

This initial section of the paper presents a comprehensive examination of the principal concerns associated with climate change and its implications in the urban setting.

The chapter commences with a framing of the climate change phenomenon, examining how it is defined and addressed by the United Nations through international agreements. The main principles of these agreements and how they are transposed and implemented by signatory countries are outlined, with a focus on mitigation and adaptation strategies.

The focus then shifts to one of the most relevant consequences of climate change in the urban context: the Urban Heat Islands (UHI) phenomenon. A detailed definition of the phenomenon is provided, analysing the main factors contributing to its formation, such as intense urbanisation, the reduction of green spaces and the massive use of heat-absorbing materials. The negative impacts of UHI on public health, energy consumption and the urban environment are also examined. The chapter then proceeds to examine potential mitigation strategies to offset the heat island effect.

Finally, the chapter considers the potential of nature-based solutions (NBS) to address both climate change and urban heat islands. It provides a comprehensive definition of NBS, explains how they are classified and analyses the multiple benefits of their implementation.

1. CLIMATE CHANGE

1.1 THE UNITED NATIONS AND ITS ROLE IN PROMOTING SUSTAINABILITY FOR THE CLIMATE CHANGE

The United Nations Organisation (UN), founded in 1945, plays an indispensable role in global governance for the promotion of sustainability, directing and coordinating plans and programmes aimed at achieving it. The UN World Commission on Environment and Development (WCED) defines sustainability as follows: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UCLA Sustainability, n.d.). The United Nations regards spatial planning as an integrated and participatory tool for the management of territories. Through the development of international guidelines, it provides a globally universal framework with the objective of improving the policies, plans or programmes of territories in order to make them more integrated and resilient to climate change.

1.1.1 STRUCTURE AND ORGANIZATION

The United Nations (UN) is an international non-profit organisation that aims to improve political and economic cooperation among its member states. Founded in the aftermath of the Second World War, the UN now has 193 member states from around the world, all of which are represented in the UN General Assembly. Headquartered in New York, its core principles are peace, security, human rights, sustainable development and climate.
The United Nations (UN) consists of five main organs: the UN General Assembly, the UN Secretariat, the International Court of Justice, the UN Security Council and the UN Economic and Social Council, as well as a number of specialised agencies and related organisations (Table 1). The structure of the UN system of organization is represented in Figure 1.

TABLE 1 - UN'S ORGANS, ROLES AND FUNCTIONS (SOURCE: AUTHOR RE-ELABORATION FROM UNITED NATIONS, N.D.)

ORGANS	ROLE	FUNCTIONS	NOTES
UN General Assembly	Principal deliberative body	Discusses and makes recommendations on international issues, oversees the budget, elects the Secretary General.	Composed of all 193 Member States
UN Security Council	The maintenance of international peace and international security	Establishment of peacekeeping operations, imposition of sanctions, authorisation of the use of force	15 members, 5 permanent with veto right (China, France, Russia, UK, USA)
UN Economic and Social Council	Coordinating economic, social and environmental work	Promoting economic and social progress, finding solutions to international problems	Election of 54 members for a three-year term of office
International Court of Justice	Principal judicial body	Resolution of legal disputes between states, advisory opinions on legal issues	Composed of 15 judges elected for nine years, seat in The Hague, Netherlands
UN Secretariat	Administration of the UN's daily work	Managing peacekeeping operations, mediating international disputes, organising conferences	Led by the Secretary General, currently António Guterres
Specialized Agencies and Related Organizations	A variety of agencies with their own constitutions, membership and budgets.	Co-operation with the UN on specific issues such as health, labour, agriculture, finance, etc.	Examples: FAO, WHO, IMF, ILO, UNESCO, World Bank Group, ICAO, WMO

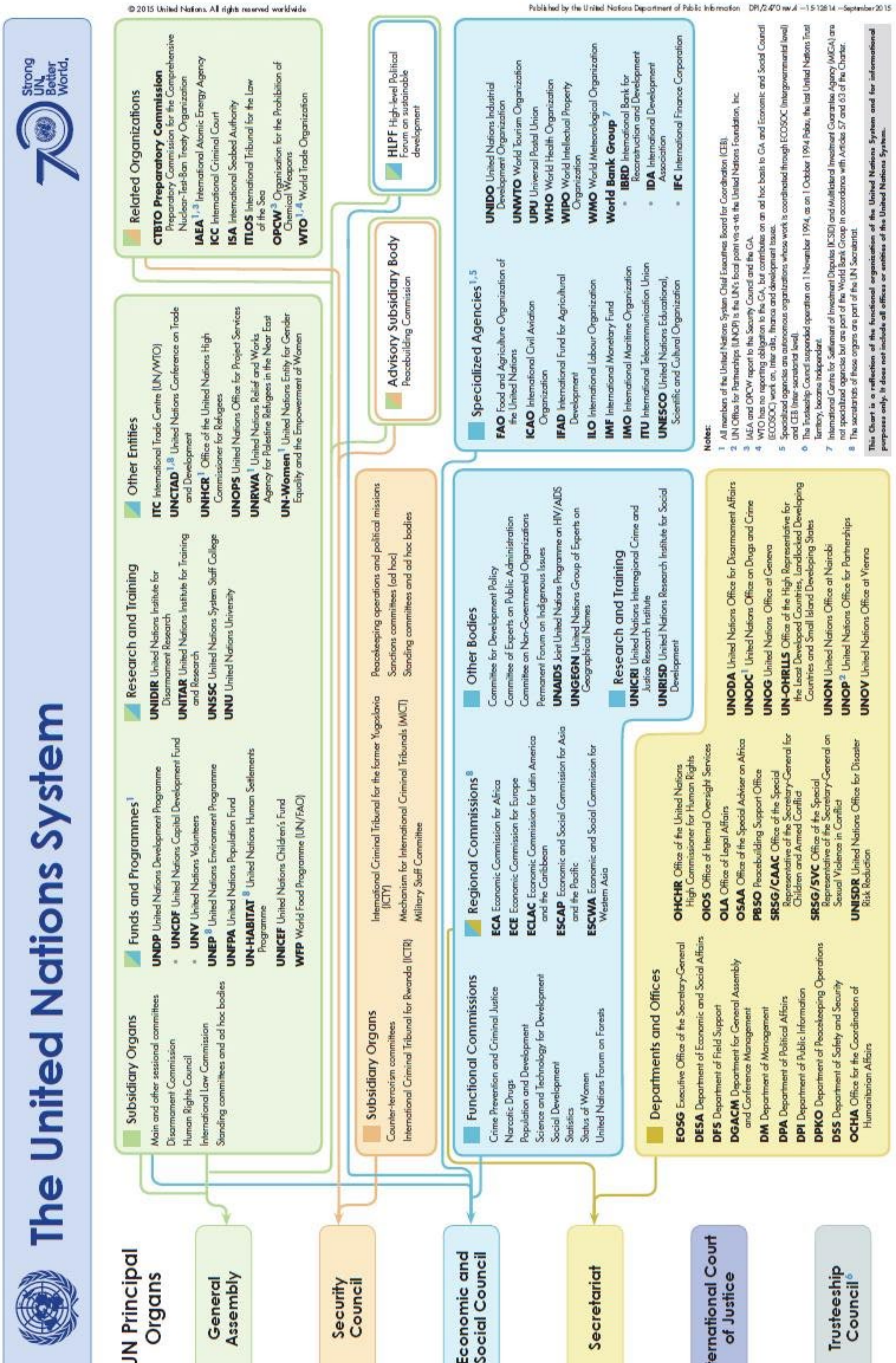


FIGURE 1 - THE OVERVIEW OF THE UN SYSTEM OF ORGANIZATIONS (SOURCE: OLTER-CASTILLO, 2021)

1.1.2 Challenges in achieving Sustainability Targets

The difficulties faced by the UN in implementing sustainability policies are many and varied, covering the economic, social and environmental spheres, as well as various aspects of governance and international cooperation of all 193 Member States. Climate change is undoubtedly one of the most pressing challenges, and it is precisely on this front that the UN is working to develop policies to mitigate and adapt to the effects of this phenomenon in the different geographical areas of the world. The aim is to act as quickly as possible to avoid reaching situations of no return, such as temperatures too high for biodiversity. To do this, the different levels of government must be as effective and coordinated as possible. However, national governance is still very fragmented between different institutions, treaties, and agreements. With this in mind, UN agencies such as the United Nations Environment Programme (UNEP) are constantly working to improve and coordinate communication between the various international organizations, states, NGOs, and private individuals. Cooperation between the different levels is essential for the development and implementation of effective environmental policies but is difficult due to political and operational differences between the different member states (United Nations, n.d.-b). The transition to sustainability also affects the cultural sphere of different countries, as it requires significant changes in individual and community behaviour. There is also the challenge of raising environmental awareness and educating the various populations involved; in this sense, the UN is working to make this information more accessible (UIL, 2020).

Another problem is the scarcity of funds, which makes it difficult for international organisations to implement environmental policies because of a lack of resources. UNEP also has one of the most limited annual budgets within the UN, a situation that does not apply to the other programmes managed by the UN. In addition, the fact that environmental treaties are often kept separate from each other makes it even more difficult for the different bodies to work together, leading to duplication of functions and, above all, costs (Ministero Dell'Ambiente E Della Sicurezza Energetica, n.d.).

It is also important to consider the impact of unrest, instability and wars between the various nations involved in the UN on the achievement of sustainability. A current example is the war between Ukraine and Russia. As these two nations are major producers of barley and wheat, accounting for 30% of the world's exports, the nations that previously relied on them for the purchase of these raw materials are now left without. The underlying issue is that, as a consequence of globalisation, nations are now interdependent on one another in order to sustain their lifestyles (Blogger, 2024).

In contrast, poverty represents another obstacle to the realisation of sustainability, despite the fact that one of the objectives of sustainable development is to eradicate it. Individuals residing in underdeveloped countries are financially disadvantaged, and these inequalities are not limited to cross-state disparities but also manifest within a single state. Inequalities may encompass gender inequality, energy poverty, access to healthcare, and so forth. Moreover, the implementation of plans and programmes in less developed countries will be more challenging due to their lack of both material and cognitive resources (Blogger, 2024).

1.1.3 PROBLEMS OF NATIONAL SOVEREIGNTY: ANALYSIS AND TENSIONS OF NATIONAL SOVEREIGNTY IN THE UN CONTEXT

The concept of national sovereignty is inherently complex, as conflicts frequently arise due to tensions between states' own principles of sovereignty and the necessity to cooperate with one another in order to address global sustainability challenges. The term 'sovereignty' is understood to signify the absolute authority of a state over its population and territory within its geographical boundaries, endowed with independence and recognised by other states in the world. It is evident that sovereignty is inextricably linked to national interests, particularly with regard to the control and exploitation of natural resources and the development of environmental policies in accordance with the state's own priorities. However, this perspective frequently conflicts with the principles of the United Nations (UN) with regard to international cooperation in addressing environmental issues (Mauricio, 2002).

The advent of global governance has led to the development of laws, policies and institutions that require member states to relinquish certain aspects of their sovereignty. Consequently, the cooperation mechanisms that are required to address environmental issues often encroach on state sovereignty, as they have to balance their national interests with those of other states, sometimes giving up profits or interests. This can be perceived by states as a genuine constraint on national sovereignty. In many instances, it is challenging to identify a genuine compromise between their own interests and those that are required by the UN (Barral, 2016).

Following this framing, there is a growing recognition that the UN must undergo a reorganization in order to be better equipped to address contemporary global challenges in an effective manner. This reform must strengthen the role of conflict prevention and resolution in order to ensure that international financial systems are able to cope with sustainable development. It is also the responsibility of the UN to intervene in order to reconcile national sovereignty with the norms imposed upon it. This should be done in a way that respects the policies and needs of the state in question, while also promoting cooperation and collective action (United Nations. Meetings coverage and press releases, 2023).

1.2 DEFINITION OF CLIMATE CHANGE

The definition of climate change started about two hundred years ago when Joseph Fourier, a French mathematician and physicist, identified the greenhouse effect. Only in the 19th century, Claude Pouillet, and later Eunice Newton Foote, furthered this work. In 1967, for the first time scientists create the first computer model of planet Earth's climate where it predicts that doubling concentrations of CO_2 could raise global temperatures by 2°C. One year after, Dr. John Mercer, a glaciologist at Ohio State University in Columbus, cautions that a catastrophic rise in sea levels could result from the disintegration of Antarctic ice sheets due to global warming. In 1988, the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) set up the Intergovernmental Panel on Climate Change (IPCC) to assess scientific, technical, and socio-economic data relevant to understanding the likelihood of human-induced climate change, its possible effects and the options available for adaptation and mitigation. The IPCC has published six assessment reports by the world's leading climate change authorities. The reports have consistently concluded that human activity, in particular the release of greenhouse gases, is the main cause of global warming. International climate negotiations, which resulted in the establishment of the Kyoto Protocol in 1997, the United Nations Framework Convention on Climate Change (UNFCCC) in 1990, and the Paris Agreement in 2015, were made possible in large part by the IPCC's reports (UK Research and Innovation, 2024).

From all these discoveries, we can define the climate-change as "*variation of average weather conditions becoming, for example, warmer, wetter, or drier—over several decades or longer. It is the longer-term trend that differentiates climate change from natural weather variability*" (World Bank Climate Change Knowledge Portal, n.d.). The main causes of it are human activities that produce greenhouse gases into the atmosphere, mostly carbon dioxide and methane, such as burning fossil fuels, deforestation, and certain industrial and agricultural processes (United Nations, n.d.). Global warming is the term for the phenomena whereby the Earth's temperature rises due to these gases trapping heat from the sun. In 2020, the average worldwide temperature increased by 1.7°C over the mean, with the greatest increase occurring in Europe, followed by Asia, Oceania, South America, North America, and Africa. The worldwide annual mean temperature changed by 1.31°C between 2011 and 2020, which is considerably greater than in prior decades and shows a strong warming trend. With the global surface temperature rising by 1.1°C between 2011 and 2020, it is clear that human activities — especially the release of greenhouse gases — are to blame for global warming. The decade of 2020 will be the warmest on record which will have a substantial influence on sea levels, glaciers, ice sheets, and extreme weather. Thus, it is evident that immediate climate action is required to keep the increase in global temperature to 1.5°C, and that cutting greenhouse gas emissions is crucial to lessening the effects of climate change (Calvin et al., 2023).

The year 2023, it is the warmest year on record, surpassing 2016's record. The worldwide average temperature for 2023 was 14.98°C, 0.17°C higher than the 2016 record, according to the ERA5 dataset (Global Climate Highlights 2023 | Copernicus, 2023). As we can see from the next figures (Figure 2, Figure 3), there is a clear difference in the global distribution of anomalies in surface air temperature in 2023 and 2022. In 2023, temperatures were above normal in almost all geographical regions. Over much of Europe, North America, and numerous other locations, annual temperatures were more than 1°C higher than the average from 1991 to 2020. For several locations in 2023, marine air temperatures were also the highest on record. This is true for a large portion of the North and Caribbean Seas, the northern, tropical, and southern regions of the Pacific Ocean, as well as a portion of the South and Indian Oceans. Sea surface temperature (SST) anomalies are strongly related to anomalies in air temperature in these and other places. The southwest of South America was the only sizable area where marine air temperatures were the lowest on record. The change from La Niña to El Niño conditions, which are addressed more below, is illustrated by the difference in temperatures across the tropical and southern subtropical eastern Pacific Ocean between 2022 and 2023, going from the coldest to almost the hottest on record.

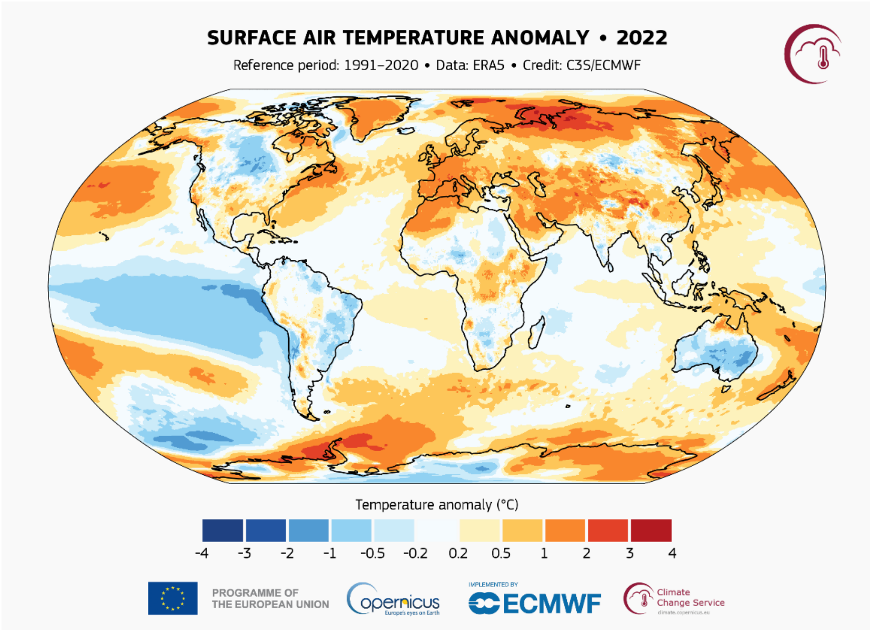


Figure 2 - Surface air temperature anomaly for 2022 relative to the average for the 1991–2020 reference period. Data: ERA5. (Source: Global Climate Highlights 2023 | Copernicus, 2023)

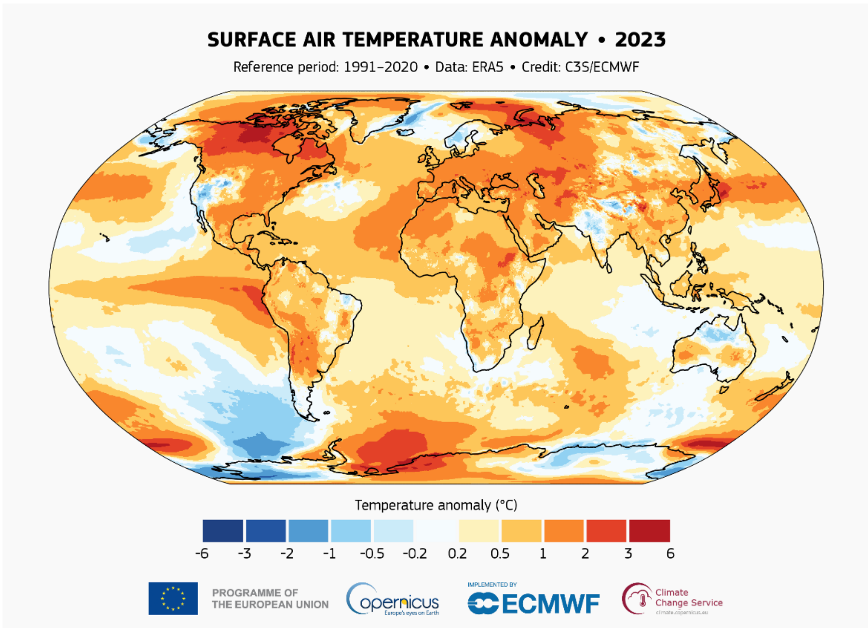


Figure 3 -Surface air temperature anomaly for 2023 relative to the average for the 1991–2020 reference period. Data: ERA5. (Source: Global Climate Highlights 2023 | Copernicus, 2023)

This steady rise in temperatures is especially due to the growth of CO2 concentrations in the atmosphere. The consequences of this trend jeopardise the achievement of the SDGs. The SDGs were adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development (United Nations, 2024). These goals represent a universal agenda to end poverty, protect the planet, and ensure that by 2030 all people enjoy equal rights and equity. The SDGs are built around 17 specific targets that address major global challenges such as poverty, hunger, health, education, gender equality, clean water, clean energy, decent work, economic growth and combating climate change (Figure 4). The SDGs are the result of a negotiation process involving the governments of 193 UN member states and millions of people from the private sector, civil society and expert groups. This process began with the United Nations Conference on Sustainable Development (Rio+20) held in Rio de Janeiro in 2012, where it was agreed that there was a need to develop goals that would guide global development after 2015. After Rio+20, a UN open-ended working group of representatives from 70 countries was established to develop a proposal on the SDGs. This group worked through a series of public hearings and thematic meetings involving a wide range of stakeholders. The process was characterised by a high level of transparency and public participation and aimed to ensure that the SDGs reflected the priorities of all countries and sectors of society (United Nations, 2024).

Number	Icon	Name	Text
1		No poverty	End poverty in all its forms everywhere
2		Zero hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3		Good health and well-being	Ensure healthy lives and promote well-being for all at all ages
4		Quality education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5		Gender equality	Achieve gender equality and empower all women and girls
6		Clean water and sanitation	Ensure availability and sustainable management of water and sanitation for all
7		Affordable and clean energy	Ensure access to affordable, reliable, sustainable and modern energy for all
8		Decent work and economic growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9		Industry, innovation and infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10		Reduced inequalities	Reduce inequality within and among countries
11		Sustainable cities and communities	Make cities and human settlements inclusive, safe, resilient and sustainable
12		Responsible consumption and production	Ensure sustainable consumption and production patterns
13		Climate action	Take urgent action to combat climate change and its impact
14		Life below water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15		Life on land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16		Peace, justice and strong institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17		Partnerships for the goals	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

FIGURE 4 - THE 17 SUSTAINABLE DEVELOPMENT GOALS AS PRESENTED BY THE UNITED NATIONS (SOURCE: GUENAT ET AL., 2022, P. 2)

As stated before, the increase of CO_2 in the air leads to various consequences, including indirect ones, on other aspects involving climate change and thus could hinder the achievement of the global targets by 2030. Below is a diagram clarifying the link between CO_2 concentrations and the achievement of the SDGs (Figure 5).

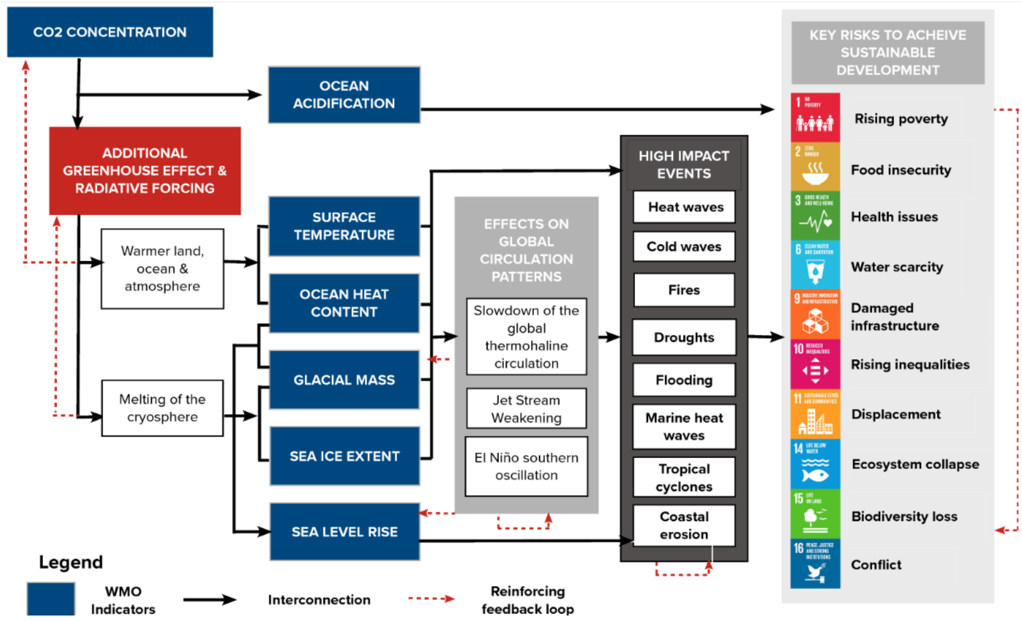


Figure 5 - Risks to achieve Sustainable Development (Source: Provisional State of the Global Climate 2022, 2022)

As far as Europe is concerned (Figure 6), temperatures exhibited significant variability particularly during spring and summer, showcasing a notable contrast in climatic conditions throughout the continent. In both seasons, Europe experienced above-average temperatures, although not reaching record-breaking levels. Spring of 2023, while notably warmer than the preceding two years, did not rank among the top ten warmest in historical data records. During this period, Iberia and northeastern Europe encountered well above-average temperatures and drier weather conditions, while a diagonal band stretching from northwest to southeast in Europe saw temperatures close to the average with wetter-than-average conditions prevailing. May stood out as the sole month in the year with conditions slightly below the climatological mean (Global Climate Highlights 2023 | Copernicus, 2023).

The summer of the year 2023 was classified as the fifth-warmest, with an average temperature of 19.63°C, marking a 0.83°C increase above the 1991-2020 climatological average, following the record-breaking warmth of the European summer in 2022. June brought hot and dry conditions to northern Europe and cooler-than-average temperatures in the south. In contrast, July and August experienced cooler and wetter conditions in northern Europe, while southern and southwestern Europe faced heatwaves, leading to the breaking of numerous daily temperature records. These heatwaves extended to marine regions, impacting both the Atlantic and the Mediterranean, with significant wildfires also reported (Global Climate Highlights 2023 | Copernicus, 2023).

From October to December, Scandinavia encountered notably cold conditions, while the rest of the continent experienced above-average temperatures, resulting in the second-warmest autumn on record. The European average temperature for this period was 10.96°C, marking a 1.43°C increase above the average, just 0.03°C cooler than the autumn of 2020 (Global Climate Highlights 2023 | Copernicus, 2023).

Europe also witnessed a series of severe storms and flooding events (Figure 7). Notable flood occurrences, triggered by heavy or record-breaking precipitation, were reported in various regions, including Emilia-Romagna, Italy, in May; Norway, Sweden (storm Hans), and Slovenia in August. Autumn brought multiple storms and associated flooding, such as in Greece in September (Storm Daniel, which also caused devastating flooding in Libya); in northern and western Europe in October (Storm Babet); across the Iberian Peninsula (storm Aline); and in most of western Europe in October (Storm Ciarán). Despite the widespread heavy precipitation in 2023, it only partially alleviated the persistently drier-than-average conditions in southern Iberia and France, parts of the Alps, the eastern Balkans, and a significant portion of eastern Europe (Global Climate Highlights 2023 | Copernicus, 2023).

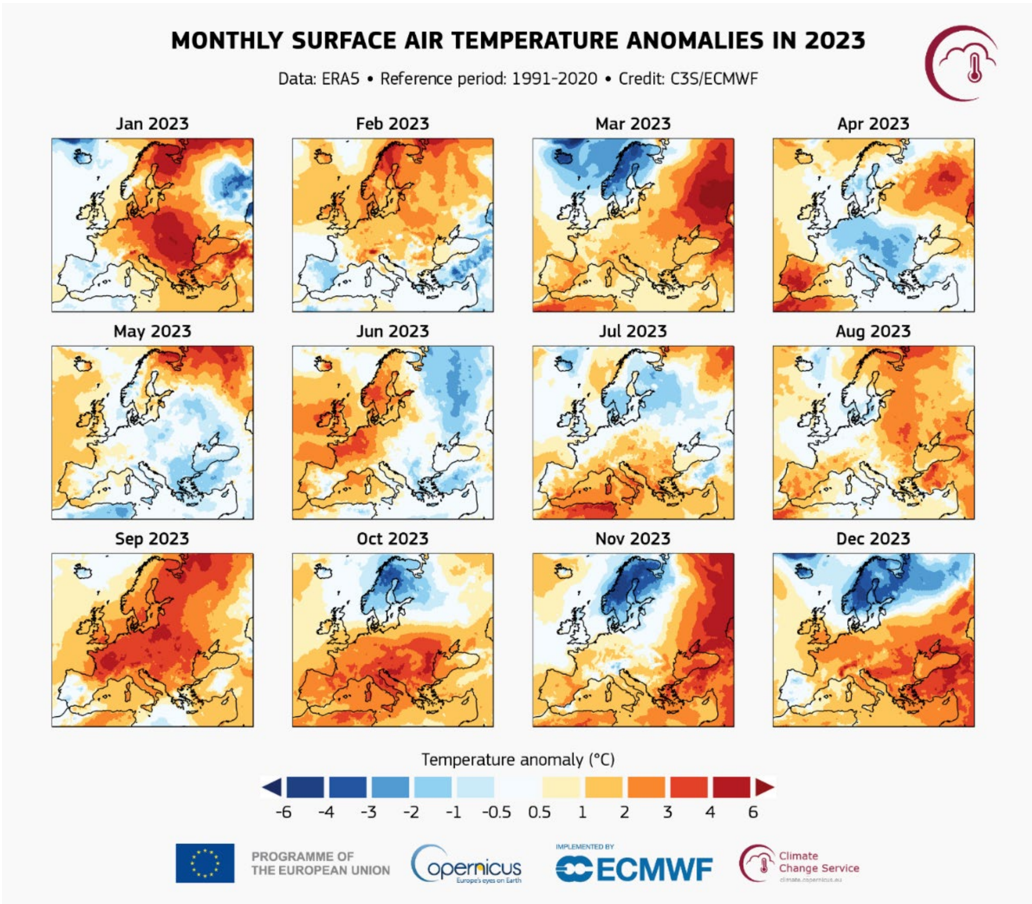


FIGURE 6 - SURFACE AIR TEMPERATURE MONTHLY ANOMALIES FOR EUROPE IN 2023, RELATIVE TO THE CORRESPONDING AVERAGES FOR THE 1991-2020 REFERENCE PERIOD. DATA SOURCE: ERA5 (SOURCE: GLOBAL CLIMATE HIGHLIGHTS 2023 | COPERNICUS, 2023)

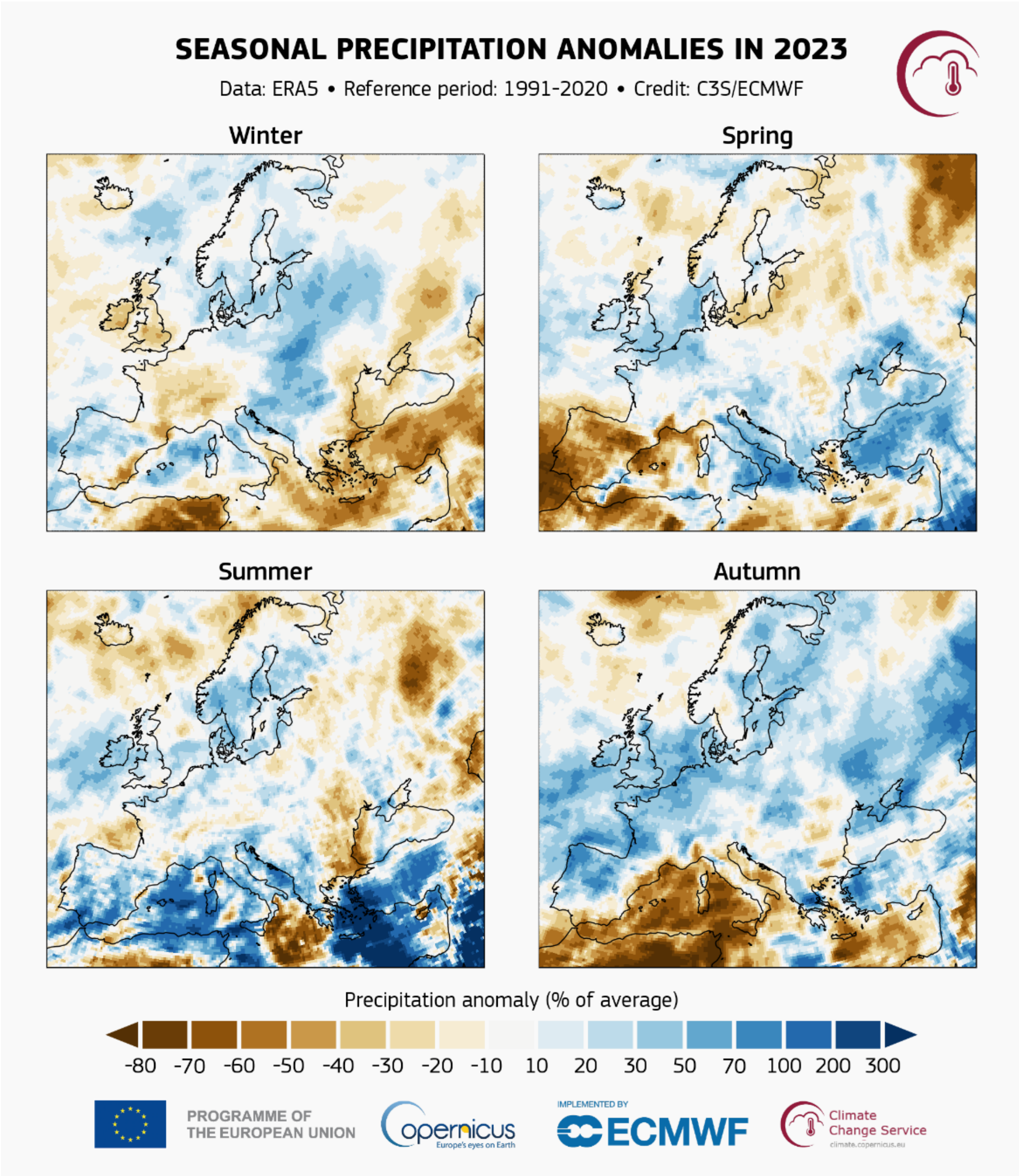


FIGURE 7 - SEASONAL ANOMALIES IN PRECIPITATION FOR EUROPE, RELATIVE TO THE CORRESPONDING SEASONAL AVERAGES FOR THE 1991-2020 REFERENCE PERIOD, FOR BOREAL WINTER 2022-2023 AND SPRING, SUMMER AND AUTUMN 2023. THE ANOMALIES ARE EXPRESSED AS A PERCENTAGE OF THE SEASONAL VERAGES FOR 1991–2020. DATA SOURCE: ERA5 (SOURCE: GLOBAL CLIMATE HIGHLIGHTS 2023 | COPERNICUS, 2023)

1.2.1 LOSS AND DAMAGE FROM CLIMATE CHANGE

The issue of climate change-related loss and damage has been at the centre of international climate negotiations for more than three decades, since the initial drafting of the United Nations Framework Convention on Climate Change (UNFCCC) in 1991. From the outset, developing countries, particularly island nations, have sought to establish financial mechanisms to address the loss and damage caused by the impacts of climate change. However, these proposals were rejected and the issue was not included in the final text of the Convention.

It was only in 2007, with the Bali Action Plan, that loss and damage began to emerge in climate negotiations. In 2013, the Warsaw International Mechanism on Loss and Damage was established with the aim of sharing knowledge and strengthening dialogue. However, this mechanism did not provide any concrete funding to help countries deal with loss and damage. In the 2015 Paris Agreement, developing countries managed to include a specific article on loss and damage (Article 8) recognising its importance and the need to address it specifically within the international agreement. However, funding related to this issue was explicitly excluded, with developed countries stating that loss and damage 'do not imply or provide a basis for any liability or compensation' (UNFCCC, n.d.)

At COP26 in 2021, vulnerable countries again called for the creation of a dedicated financial instrument, but the proposal was rejected. Instead, a two-year dialogue was set up to discuss possible funding arrangements, and the Santiago Network on Losses and Damages (SNLD) was funded with more than EUR 30 million by some EU Member States (*What Is 'Loss and Damage' from Climate Change? 8 Key Questions, Answered*, n.d.). At COP27 in 2022, the formal agenda included loss and damage financing agreements for the first time, culminating in the historic decision to establish a 'loss and damage fund'. At COP28 in 2023, countries launched the fund and agreed on critical details, such as the choice of the World Bank as host country. Nearly $700 million was also pledged to start filling the fund. At COP29 in 2024, countries will need to confirm that the World Bank meets the conditions required to host the fund, and developed nations will need to allocate much more funding to adequately fill it, as estimated damages could reach $580 billion by 2030 (Bhandari, n.d.).

Currently, there is not an official definition of loss and damage but UN used to define it as all the consequences that climate change entails and usually it refers to something that goes beyond what people can adapt to (Bhandari, n.d.). This kind of problem, are disproportionately affecting the most vulnerable communities around the world thus making this an urgent issue of climate justice. To ensure that these communities are protected, the more developed countries, because they have more instruments and financial means at their disposal, should cooperate with them to address these losses and damages. To do this, however, there have been difficulties as the countries have not been able to reach an agreement on the monetary amounts that developed countries should provide to less developed ones. The more developed countries have a duty to help others as the less developed countries, despite being more affected by environmental disasters, have at the same time contributed less to the future of these. For this reason, for economic subsidies to reach these countries, the more affluent countries will have to find constructive dialogue and political compromises to come up with more inclusive solutions, taking into consideration the different responsibilities and capacities of all countries involved (OXFAM, 2023)

Losses and damage can occur due to extreme weather events such as cyclones, droughts, and heat waves, as well as slow-moving changes such as sea level rise, desertification, melting ice, land degradation, ocean, and salinity. So, in some cases, we can say that the damage can permanently alter the places. These damages can be quantified in two types: economic losses and non-economic losses. The former refers to losses of resources, material goods, and services, such as infrastructure, and real estate. The latter, on the other hand, refers to losses of non-material assets that are incalculable, such as the death of people, the irreversible disappearance of culture or landscape and artistic assets, or simply the trauma resulting from the disaster (Bhandari, n.d.).

We can therefore state that, despite the adaptation measures implemented over the past few years, losses and damage are beginning to occur and that several communities lack the resources to deal with them. It is therefore emphasized that mitigation and adaptation policies should in the future also take into account consequential loss and damage (Bhandari, n.d.).

1.3 CLIMATE CHANGE AT THE URBAN SCALE

Nowadays, more than three-quarters of the population lives in cities and this makes them particularly vulnerable to certain effects of climate change and urban areas are affected differently by this depending on their location. Several urban life components, such as temperature, air quality, water supplies, and human health, are significantly impacted by climate change. Indeed, the concentration of buildings, roads, and other infrastructures, that absorbs and re-emits heat more than natural landscapes, causes cities to suffer greater temperatures than surrounding rural areas; this phenomenon is known as the Urban Heat Island (UHI) effect (*Urban Heat Islands 101*, n.d.). Warmer temperatures have the potential to produce more pollutants like ozone, which can lower air quality in cities. According to the EEA studies (Air Quality in Europe 2022, n.d.), in 2020 over then 96% of the population in European cities have been exposed to levels of PM 2.5 exceeding WHO guidelines. Additionally, warmer waters entering nearby streams can degrade water quality by stressing their ecosystems. Climate change may also cause problems for cities in terms of food instability and water scarcity, which can worsen human health and wellness (Barata et al., 2011).

1.3.1 HUMAN HEALTH IMPACTS

The intertwining of environment, climate change, human health and well-being is exemplified by the assessment of global air quality changes and the impacts of temperature take-off. These phenomena contribute to a number of health problems, in particular exposure to heat, which can lead to higher than average mortality rates. For instance, the impact of UHI is much greater for the most vulnerable social groups in urban areas, such as the elderly, children and low-income groups. However, vulnerability is greatest among people with pre-existing conditions, limited mobility, unstable housing or small flats, and insufficient resources to access safer alternative living environments such as refrigerators (Heaviside et al., 2017). Furthermore, pregnant women, infants and old people are highly vulnerable to direct and indirect impacts of climate change, such as heat stress, extreme weather events and air pollution, and can cause immediate and long-term health effects (Roos et al., 2021).

Air pollutants have also been shown to negatively affect air quality and cause lung and cardiovascular diseases that lead to premature death. For example, recent studies have highlighted that cities with poorer air quality have higher death rates from COVID-19. (Frontera et al., 2020). In countries with poor air quality, health systems are witnessing an increase in air pollution-related health conditions, but may lack the capacity and resources to effectively treat and manage long-term diseases. Furthermore, climate change affects the cost of services provided to the target group. As temperatures rise, the need for electricity to provide air conditioning in rooms increases. In addition, due to rising sea levels, coastal areas may have to find alternative sources of drinking water or consider desalination due to the intrusion of salt water into fresh water, thus increasing the price of water. Changes in water availability also affect agricultural production, which, in addition to contributing to malnutrition, may also lead to a decrease in income, which affects the ability to pay for health services at the same time (Ebi et al., 2017).

As far as global health systems are concerned, in this context they should increasingly act to understand how climate change affects their ability to manage and protect public health. assess the effectiveness of their measures and systems under different climatic conditions and environmental effects and identify opportunities to improve their institutional capacity to deal with this crisis (World Health Organization, 2015). Therefore, they must strengthen their capacity to adapt, adjust, and change to ensure reasonable, accessible, and quality care for the communities they serve every day, not only during periods of shock. Thus, to assess a shock/stress at the community or system level, the following factors must be considered: the relative intensity and cost of the shock/stress; and the required and appropriate response, considering the transactional costs to implement and sustain the response. Through this, it will then be possible to define the short-term and long-term outcomes of the system.

1.4 MITIGATION AND ADAPTATION SOLUTIONS

To mitigate the effects of global warming and lower greenhouse gas emissions, techniques for adaptation and mitigation of climate change are essential. These two solutions differ spatially and temporally**.** Mitigation refers to efforts aimed at reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by decreasing their sources (such as the burning of fossil fuels for electricity, heat, or transport) or increasing the "sinks" that accumulate and store these gases (like the oceans, forests, and soil). The objective of mitigation is to prevent significant human interference with Earth's climate, stabilize greenhouse gas levels to allow ecosystems to adapt naturally, ensure food production is not threatened, and enable sustainable economic development. This kind of solution is often enacted at the international or national levels, and its benefits are global (NASA Science, n.d.).

Adaptation, on the other hand, focuses on adjusting to the actual or expected future climate. The goal is to minimize the risks from harmful effects of climate change, such as sea-level rise, more intense extreme weather events, or food insecurity. Adaptation also involves taking advantage of any potential beneficial opportunities associated with climate change, such as longer growing seasons or increased yields in some regions (NASA Science, n.d.). Adaptation measures are enacted by local or regional authorities, providing benefits at both the local and national levels.

1.5 INTERNATIONAL PLANS, TREATIES AND CONVENTIONS FOR THE ENVIRONMENT AND SUSTAINABLE DEVELOPMENT FOR CLIMATE CHANGE

Since the mid-twentieth century, there has been a growing awareness of the environment and the need for all this good. This led to the need to provide a global response to the ecological problems that were beginning to arise, resulting in the creation of a series of international plans, treaties, and conventions. These documents, increasingly adapted to planetary needs, represent efforts to try to address and mitigate environmental challenges to combat ongoing climate change and promote sustainable development (Galizzi & Sands, 2004).

Following is a list in chronological order of the most important international documents issued over the decades for the protection of the environment (Galizzi & Sands, 2004).

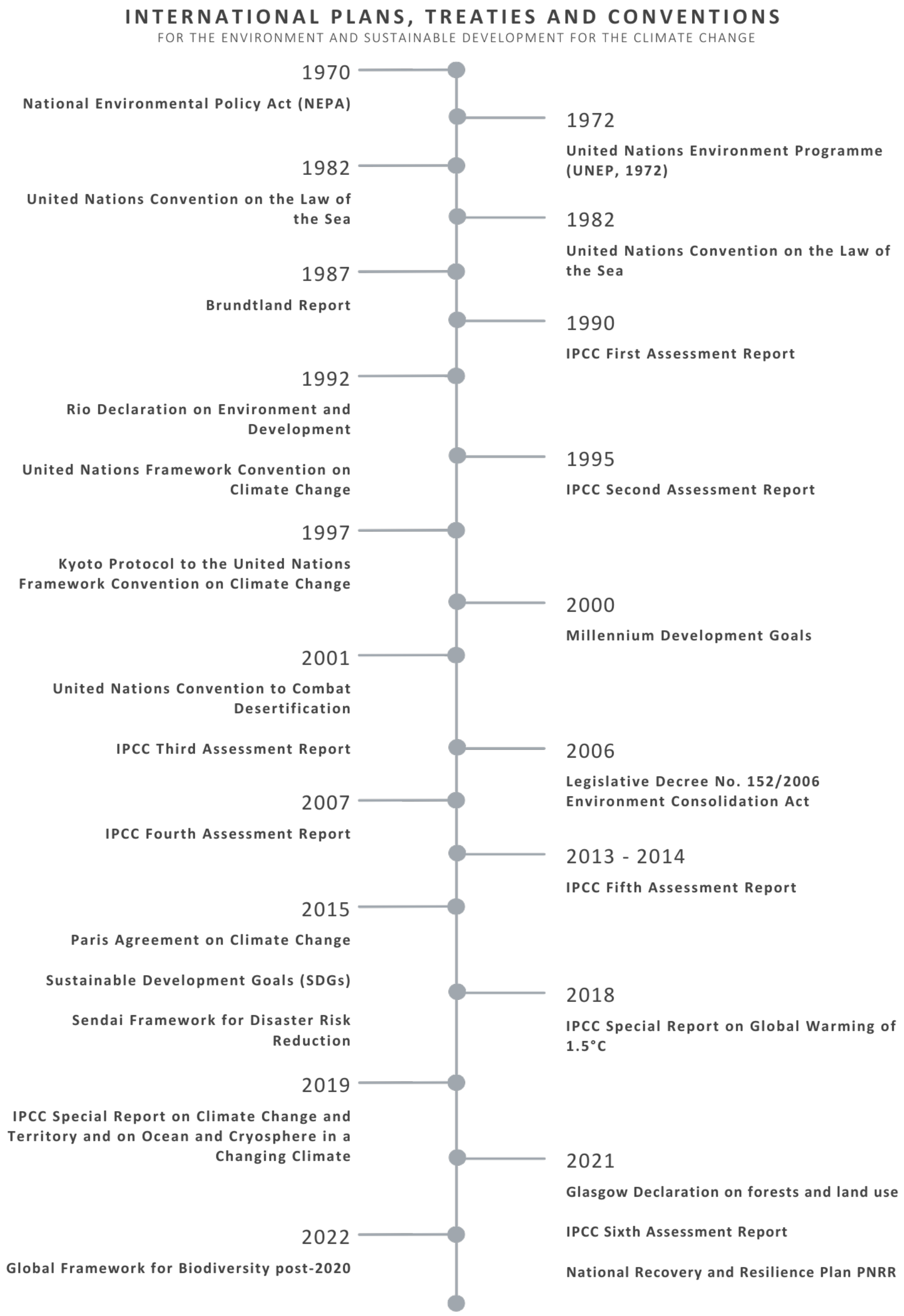


FIGURE 8 - CHRONOLOGY OF INTERNATIONAL PLANS, TREATY AND CONVENTIONS FOR THE ENVIRONMENT AND SUSTAINABLE DEVELOPMENT FOR CLIMATE CHANGE (SOURCE: AUTHOR ELABORATION FROM GALIZZI & SANDS, 2004)

1970 - National Environmental Policy Act (NEPA)
NEPA is a US federal law that established a national policy for the environment. It requires federal agencies to assess the environmental impact of their actions and to consider more environmentally friendly alternatives. It was a milestone in environmental legislation in the United States.

1972 - United Nations Environment Programme (UNEP, 1972)
UNEP was established as a result of the 1972 Stockholm Conference. It is the environmental agency of the United Nations, with a mandate to coordinate UN environmental activities and to assist countries in implementing environmental policies.

1982 - United Nations Convention on the Law of the Sea
This convention establishes a legal framework for the use and management of the oceans and their resources. It addresses issues such as delimitation of maritime zones, protection of the marine environment and sustainable use of marine resources.

1987 - Brundtland Report
The Brundtland Report, entitled 'Our Common Future', was published by the United Nations World Commission on Environment and Development. It introduced the concept of 'sustainable development', defining it as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

1990 - First IPCC Assessment Report
The First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) provided a scientific assessment of the state of knowledge on climate change, its causes, impacts and possible responses.

1992 - Rio Declaration on Environment and Development
Adopted at the Earth Summit in Rio de Janeiro, the Rio Declaration established 27 principles to guide sustainable development globally, including the principle of common but differentiated responsibility.

1992 - United Nations Framework Convention on Climate Change
This international convention established a framework for addressing climate change globally, with the goal of stabilising greenhouse gas concentrations in the atmosphere.

1995 - Second IPCC Assessment Report
The IPCC Second Assessment Report provided further scientific evidence on climate change and reinforced the conclusions of the first report.

1997 - Kyoto Protocol to the United Nations Framework Convention on Climate Change
The Kyoto Protocol set binding targets for industrialised countries to reduce greenhouse gas emissions. It was the first legally binding international agreement to address climate change.

2000 - Millennium Development Goals
The Millennium Development Goals were a set of 8 goals to be achieved by 2015, including eradicating extreme poverty and hunger, improving maternal and child health, and promoting gender equality.

2001 - United Nations Convention to Combat Desertification
This convention promotes internationally coordinated actions to combat desertification and mitigate the effects of drought, particularly in the most vulnerable countries.

2001 - IPCC Third Assessment Report
The IPCC Third Assessment Report provided further scientific evidence on climate change and emphasised the urgency of action to address it.

2006 - Legislative Decree No. 152/2006 Environment Consolidation Act
This Italian legislative decree brought together the main environmental laws, including environmental impact assessment, waste management and water protection, into a single text.

2007 - IPCC Fourth Assessment Report
The IPCC Fourth Assessment Report confirmed with greater certainty the role of human activity in causing climate change and outlined scenarios and options for addressing it.

2013 - 2014 - Fifth IPCC Assessment Report
The IPCC Fifth Assessment Report provided an even more comprehensive and detailed assessment of scientific knowledge on climate change, its impacts and possible solutions.

2015 - Paris Agreement on Climate Change
The Paris Agreement is an international treaty that aims to limit global temperature increase to well below 2°C above pre-industrial levels, and to pursue efforts to limit it to 1.5°C.

2015 - Sustainable Development Goals (SDGs)
The Sustainable Development Goals (SDGs) are a set of 17 global targets adopted by the United Nations to address the most pressing social, economic and environmental challenges by 2030.

2015 - Sendai Framework for Disaster Risk Reduction
This global framework for action aims to substantially reduce disaster risk and losses in lives, livelihoods and health by 2030.

2018 - IPCC Special Report on Global Warming of 1.5°C
This IPCC Special Report assessed the impacts of global warming of 1.5°C above pre-industrial levels and options for limiting warming to this level.

2019 - Green Deal (European Commission)
The European Green Deal is a European Union strategy to achieve climate neutrality by 2050 through actions in different sectors such as energy, industry, mobility, agriculture and biodiversity.

2019 - IPCC Special Report on Climate Change and Territory
This IPCC Special Report examined the impacts of climate change on land, land use and food security.

2019 - IPCC Special Report on Ocean and Cryosphere in a Changing Climate

This IPCC Special Report assessed the impacts of climate change on oceans, glaciers, ice caps and the cryosphere in general.

2021 - Glasgow Declaration on forests and land use
This declaration, adopted at COP26, commits signatories to reverse forest and land loss by 2030.

2021 -2022 IPCC Sixth Assessment Report
The IPCC Sixth Assessment Report is the latest comprehensive assessment of scientific knowledge on climate change, its impacts and options for mitigation and adaptation.

2021 - National Recovery and Resilience Plan PNRR
The PNRR is the Italian plan for the use of Next Generation EU funds, with the aim of promoting economic recovery and ecological and digital transition.

2022 - Global Framework for Biodiversity post-2020
This framework, adopted during the COP15 on biodiversity, sets global targets for the protection and restoration of biodiversity by 2030.

1.5.1 Spatial and temporal analysis of climate change documents at the international level

Key urban development plans in the management and evolution of urban and metropolitan areas can be classified into three typologies, each with specific objectives and methodologies. The first typology deals with complex plans, i.e. planning instruments that look at urban and environmental regeneration and involve public and private actors. The second typology looks at mitigation plans, which focus on reducing greenhouse gas emissions and mitigating negative environmental impacts from human activities. These plans are often integrated into urban development policies to promote sustainable construction practices, low-carbon mobility and efficient management of energy resources. Finally, there are adaptation plans that are aimed at increasing cities' resilience to climate change. Furthermore, these plans look at identifying particularly vulnerable areas and develop strategies to manage any associated risks such as sea level rise, heat waves and flooding. Adaptation requires a flexible and proactive approach to modifying urban infrastructure and services so that they can withstand current climate impacts and prevent future ones (ASVIS, 2023).

Internationally, growing global concerns about sustainability and climate change are driving the development of urban planning. As the first modern urban plans of the late 19th century focused mainly on improving health and regulating land use, environmental issues became increasingly important in the 1970s and 1980s. This change was driven in part by the growing awareness of the environmental impacts of urbanisation and the need for sustainable development policies. Analyzing all documents issued at the international level since around 1990, a total of 300 documents were identified, divided into complex (50%), adaptation (32%) and mitigation (18%) documents. The first mitigation and adaptation documents appeared as early as the 1990s, but it was not until the early 2000s that there was a significant increase in their number, at which time the first complex-type documents were also created. In particular, 2012 was a peak year for the publication of complex documents, with 19 new documents issued. In more recent years, it is visible how the number of documents issued has significantly increased. Indeed, thanks to international agreements such as the Kyoto Protocol in 1997 and the Paris Climate Agreement in 2015, there has been a significant push towards integrating mitigation and adaptation strategies into urban development plans. These agreements have reinforced the need to adopt approaches that consider both reducing emissions and increasing resilience to climate change.

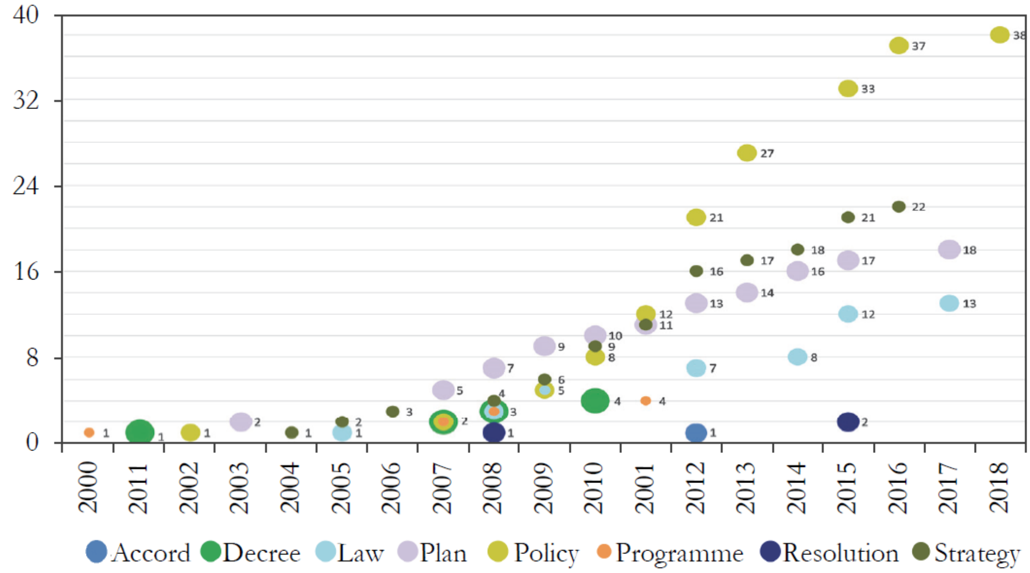


FIGURE 9 - TEMPORAL EVOLUTION OF COMPLEX-TYPE DOCUMENT KINDS AND THEIR CUMULATIVE NUMBERS (SOURCE: KISS & BALLA, 2022)

Looking instead at the spatial distribution of document types, adaptation, mitigation and complex, significant differences are found between continents (Figure 10).

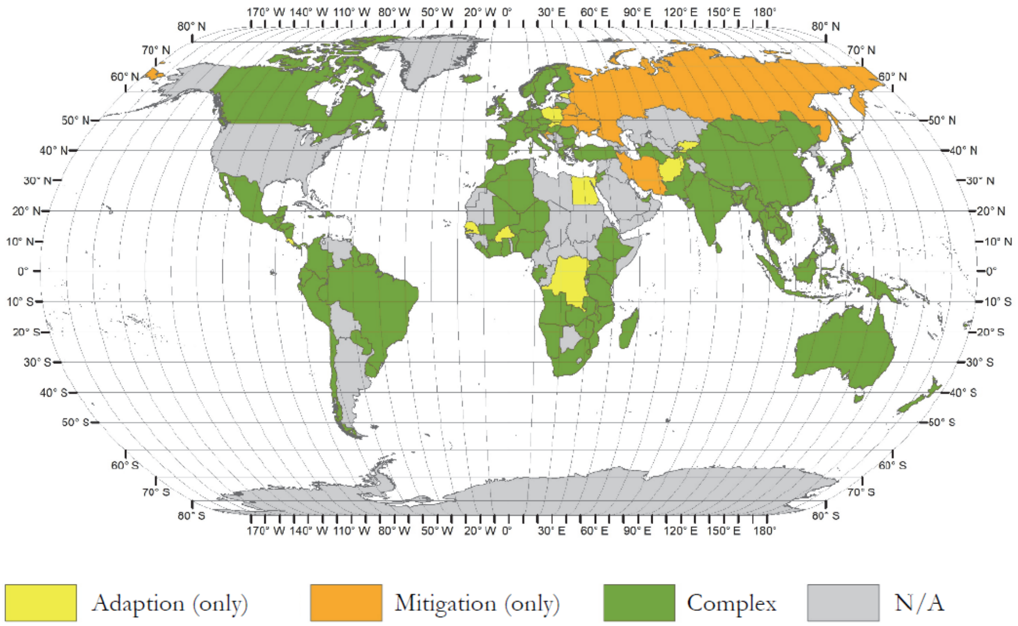


FIGURE 10 - SPATIAL DISTRIBUTION OF THE CCS CATEGORIES WORLDWIDE BY CATEGORY (SOURCE: KISS & BALLA, 2022)

Based on the analysis of the African continent, no mitigation-type documents were ever issued, while complex-type documents were the most frequent. This could be due to a greater emphasis on integrated strategies that address both mitigation and adaptation due to a greater perception of immediate vulnerability to climate change as it is more visible and catastrophic in those contexts, such as drought and desertification. In Asia, on the other hand, there is great diversity in the types of documents, with all three types present (mitigation, adaptation, and complex), reflecting the variety of economic, environmental and social approaches adopted by different countries on this continent. The European context shows a predominance of mitigation documents, followed by adaptation and complex, suggesting a strong commitment to reducing greenhouse gas emissions, in line with the EU's broader goals for sustainability and energy transition. The opposite can be seen in North and Central America, where complex-type documents accounted for the majority of documents issued, indicating an integrated approach and perhaps a greater need to implement mitigation and adaptation strategies simultaneously. Similarly, in South America, no mitigation-type documents were produced, while complex documents were prevalent (Kiss & Balla, 2022).

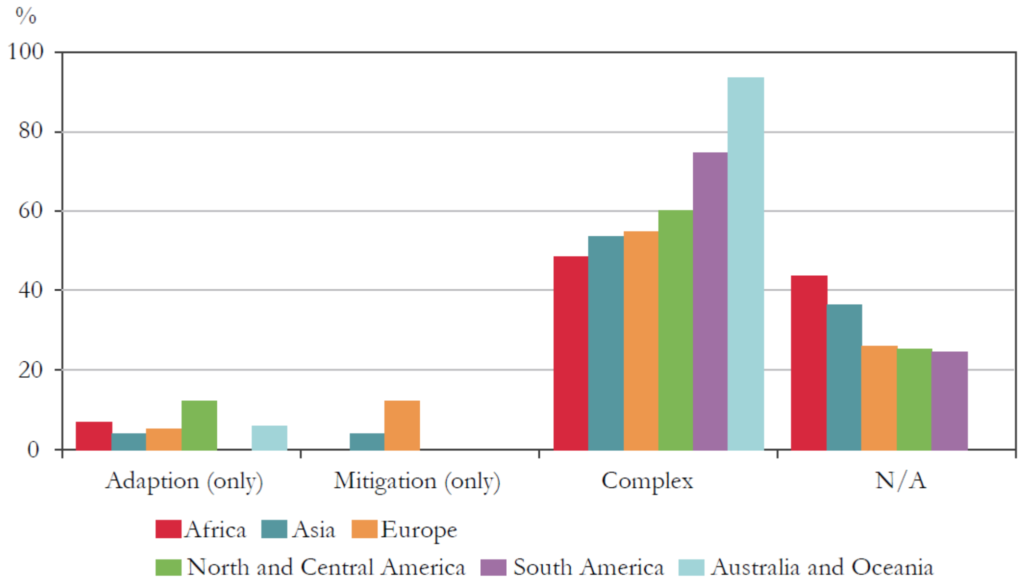


FIGURE 11 - PROPORTION OF THE CCS CATEGORIES BY CONTINENT (SOURCE: KISS & BALLA, 2022)

1.5.2 SPATIAL AND TEMPORAL ANALYSIS OF CLIMATE CHANGE DOCUMENTS AT THE EUROPEAN LEVEL

Mitigation documents

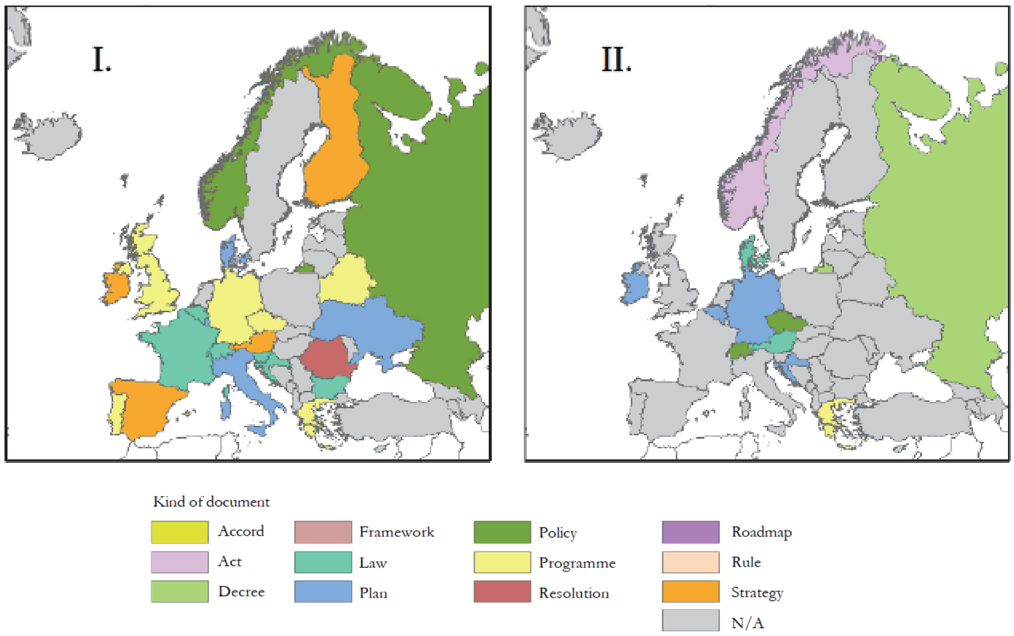


FIGURE 12 - EUROPEAN MITIGATION DOCUMENTS TYPOLOGIES (SOURCE: KISS & BALLA, 2022)

From the image above, it can be seen that the different states belonging to the European continent have issued different types of documents related to climate change mitigation. The states that we see listed most often and have therefore drafted and issued more than one set of documents are Norway, Russia, Ireland, Denmark, Germany, Belgium, Switzerland, Austria, the Czech Republic, Croatia and Greece. England, Portugal, Greece and Belarus have only issued mitigation agreements; Germany, on the other hand, has not only issued a series of agreements, but has also drawn up mitigation plans. Plans have also been issued by the Italian, Ukrainian, Irish, Croatian and Belgian states. As for Finland, Spain, Austria and Ireland, strategies have been issued. Finally, France, Switzerland, Belgium, Austria, Slovenia, Croatia and Denmark have also issued mitigation laws (Kiss & Balla, 2022).

Adaptation documents

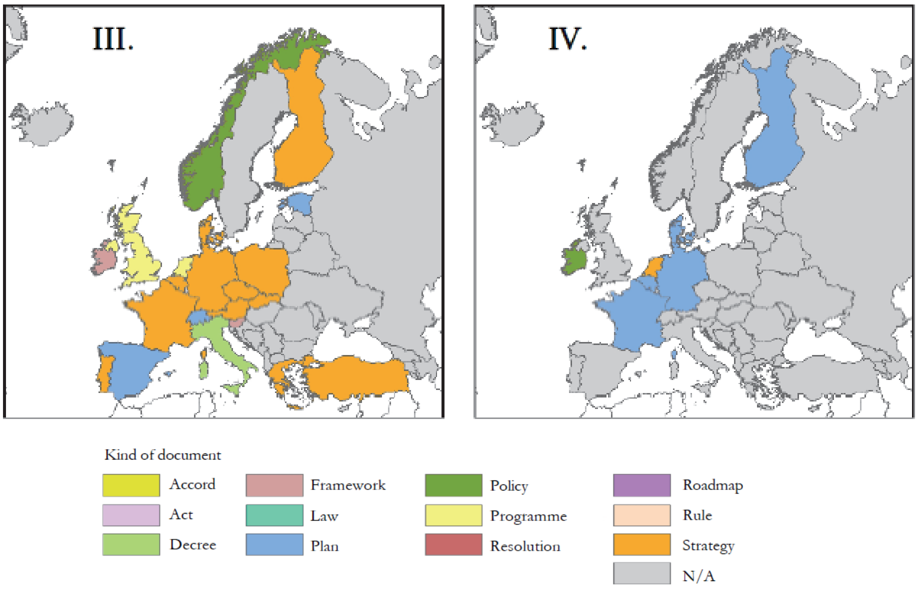
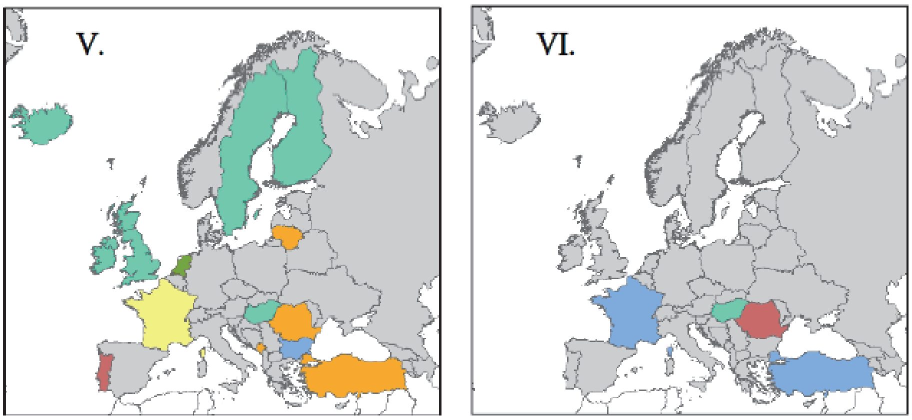


FIGURE 13 - EUROPEAN ADAPTATION DOCUMENTS TYPOLOGIES (SOURCE: KISS & BALLA, 2022)

In the case of climate change adaptation documents, there is greater homogeneity in the types of documents issued. In fact, it can be seen that for the majority of states, numerous strategies have been issued in this regard. Italy stands out, which issued decrees, England issued programmes and Ireland issued frameworks and policies, Spain issued plans and finally Norway issued policies (Kiss & Balla, 2022).

Complex documents



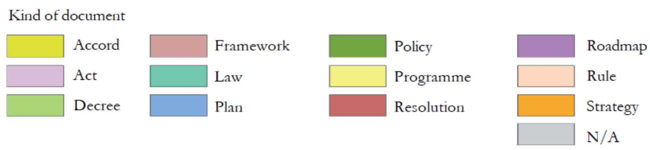


FIGURE 14 - EUROPEAN ADAPTATION DOCUMENTS TYPOLOGIES (SOURCE: KISS & BALLA, 2022)

Regarding the issuing of complex documents, i.e. composed of both mitigation and adaptation strategies, we see that these are literally less common in European states. Some of them had already issued documents concerning either mitigation or adaptation strategies while others only issued complex documents. In fact, the only states to have dealt only with these are Romania, Turkey, Bulgaria, Montenegro, Hungary, Lithuania, Sweden and Iceland (Kiss & Balla, 2022).

1.6 CLIMATE CHANGE MODELLING AND ANALYSIS: THE ROLE OF GIS

The use of geographic information systems (GIS) is of significant importance in modelling and analysis of climate change. GIS enables the integration, analysis and visualisation of spatial data. It can reveal patterns, trends and location relationships between data (Chang, 2019).

In the field of climate change, the analysis of spatial and temporal relationships of the climate variables with the geographic context is of paramount importance. Therefore, GIS technology plays a crucial role in the modelling, analysis and integration of heterogeneous and complex climate data (Antoniou, 2024).

The study of temperature and precipitation data is a typical analysis used in climate change research: GIS tools allow scientists to understand the spatial and temporal trend of these data, making anomalies easier to detect. In addition, map products can be used to assist in the identification of areas that are particularly vulnerable to the impacts of climate change (Antoniou, 2024).

Another common application concerns the study of distribution of greenhouse gas (GHG) emissions, where GIS can be used to identify the main sources of emissions and the most exposed areas, providing guidance for the effective application of mitigation strategies (Antoniou, 2024). GIS can be used also to model the sea level rise, facilitating the identification of most potentially affected areas through maps, thus supporting preparation and mitigation strategies for impacted coastal communities (Chang, 2019).

The impact of climate change on biodiversity can also benefits of GIS approach, which through the integration of climate data with species occurrence data enables the prediction of the potential distribution shifts of various species due to climate change. This capability is of significant value for conservation initiatives, as it facilitates the identification of species particularly susceptible to climate change (Antoniou, 2024).

Last but not least, maps, as visual outputs of GIS processes, are employed in the dissemination of information on climate change and represent a powerful tool for conveying complex and technical information to the general public and policy makers. This can increase awareness of climate change and facilitate decision making (Antoniou, 2024).

2. Urban Heat Island (UHI)

2.1 Definition

The heat island phenomenon is a problem that is increasingly evident in urban areas, resulting in its growing relevance and urgency following the exponentially accelerating trend of global urbanization. All man-made elements such as infrastructures and buildings, i.e. everything that makes the ground sealed and thus limits the presence of greenery, tend to absorb and emit greater amounts of heat from the sun. This leads to greater heat stress, high energy consumption, and increasing levels of air pollution in cities rather than in their peripheral areas (Iberdrola, n.d.).

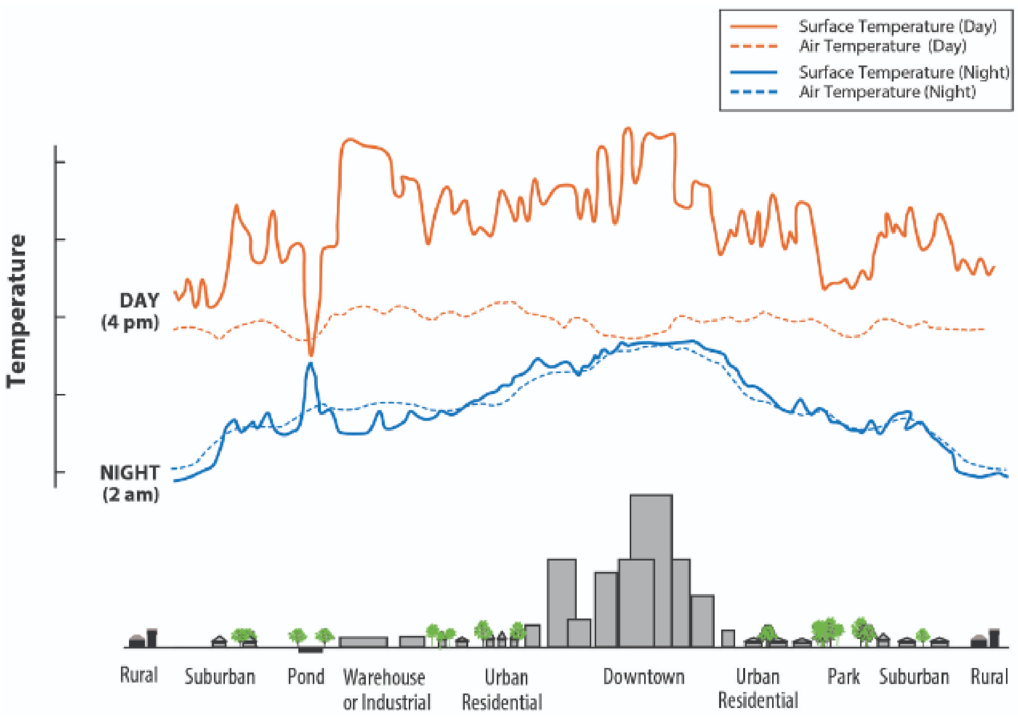


Figure 15 - Heat Island Effect Diagram (Learn About Heat Islands | US EPA. (n.d.). US EPA (Source: Learn About Heat Islands | US EPA, 2023)

The introduction of the concept of the 'heat island' was by Luke Howard, an English meteorologist, in 1818, when he found a temperature difference between the urban environment and its surrounding suburbs; in fact, it was shown that temperatures in the city were higher than in the rural environment (Howard, 1818). Over the years and with increasing urbanization, this phenomenon began to be recognized as a problem for human health and the environment same. Over the years, therefore, different ways of forming heat islands have been studied: they can occur during the day as well as at night, in small and large cities, and any season of the year (PubMed Central (PMC), n.d.).

2.2 Factors affecting urban heat islands

Nowadays, we can accurately describe the variables that influence the formation of the urban heat island: controllable variables and uncontrollable variables. Following the diagram (Figure 16), the so-called 'controllable' variables can be subdivided into variables concerning the form of the city, such as the materials used in urban settings, urban geometry and green spaces, and variables concerning the functions and activities taking place in the city, such as energy use, water consumption and pollution. The remaining variables, such as geographical location, period or weather are so-called 'uncontrollable'.

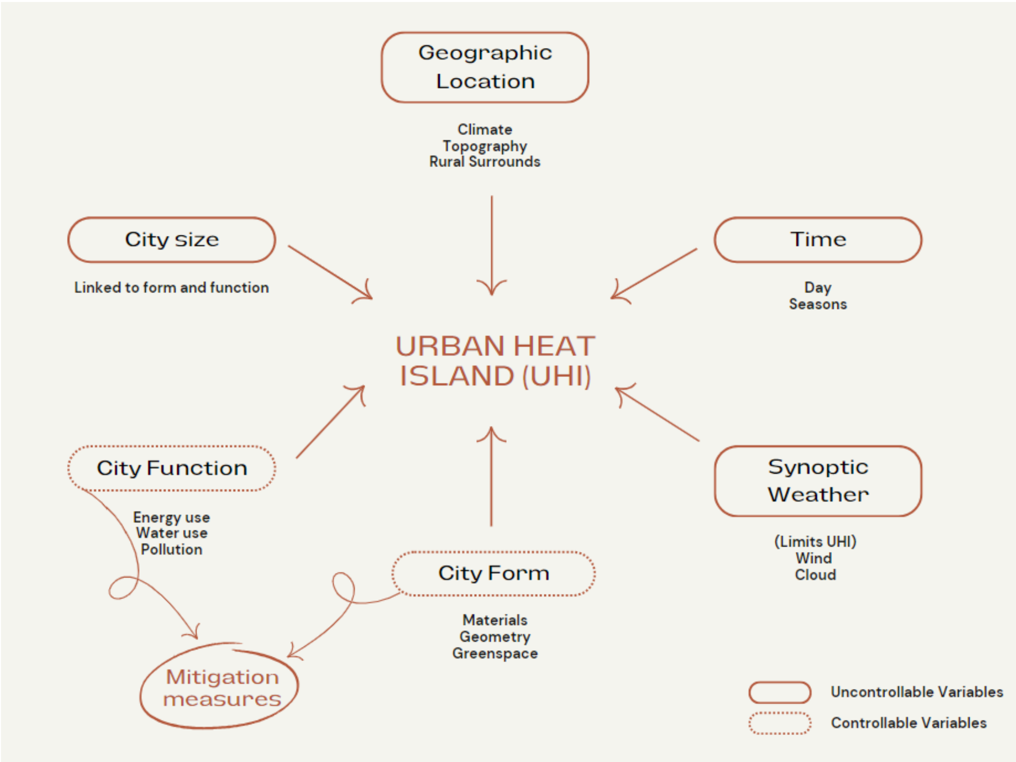


FIGURE 16 - FACTORS AFFECTING URBAN HEAT ISLANDS (SOURCE: AUTHOR'S RE-ELABORATION FROM VOOGT, 2008)

As far as the shape of the city is concerned, the characteristics of the materials used in the construction of artifacts in urban contexts are a fundamental component that contributes to the formation of heat islands. Their physical and radiative properties, as well as the colour of the material, determine different surface albedo values and different thermal and emissive capacities. The urban geometry, determined by the coexistence of residential, work, and leisure activities, that occur predominantly within the built space, is what most distinguishes urban from rural areas (Mohammed & Salman, 2018). The interaction between solar radiation and the more or less dense matrix of buildings contributes to the formation of UHI: indeed, the high curtains formed by building fronts, separated from urban streets, often generate the urban canyon phenomenon, which results in the repeated reflection of solar radiation between the street surface and building wall surfaces, which absorb more heat that they subsequently release to the atmosphere (Figure 17) (Firdausah & Wonorahardjo, 2018).

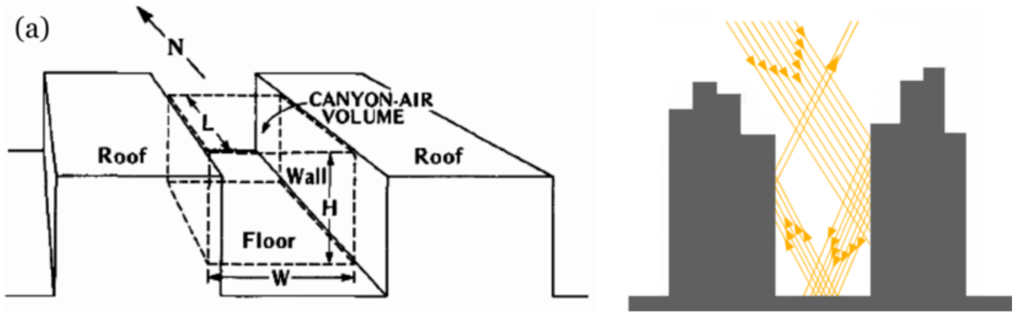


FIGURE 17 - SCHEMATIC REPRESENTATION OF AN URBAN CANYONS AND MULTIPLE REFLECTIONS AND ABSORPTION THAT OCCURS WITHIN IT (SOURCE: GERUNDO, 2016, P. 57-64)

The formation of heat islands is also increased by the lack, or scarcity, of urban green areas. The beneficial contributions that vegetation makes to urban areas in reducing heat flows are manifold. In addition to guaranteeing areas of shade thanks to the crowns of tall trees, vegetation contributes to mitigating temperatures thanks to the processes of evapotranspiration (Figure 18), defined as 'the quantity of water that is transferred into the atmosphere due to the phenomena of direct evaporation from water, soil and vegetation (interception) and transpiration of vegetation' (ISPRA Ambiente, n.d.). From a mitigation design perspective, which will be addressed below, it should be noted that some studies have shown that diffuse locations of greenery in urban areas lead to a more pronound reduction in the surface temperature of an area than large concentrated areas (Li et al., 2011).

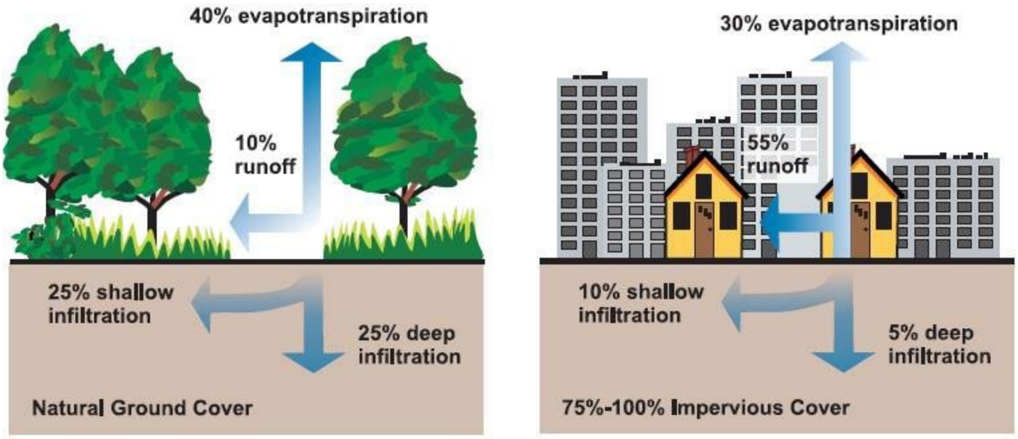


FIGURE 18 - IMPERVIOUS SURFACES AND REDUCED EVAPOTRANSPIRATION (SOURCE: FERNANDO, 2019)

2.3 ACTIONS FOR UHI MITIGATION

Having defined the causes that contribute most to the heat island phenomenon, it is clear that action needs to be taken on them to try to mitigate their negative effects on the climate and the human health. The main mitigation actions should therefore aim at reducing the urban structure's stored heat flux, anthropogenic heat flux and net radiation.

The strategies used concern interventions on the urban geometry, that is, on the surfaces and volumes of the built-up area, and on the use of materials with lower thermal transmittance, such as, for example, interventions to improve the insulation performance of buildings. With regard to the materials used, mitigation actions also focus on increasing the albedo of the surfaces involved in thermal exchange. Another line of action that needs to be focused on and that, as we shall see, produces positive environmental and socio-economic externalities, is the use of vegetated surfaces and the implementation of Nature Based Solutions (NBS) within the urban area. The latter action is closely linked to increasing the percentage of permeable areas, which urban contexts have less and less of. While the solutions described so far are aimed at reducing urban heat flux and net radiation, the potential actions that are most aimed at reducing anthropogenic flux concern the habits of the inhabitants. Consider, for example, actions that incentivize the reduction of electricity consumption or domestic heating, or actions that incentivise the use of sustainable public and private transport. It is evident, however, that not all of the aforementioned actions are practically feasible in consolidated urban fabrics, such as, for example, interventions on the volume of existing buildings, a strategy that should certainly be implemented in the case of new settlements (Tabatabaei & Fayaz, 2023).

In planning the measures to be implemented to reduce UHI, it is necessary to consider that each heat island has its own characteristics: it is determined by different causes that lead to different effects depending on the specific contexts. Therefore, there is no universal 'recipe' for UHI mitigation and some actions may prove ineffective or even counterproductive if they are applied without considering local specificities.

As mentioned earlier, the natural component within urban contexts is, increasingly, of utmost importance and, to foster its development and increase, NBS can be implemented, i.e. integrated NBS that not only pursue ecological and environmental objectives but also have effects on the social and economic sphere.

3. Nature-Based Solutions (NBS)

3.1 Introduction to NBS and definition

The innovative concept of Nature-Based Solutions (NBS) is defined as "*solutions that are inspired by nature and supported by it, that are cost-effective, provide environmental, social and economic benefits at the same time, and contribute to resilience; such solutions bring a greater, and more diverse, presence of nature and natural features and processes into cities and landscapes on land and sea, through locally adapted and resource-efficient systemic interventions*" (European Commission, 2015). These solutions are adapted to different application scales, from point scales to larger spatial scales, aiming to restore nature's role in established urban environments and support existing rural and natural systems. NBS, however, is designed not only to affect the purely environmental sphere but, by applying them to urban contexts, also benefit society and economies, supporting sustainable development and promoting resilience.

The term NBS was first used in 2002 (Somarakis et al., 2019) and, over time, has been adopted by global institutions (Figure 19); while at its inception this term was more directed at biodiversity and ecosystem conservation-based initiatives in terms of environmental management, nowadays the term involves many more aspects, also touching on the social sphere and the benefits it derives through the ecosystem services provided. Thus, through this integrated approach, the role of nature in improving the health and well-being of the population, while promoting economic growth, has been recognized. Since 2013, the term NBS has been widely adopted in the EU research and innovation policy agenda to promote synergies between three spheres: nature, society, and the economy.

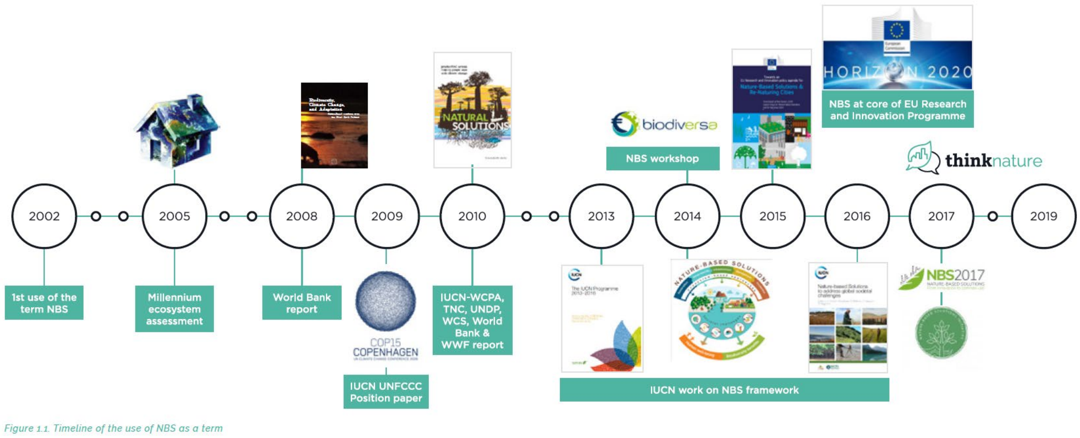


Figure 19 - Timeline of the use of NBS as a term (Source: Somarakis et al., 2019)

The NBS are characterized into three main typologies (Eggermont et al.,2015), based on the degree of intervention they deal with and the type of engineering that is employed:

- *Typology 1 | Better use of protected/natural ecosystems* such as protection and conservation strategies in terrestrial ecosystems;

- *Typology 2 | NBS for sustainability and multifunctionality of managed ecosystems* such as extensive management of urban green spaces, agricultural landscape management, etc.;

- *Typology 3 | Design and management of new ecosystems* such as intensive management of urban green spaces, urban water management, ecological restoration of degraded terrestrial ecosystems, etc.

This definition of NBS typologies brings to light the open nature of this term which, at the same time, leads to difficulties and challenges in defining what is meant by 'nature' and what is considered 'natural'. To better understand this, one only has to think of the solution of putting green roofs on a building: this solution can only be considered an NBS if, at the same time, specific aspects such as biodiversity and sustainability are also taken into account in the realization of it, otherwise it falls short.

A further classification criterion of NBS can be defined according to application dimensions. Spatial scale levels can, for example, include buildings, blocks, neighbourhoods, cities, regions, etc., while social scale levels include individuals, households and groups, i.e. the population at large. The classification of scale levels as local, neighbourhood or regional scale is a matter of subjective judgement and depends on the classification criteria. In the context of NBS, the determination of scale levels can be made according to specific planning functions in scalar analysis (Thinknature et al., 2019):

- *Local Scale*
  At this scale, NBS are concerned with small-scale point areas such as gardens, courtyards, small parks, roofs and walls, etc. The function of NBS at this scale can help mitigate noise pollution, urban heat islands, support biodiversity, reduce the energy consumption of buildings, and also decrease the risk of flooding from significant rainfall events. The implementation of greenery at the local scale ensures equitable access to nature for the population, providing recreational, cool, and visual opportunities. Consequently, nature at this scale contributes to improving the well-being of urban residents and developing a sense of place identity (individual and collective), leading to public space improvement initiatives.
- *Neighbourhood scale*
  The introduction of NBS at this scale performs the function of regulating the local climate. Indeed, trees, parks, forests, and other green spaces change the local environment by enhancing the landscape, improving air quality, protecting wildlife, reducing the risk of flooding, and conserving water. In addition, an abundance of local vegetation is an effective strategy for improving health and quality of life in cities. With regard to water management, stormwater management solutions are frequently implemented on a large scale. However, an NBS-scale capture approach can be highly effective in reducing runoff and flooding risks for urban stormwater management systems. In addition, NBS must seek clean water resources by reducing surface runoff and pollutants. Furthermore, green spaces and vegetation in the city cool the local environment by providing shade and coolness, thus mitigating the heat island effect. A recent review of previously published studies concluded that parks are 0.94 °C cooler than sealed urban areas during the day (Bowler et al., 2010).
- *Regional scale*

Integrated solutions on a large scale (i.e. beyond urban boundaries) are more effective for holistic risk and resilience management. In several cases, green systems integration is considered an effective and successful solution at the larger scale. However, it is important to note that investing in ecosystems cannot be the sole solution to disasters; in fact, NBS should be used in combination with other risk reduction measures. At a larger scale, the objective of NBS is to re-establish natural biotopes through renaturation and the creation of corridors between fragmented ecosystems.

3.2 CHALLENGE AND GOALS

The multifunctional role of NBS makes it possible to simultaneously address the social, environmental, and economic dimensions of global fide. Currently, for the improvement of well-being and resilience in urban areas, the role of NBS has been recognized as crucial and, for this very reason, these solutions are being applied to mitigate the effects of climate change for water management, land-use regulation, and urban development (Thinknature et al., 2019).

NBS solutions have been promoted as a way to use nature in a sustainable way to solve societal challenges by various bodies and through policies by the European Union itself. The International Union for Conservation of Nature (IUCN) is one of the main organizations promoting NBS, defining them as solutions that use natural processes to address societal challenges effectively and adaptively, while simultaneously providing benefits for human well-being and biodiversity (IUCN, 2020). The IUCN has therefore played a crucial role in disseminating the concept of NBS and promoting their global adoption.

The concept of collaborating with nature to innovate and solve global challenges has, as mentioned above, been translated into various objectives and incorporated into numerous reports and action plans. A significant example is the Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and the Renaturalisation of Cities'(Horizon 2020, 2015). This document lists the objectives of NBS, which are:

- Enhancing Sustainable urbanization: urban areas, which are home to a large proportion of the world's population, face numerous challenges such as scarcity of natural resources and human well-being.

- Restoration of degraded ecosystems: multiple ecosystems have been severely damaged by human activities, such as agriculture and industry

- Adaptation and mitigation of climate change: climate change is a global challenge that impacts not only the environment but also the economy and society.

- Risk management and resilience: various hazards can cause severe losses to natural and social resources if one is not adequately prepared.

A further action plan that needs to be mentioned is the United Nations 2030 Agenda for Sustainable Development. As mentioned above (Section 1.1), SDGs were adopted by all UN member states in 2015 and consists of 17 goals and 169 sustainable development targets (SGDs) to address global challenges by 2030. NBS have been integrated into the 2030 Agenda as essential tools for the effective achievement of the various SDGs.

To understand how NBS address SDGs, a few examples of approaches developed across Europe should be given (Figure 20). According to several studies, it has been shown that, for example, access to recreational/green spaces can prevent socioeconomic inequalities from leading to health inequalities. Indeed, many chronic diseases affect people living in communities that lack sufficient green space. Other studies have shown a direct relationship between the presence of green spaces in urban environments and reduced morbidity and mortality (Faivre et al., 2017). Therefore, access to a healthy natural environment is essential for vulnerable populations and to make this happen, increasing access to green spaces through green solutions and green infrastructure networks can achieve Goal 10 (which aims to reduce inequalities between communities) and Goal 3 (which aims to improve health and well-being). Objective 11 on 'Making cities and human settlements accessible, safe, sustainable and viable' is at the heart of the EU's research and innovation program. Urban areas represent an important part of the total population (75% of the EU population lives in cities, as well as 54% of the world population) and are the engine of economic growth. These factors, together with limited access to natural resources in urban areas, indicate that the introduction of environmental solutions in urban areas can be very effective. If, on the other hand, we refer to the application of NBS concerning water management, Goal 6 on clean water and sanitation, through solutions such as natural and artificial wetlands, help to improve water quality and manage water resources sustainably. NBS solutions, on the other hand, such as reforestation and sustainable forest management, help to sequester carbon and mitigate the effects of climate change, contributing to the achievement of Goal 13 entitled 'Climate Action'.

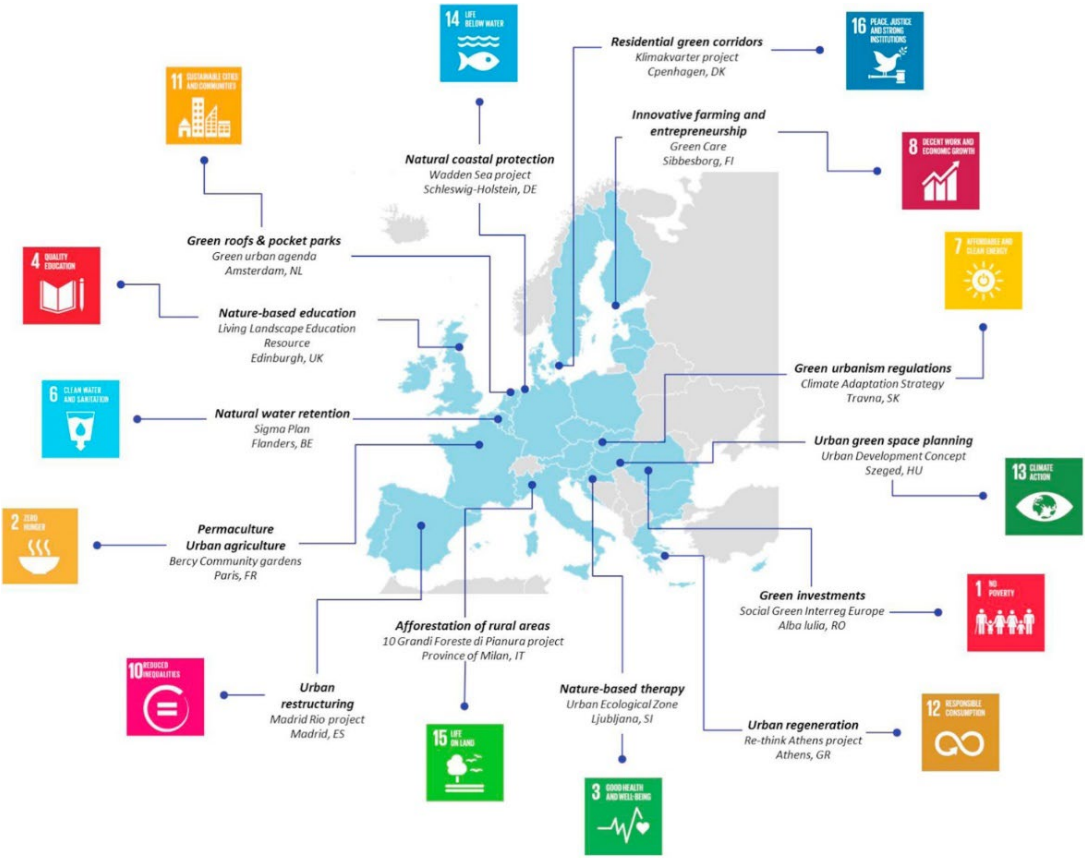


FIGURE 20 – INTEGRATION OF NBS FOR THE ACHIEVEMENT OF THE SDGS (SOURCE: FAIVRE ET AL., 2017)

3.3 EUROPEAN POLICY FRAMEWORK

The multifunctional actions of NBS have been recognized over time by the European Union as strategic actions for achieving sustainability. The idea behind the European Commission is to make the EU a leader in nature-based innovation in the field of urban resilience (Thinknature et al., 2019).

To make this happen, the EU has been supporting environmental research programs since the inception of its Framework Programmes for Research and Technological Development. These programs, as mentioned earlier, have focused on the assessment of biodiversity, a better understanding of ecosystem functioning, and the evaluation of ecosystem services and their vulnerability when subjected to stressful conditions. One of the most important of these programs was the European Union's 'Sixth Framework Programme' (FP6), adopted by the Employment and Social Affairs Council on 3 June 2002. FP6 aimed to contribute to the creation of the European Research Area (ERA) and to strengthen the competitiveness of European industry through the funding of research and technological development projects. This program is important to remember for its positive impacts, including increasing transnational scientific cooperation, supporting technological innovation and industrial competitiveness, and, finally, addressing the global challenges of climate change. Europe is therefore well placed to address the challenge of global sustainability through innovative environmental technologies and policies using natural solutions (Thinknature et al., 2019).

In the Paris Agreement (2015), the New Urban Agenda (2016), and the Sendai Framework, the European Union played a key role in the negotiations. These agreements emphasize the importance of the role of Research and Innovation for their implementation. Indeed, the preamble of the Paris Agreement highlights the importance of preserving the integrity of all ecosystems and underlines the crucial role of adaptation to protect livelihoods and ecosystems (Article 7, Paris Agreement). The New Urban Agenda explicitly mentions nature-based innovation as a key element for urban and spatial planning (Article 157, New Urban Agenda). Furthermore, NBS and other ecosystem approaches have been promoted in the decisions of the UN Convention on Biological Diversity, with a focus on biodiversity restoration, climate change, and biodiversity integration. All this, however, can only be realized in practice through the fundamental role that strategic urban planning plays.

To ensure that the implementation of NBS and their integration into existing national policy frameworks is effective, the European Commission has proceeded with the harmonization of the research and innovation agenda on NBS with various European policies and initiatives that support the adoption of ecosystem approaches. These policies and initiatives include:

1. *An EU Action Plan for Disaster Risk Minimisation*, closely linked to the implementation of the EU Plan for the Sendai Framework, also aimed at disaster risk reduction;

2. *The 2030 Agenda for the Protection of Water Resources* emphasizes the importance of natural water retention measures and the regulation of water use and conservation;

3. *The EU Adaptation Strategy and the new Covenant of Mayors for Climate and Energy* to understand the relevance of ecosystem-based adaptation to improve urban resilience and provide multiple benefits to communities as well;

4. *The Commission's Green Infrastructure Strategy*, which is part of the broader EU biodiversity strategy and aims to promote and create green infrastructure in urban and rural areas of the EU.

However, as mentioned earlier, there are still limitations in terms of standards and guidelines for the implementation of NBS. To fill this gap, research programs such as HORIZON 2020 or FP7 (2007-2013) can offer information on their designs, and implementations but also provide guidelines for cost-benefit analysis of their application. Projects developed in Framework Programme 7 (7FP) were able to demonstrate the effectiveness of the application of NBS and the positive externalities resulting from it while those in Horizon 2020 focus more on providing opportunities for larger-scale projects by implementing innovative solutions in European cities (Faivre et al., 2017). An EU-funded project within the Horizon 2020 program is ThinkNature, implemented to provide a platform to support the understanding and promotion of NBS at different scales of application, from local to large (A recap from EU project ThinkNature – ISOCARP Institute, n.d.). ThinkNature was designed to facilitate communication between the different stakeholders involved in the project to identify regulatory, economic, and technical barriers in the application of NBS

(ThinkNature – Discover the key services, thematic features and tools of Climate-ADAPT, n.d.). This project resulted in the 'ThinkNature Handbook', a handbook that brings together and promotes knowledge of NBS and provides guidance on how to choose the most suitable one for specific application contexts. Within this, we can find guides for the design and development of NBS, but also guidance on funding and policy formulation for their implementation. In addition to this project, the European Union has also mobilized for the stimulation and promotion of other NBS programs. Below is a list of the main initiatives (Table 2):

- *BiodivERsA*
  A network of national and regional funding organizations promoting pan-European research on biodiversity, ecosystem services, and NBS. This network supports the creation of a strong knowledge base for the identification and implementation of NBS by organizing transnational and transdisciplinary research opportunities. It explores the synergies and trade-offs between different ecosystem services, different stakeholder views, and the relationship between ecosystem services and biodiversity, which are fundamental to NBS.

- *EKLIPSE*
  The project is tasked with creating a sustainable and innovative way to know, network, and learn about biodiversity and ecosystem services. EKLIPSE developed the first version of an impact assessment framework with a list of criteria to evaluate the performance of NBS in addressing societal challenges. This tool serves to compare different NBS and provide an evaluation framework for demonstration projects in the design, development, implementation, and evaluation of NBS in urban areas.

- *TURAS*
  Provides examples of solutions to improve urban resilience, such as the development of urban modular green walls that can be installed almost anywhere at a reasonable cost for local authorities.

- *GREEN SURGE*
  It developed planning principles for urban green infrastructure and identified ways to connect green spaces, biodiversity, people, and the green economy, addressing urban challenges such as land-use conflicts, climate change adaptation, demographic change, and human health and well-being. This project provides a solid basis for the planning and implementation of urban green infrastructure.

- *OpenNESS*
  It aims to translate the concepts of natural capital and ecosystem services into operational frameworks, offering practical solutions for integrating ecosystem services into land, water, and urban management and decision-making. It examined how these concepts support EU economic, social, and environmental policies, analyzing the potential and limitations of ecosystem services and natural capital.

- *OPERAs*
  It aims to put cutting-edge ecosystem science into practice. Researchers and practitioners from 27 organizations helped stakeholders apply the concepts of ecosystem services and natural capital in practice. A case study of the project

demonstrated how to combine NBS with traditional solutions, building and maintaining semi-fixed dunes on 15 km of Barcelona's urban coastline to optimize ecosystem service flows and improve coastal defense against sea-level rise. A systematic analysis led to a simpler and more cost-effective strategy, integrating natural capital construction and climate change adaptation.

- *OPPLA*
  An open platform for collaboration between scientific, policy, and practice communities on natural capital, ecosystem services, and NBS. It offers various tools, including a case study finder and a tool to support the assessment of ecosystem services, as well as a 'Questions and Answers' helpdesk. This helpdesk complements EKLIPSE's "call for requests" service, which invites policy-makers and other social actors to identify issues related to biodiversity and ecosystem services where more evidence and analysis are needed.

- *Ongoing Projects*
  CONNECTING NATURE, GROW GREEN, UNALAB, and URBAN GreenUP aim to demonstrate the benefits of city renaturation by providing an EU-wide evidence base on the effectiveness and benefits of tested and scalable NBS. They also support projects such as Nature4Cities and NATURVATION, which explore new governance, business and financing models, and economic impact assessment tools. The NAIAD project complements these actions, providing a framework for assessing the insurance value of ecosystem services and working with insurers and municipalities to develop tools applicable across Europe.

- *Future projects*
  New EU-funded projects include OPERANDUM, progress, RECONNECT, EdiCitNET, URBINAT, CLEVER Cities, PHUSICOS and RENature. OPERANDUM develops NBS to mitigate the impact of hydro-meteorological phenomena in areas at risk. ProGIreg uses nature for post-industrial urban regeneration. RECONNECT aims to reconcile Europe with its citizens through democracy and the rule of law. URBiNAT focuses on the regeneration of deprived neighborhoods through innovative NBS. CLEVER Cities uses NBS to address social, economic, and environmental problems, involving residents and businesses. PHUSICOS demonstrates how NBS reduce the risk of extreme weather events in rural mountain areas. RENature aims to establish an NBS research strategy for Malta, promoting research and innovation for economic growth and human well-being, and addressing environmental challenges.

The following table (Table 2) shows two types of EU initiatives for the promotion of NBS. The first column lists all those projects and partnerships that focus on research and innovation with the aim of creating new knowledge and technologies. The second column, on the other hand, lists all those platforms that facilitate dialogue, knowledge sharing and collaboration between the different stakeholders involved in the promotion of NBS innovation.

TABLE 2 – EU INITIATIVES FOR THE PROMOTION OF NBS (SOURCE: THINKNATURE ET AL., 2019)

RESEARCH AND INNOVATION ACTIONS AND PARTNERSHIPS		DIALOGUE PLATFORMS TO PROMOTE INNOVATION WITH NBS	
Project	Source	Project	Source
Biodiversa	http://www.biodiversa.org/	ThinkNature	https://www.think-nature.eu/
CLEVER Cities	http://clevercities.eu/	Oppla	https://www.oppla.eu/
Connecting Nature	https://connectingnature.eu/	EU Smart Cities Information System (SCIS)	https://www.smartcitiesinfosystem.eu/
EdiCitNET	https://cordis.europa.eu/project/rcn/216082_de.html	EU Climate Adaptation Platform CLIMATE-ADAPT	https://climate-adapt.eea.europa.eu/
Eklipse	http://www.eklipse-mechanism.eu/	SUSTAINABLE CITIES PLATFORM	http://www.sustainablecities.eu/
GraBS	http://www.ppgis.manchester.ac.uk/grabs/		
GREEN SURGE	https://greensurge.eu/		
Grow Green	http://growgreenproject.eu/		
Inspiration	http://www.inspiration-h2020.eu/		
Nature4Cities	https://www.nature4cities.eu/		
Naturvation	https://naturvation.eu/		
NAIAD	http://www.naiad2020.eu/		
OpeNESS	http://www.openness-project.eu/		
OPERAs	http://operas-project.eu/		
OPERANDUM	https://www.operandum-project.eu/		
PHUSICOS	https://phusicos.eu/		
proGIreg	http://www.progireg.eu/		
RECONNECT	https://reconnect-europe.eu/		
TURAS	http://r1.zotoi.com/		
Unalab	https://www.unalab.eu/		
URBAN GreenUp	http://www.urbangreenup.eu/		
URBINAT	http://urbinat.eu/		
ReNAture	http://renature-project.eu/		

To better understand how the European Union has allocated the various projects mentioned above over time, a timeline proposed by ThinkNature has been reworked (Figure 21) (Thinknature et al., 2019).

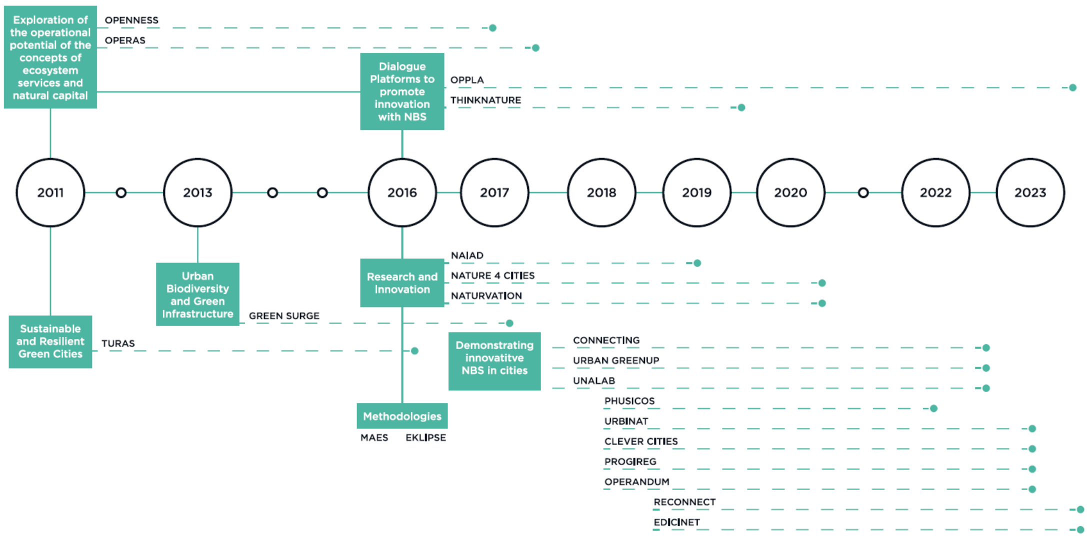


Figure 21 – Timeline of NBS projects in the EU (Source: ThinkNature et al., 2019)

From the timeline, it is visible how in the last six years the European Union has mobilized to approve and elaborate more and more projects and programs to help the underlying nations to introduce urban spatial planning projects that find the application of NBS. All these interventions are to be considered as a guideline for understanding, based on the intrinsic characteristics of the application case, which NBS solutions are best to adopt, the related positive externalities for the environment, economy, and population, but also the future impacts not only in the environmental sphere but also economically, in terms of management and application costs.

3.4 NBS Classification

As discussed in the previous section, the European Commission has played and still plays a key role in the research and innovation of NBS. However, there is still a need to develop a research program aimed at developing a scientifically valid integrated repository of strategies and solutions using NBS. The goal is to establish guidelines on the scale and levels of application, develop effective communication between the stakeholders involved, and provide tools and methodologies to implement and monitor NBS. To achieve this, experts such as the EKLIPSE Expert Working Group (EWG) have done substantial work in the development of an NBS assessment framework for promoting climate resilience in urban areas, making a major contribution in identifying indicators, actions, and methods to underpin an assessment framework for water management, coastal resilience, green space management, and urban regeneration through the implementation of NBS (Raymond et al., 2017).

In order to facilitate the implementation and evaluation of the many benefits that can be derived from NBS, it is considered appropriate to define a clear classification of the different types of NBS. The ThinkNature project, through a review of existing literature and discussions with a range of expert stakeholders, has identified four approaches to classifying NBS:

- *Approach 1*, considers the level and type of engineering or management applied to biodiversity and ecosystems, as well as the amount of ecosystem services provided and the number of stakeholders involved.

- *Approach 2*, classifies NBS according to the approaches used. These may be classified as ecosystem-based, community-based, ecological engineering, and so forth.

- *Approach 3,* in which NBS are grouped according to the challenges or problems they aim to address, such as climate change mitigation and adaptation, water management, coastal resilience, and so forth. This approach is closely linked with the UN SDGs and the EKLIPSE Impact Framework, which employs a performance-based assessment of NBS.

- *Approach 4*, where categorizes NBS based on the ecosystem services they provide according to the Millennium Ecosystem Assessment (MEA) classification. These may offer provisioning, regulating, cultural, and support services.

Of the approaches enumerated above, the first appears to be the most prevalent and, therefore, necessitates a more comprehensive examination. The first approach for the identification of the classification of the NBS was developed by Eggermont in 2015. The classification developed by Eggermont was used by the ThinkNature group (Thinknature et al., 2019) to identify other types of NBS. To better understand the differences between the two classification methods, a table was created (Table 3).

TABLE 3 – COMPARISON BAPPETWEEN EGGERMONT AND THINKNATURE CLASSIFICATIONS OF NBS (SOURCE: AUTHOR RE-ELABORATION FROM THINKNATURE ET AL.,2019)

NBS TYPE	EGGERMONT (2015) CLASSIFICATION	THINKNATURE (2019) CLASSIFICATION	SPECIFIC STRATEGIES
Type 1	No or minimal intervention to preserve and enhance the effects of ecosystem services in existing or slightly managed natural ecosystems. The promotion of NBS is intended to facilitate the more optimal utilization of natural ecosystems and the provision of ecosystem services to stakeholders who are affected by their use	Improved use of protected/natural ecosystems. This included strategies to protect and conserve terrestrial ecosystems (e.g. Natura2000), marine ecosystems (e.g. MPAs) and coastal ecosystems (e.g. mangroves).	- Limiting or preventing specific uses and practices - Ensuring continuity with the ecological network - Protect forests from deforestation and degradation caused by logging, fire, and unsustainable levels of non-timber resource extraction - Maintain and enhance natural wetlands - Protect remaining intertidal mudflats, salt marshes, and mangrove communities, seagrass beds, and vegetated dunes from further degradation, fragmentation, and loss - Structure of the Protected Natural Areas network - Protected areas of mangrove forests MPA network structure
Type 2	Comprises Nature-Based Solutions (NBS) for the sustainability and multifunctionality of managed ecosystems. It entails the provision of a reduced number of ecosystem services to a smaller number of stakeholders	NBS for the sustainability and multifunctionality of managed ecosystems, such as agricultural landscape management, coastal landscape management, extensive management of urban green spaces, and their monitoring	- Agricultural landscape management - Coastal landscape management - Monitoring
Type 3	Represents the most innovative approach, as it is designed to create new ecosystems. The primary objective of this approach is the restoration of degraded ecosystems through the implementation of design and management strategies that aim to maximize the provision of key ecosystem services for the stakeholders involved	Design and management of new ecosystems encompasses a range of activities, including the intensive management of urban green spaces, urban planning strategies, urban water management, ecological restoration of degraded terrestrial ecosystems, restoration and creation of semi-natural water bodies and hydrographic networks, and ecological restoration of degraded coastal and marine ecosystems	- Intensive management of urban green spaces - Urban planning strategies - Urban water resources management - Ecological restoration of degraded terrestrial ecosystems - Restoration and creation of semi-natural water bodies and hydrographic networks - Ecological restoration of degraded coastal and marine ecosystems

3.5 NBS BENEFITS

The implementation of NBS can result in the simultaneous acquisition of numerous ecosystem benefits or services. However, their installation requires careful study, as their improper planning can lead to the production of negative effects from the consumption of natural resources, including the depletion of these resources themselves. As previously mentioned, the benefits to be gained from implementing these solutions are not only environmental but also economic and social (Thinknature et al., 2019).

NBS offer the potential to provide multifunctional benefits, i.e. the capacity to produce several services simultaneously, to those who both invest in and reside in these places. Consequently, it is essential to examine NBS holistically, i.e. by considering all their scalar dimensions, to fully comprehend the implications of selecting a particular type of NBS. A holistic, multidimensional, multiscale approach considers the interdependencies between different dimensions and scales (Faehnle et al., 2014). NBS are complex entities that are based on the functioning of ecosystems, which evolve and vary according to time and place. Consequently, the assessment of their usefulness is closely related to complex thinking, which examines processes and dialogue cycles and the basic concepts through which they can be linked (Morin, 2005; Rouleau & Laborit, 1982).

As previously stated, the notion that NBS are inherently sustainable and capable of conferring a multitude of benefits is frequently associated with them. However, it is possible that inadequate planning and the neglectful implementation of NBS can result in adverse effects on the ground due to imbalances in the consumption of natural resources or the utilization of unsuitable materials. The advantages that can be derived from their implementation can be observed across multiple spheres, including the environmental, social, and economic realms. For instance, NBS that aims to reduce air pollution can also indirectly benefit human health by decreasing pollution-related illnesses and, consequently, the need for treatment. This can result in public financial savings for treatment, which is another economic benefit (Thinknature et al., 2019).

Each NBS must be meticulously evaluated at the planning stage with the objective of maximizing benefits and minimizing the occurrence of adverse effects. A practical illustration that elucidates the correlation between benefits and potential negative impacts is the planting of trees in urban areas. While this NBS confers advantages such as carbon sequestration and the cooling of the environment, it can concurrently result in the emission of biogenic volatile organic compounds, allergic reactions, and an increased risk of fires (Thinknature et al., 2019). Consequently, in order to mitigate at least some of these undesirable effects, it is advisable to select the most appropriate tree species, carefully studying the characteristics of each area, including the spatial configuration, management methods and the number of trees to be planted. The following table (Table 4) outlines some of the risks that can arise from inadequate NBS planning.

TABLE 4 – EXAMPLES OF BENEFITS VERSUS POSSIBLE HARMFUL IMPACTS OF NBS (SOURCE: AUTHOR RE-ELABORATION FROM THINKNATURE ET AL., 2019)

MAIN STRATEGIES	LOCAL RISKS	WIDE-SCALE RISKS
Reduction of air pollution	Release of VOC, increased pollution by slowing air flow	Pollution emissions during production and transport
Support biodiversity, offer space for declining species	Damaging biodiversity via transport of exotic species	Homogenised landscapes with one-size-fits-all solutions
Mitigation of urban heat island	Heat retention via prevention of air flow	Increased global warming due to carbon release during production
Preventing and recovering from pluvial flooding	Flood risk not reduced enough due to poor solutions	Exacerbating cloud bursts and sea level rise due to carbon release
Improved landscape and greenspace connectivity	Malfunctioning connectivity for the related organisms	Wide-scale dispersal of unwanted organisms
Noise abatement	Noise from management machinery or unexpected forms of use	Noise from production and transport
Social cohesion and social inclusion	Exclusion due to failure of recognising different user groups' needs	Segregation due to unequal access to NBS
Offer public space and accessibility	Spaces remaining unused	Wasted natural resources
Savings in energy use and costs via cooling	Cooling impact not achieved due to unsuitable plants	Fossil fuels used for material production
Increased value of the space or area	Inequality among different societal groups, space needed for NBS	Gentrification of areas

There are many benefits to be gained from the implementation of NBS, if properly planned. These can be defined according to the dimensions of implementation mentioned in section 3.4 and the spheres they affect, such as environmental, social, administrative, cultural or economic (Table 5).

TABLE 5 – EXAMPLES OF VARIOUS ECOSYSTEM SERVICES AND OTHER NBS BENEFITS RELATED TO RELEVANT NBS TYPES AT DIFFERENT SCALES (SOURCE: AUTHOR RE-ELABORATION FROM THINKNATURE ET AL., 2019)

SPHERE	ECOSYSTEM SERVICES	LOCAL SCALE	NEIGHBOURHOOD SCALE	REGIONAL SCALE
PROVISIONING SERVICES	Nutrition and food security	Ground-level and roof gardens, planting boxes, temporary re-use of space for growing food	Allotment gardens, edible forests, food sites (for fishing, mushroom and berry picking), edible greening	Crops, pastures, wild food
	Drinking water and water resources	Permeable vegetated surfaces that increase infiltration	Ponds, streams, shores, reed beds, ground-water protection	Water-shed protection, lakes, oceans, flooding areas

(*Continued next*)

SPHERE	ECOSYSTEM SERVICES	LOCAL SCALE	NEIGHBOURHOOD SCALE	REGIONAL SCALE
REGULATION AND MAINTAINANCE	Carbon sequestration	Installing NBS with low carbon footprint, use biochar in substrates	Green areas, trees, management without using fossil fuels	Low-carbon approaches, Protecting and restoring forests, coastal biotopes, peatlands
	Biodiversity including genetic resources	Vegetated roofs, parks, open waters, plants propagated from wild local origin, woodland	Variety of NBS using local declining species propagated from wild origin, open waters	Connectivity, large nature areas, conservation areas, variety of landscapes
	Pollinators for food security and biodiversity	Native flowers from early spring to late autumn, forage plants for larvae, nesting sites (sand, soft wood)	Meadows and parks rich with nectar plants, habitat for species in decline, linear NBS (e.g. transport corridors)	Connectivity, large nature areas, reconfiguration of infrastructure (e.g. streets into greenspace)
	Flood risk control, storm-water management	Permeable vegetated surfaces, green roofs, local green, sustainable drainage	Trees, flood areas, meandering rivers, bogs, mangroves, permeable pavements, green tramways	Watersheds with abundant vegetation and tree cover, large deltas, wetlands and bogs, flood plains
	Erosion control	Using mulch, compost, plant residues as soil cover; planting of seagrass and mangroves	Revegetation of riverbanks, meandering riverbeds, agroforestry	Preservation of forests and vegetation cover
CULTURAL AND SOCIAL	Aesthetic improvement	Vegetated roofs and facades, multisensory NBS, restoring waterways in cities	NBS nourishing all senses, local nature, meandering riverbeds	Large connected green infrastructure
	Cultural heritage	Individual trees, plantings, nature elements; sites with historical, cultural, or identity value	Local vegetation, official heritage sites, valuable sites for recreation and nature appreciation	Nature conservation areas, use of local vegetation in NBS
	Active life style	Easy access to inspiring green space for all (including children, elderly and disabled)	Gradients of challenge, elongated green spaces, connectivity, variation, attractions	NBS for soft mobility – forests, meadows, bogs, parks, and streets transformed into greenways
	Restoration from stress or illness	Quiet lush NBS, views from windows to NBS, easy access	NBS supporting walking and relaxed social activities	Large nature areas

(*Continued next*)

	ECOSYSTEM SERVICES	LOCAL SCALE	NEIGHBOURHOOD SCALE	REGIONAL SCALE
	Knowledge creation, education and awareness raising	Indigenous species, pollinators, variety of NBS, biodiversity elements, long-term research sites	(Semi-)wild nature, open waters, remnant forests, meadows, dead wood, long-term research sites	Large nature areas with little maintenance, natural dynamics, nature conservation areas
	Social cohesion, social capital	Community gardens	Co-management & co-planning of green space	Co-management & co-planning of landscape
ECONOMIC	Touristic development	Diverse NBS based on local species at tourist attractions and hotels	Lush and diverse NBS along major touristic routes	Large destinations with local nature, land-race and wild species
	Increased regional value	Visible vegetated roofs and facades	NBS providing recreational opportunities: open waters, forests, parks	Large preserved nature areas with recreational opportunities
	Other economic benefits	Nature-based tourism	Reduced costs for water treatment	Production of timber, food, plants for NBS

NBS can affect several issues that are currently receiving significant attention, due to their capacity to simultaneously provide numerous benefits for both biodiversity and human well-being. The benefits that can be derived from these solutions result from the resolution of the social challenges that are addressed. In other words, the definition of the benefit categories of NBS depends on the choice of the social problems to be improved or resolved, which allows a more detailed analysis of the benefits of NBS according to five macro categories (Table 6).

TABLE 6 – MACRO AND SPECIFIC CATEGORIES OF BENEFITS (SOURCE: AUTHOR RE-ELABORATION FROM LOZANO ET AL., 2023)

CATEGORY	GENERIC BENEFITS	SPECIFIC BENEFITS
Category 1	Adaptation to climate change	- Reduced flood risks (rivers, wetlands, sea-level) - Heat mitigation (Urban Heat Island) - Alleviation of storm impacts - Reduced incidents of droughts and water scarcity
Category 2	Mitigation of climate change	Reducing impacts of climate change
Category 3	Disaster risk reduction	Reduced damage from avalanches, landslides, earthquakes
Category 4	Improved environmental quality	- Reduced erosion - Improved air quality - Improved water quality - Enhanced biodiversity - Improved noise pollution
Category 5	Socio-economic benefits	- Improved economic possibilities and jobs - Reduced economic challenges - Improved health and well-being - Improved equality, integration, environmental justice, social inclusion, including improved security and reduced crime rates - Increased awareness and education - Reduced energy-related challenges, sustainable transport patterns

Category 1 | Climate Change Adaptation

The term 'adaptation' is defined as *'adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects'. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change'* (UNFCCC, 2007). NBS offer a method to enhance these capacities, leading to benefits in the social, environmental, and economic spheres as well. The implementation of urban greenery or blue infrastructure, for instance, can lead to a significant reduction in local temperatures, thus reducing the heat island effect that occurs in extensively built-up urban settings by reducing heat absorption. Another function that NBS can take on is to improve flood regulation through, for example, the restoration of wetlands or through reforestation measures that can improve water absorption capacity in the event of large-scale rainfall events. Furthermore, measures such as rain gardens, in addition to acting as a water catchment area in the event of heavy rainfall, can also act as an emergency catchment area to be used in the event of drought periods, thus preserving water resources. NBS also perform other functions such as carbon sequestration, promotion and preservation of natural habitats, filtering of pollutants in both aeriform and water form (Lozano et al., 2023).

Category 2 | Climate Change Mitigation

Climate change 'mitigation' refers to 'efforts to reduce emissions and enhance sinks' (UNFCCC, 2007). Mitigation strategies will therefore aim to reduce greenhouse gas (GHG) emissions, in particular carbon emissions, through the implementation of NBS at all scales of application (Table 5). These NBS may therefore consist of the protection and restoration of natural ecosystems that act as carbon sinks, through the protection of forests or the creation of new protected areas. Green roofs or urban parks can also largely perform this function of capturing pollutants from the air. These actions also have positive implications for the population as they can ensure cleaner and thus healthier air for the population, thereby also reducing the risk of contracting respiratory diseases (Lozano et al., 2023).

Category 3 | Disaster Risk Reduction

The introduction of NBS will also facilitate the reduction of the impacts that natural disasters can have on the territory. This aspect should not be underestimated, as these prevention activities can bring numerous benefits, not only in terms of human lives but also economically. The principal advantages of NBS include a reduction in the value of damage to structures and inventories, a reduction in damage to infrastructure, a reduction in the value of damage to habitats, a reduction in clean-up costs after natural events, a reduction in evacuation and temporary accommodation costs, a reduction in health risks, a reduction in the loss of agricultural crops, a limitation of potential loss of time in transport, a reduction in health risks, and a reduction in costs for permanent relocation of buildings and infrastructure. Furthermore, a further natural issue that often occurs is the case of landslides: Furthermore, NBS can be applied in contexts that require a reduction of slope erosion, thus acting as slope stabilizers (Lozano et al., 2023).

Category 4 | Environmental Quality Improvement

As illustrated in the table above (Table 6), there are five specific benefits within this macro-category. Erosion damage reduction (coastal and soil) and erosion risk reduction are closely aligned with 'climate change adaptation' and 'damage risk reduction' in relation to landslides and mudslides. Overall, erosion reduction reduces surface runoff, maintains soil integrity, controls pollution and sediment, and preserves habitat and biodiversity. These benefits give rise to further tangible benefits, including a reduction in soil carbon, a decline in weed productivity, and a diminution in the damage and destruction to road infrastructure, buildings, and habitats (Lozano et al., 2023).

Furthermore, there has been an improvement in air quality, which has led to a reduction in the risk of air pollution and health problems, as well as the prevention of crop losses. In terms of health benefits and cost savings for the health system, NBS measures have been linked to reductions in pollution-related illnesses (e.g. chronic bronchitis, asthma flare-ups), reduced health care costs, reduced infant and adult mortality, etc., reduced hospital admissions and emergency visits. The reduction of air pollution provides protection for microorganisms, enhances the quality of life, preserves biodiversity, and offers protection from noise, entertainment, and cultural activities (Lozano et al., 2023).

Reducing water pollution is also an important aspect with several advantages. Firstly, it avoids the future costs of restoring water systems. Secondly, it is cheaper to prevent degradation than to restore degraded ecosystems. Thirdly, it avoids pollution removal costs. Fourthly, it increases recreation and tourism in water bodies. Fifthly, rivers with better water quality are cheaper than restoring already degraded ecosystems. At the same time, an increase in agricultural production (e.g. wild rice) and an increase in fishing may also occur (Lozano et al., 2023).

The reduction of air and water pollution has the potential to increase economic income for citizens, as it can lead to a reduction in the costs associated with medical treatment, loss of productivity and thus turnover, lower prices of raw materials and resources, and so on. Furthermore, it can contribute to the reduction of biodiversity loss and improvement of habitat quality through the maintenance of vital ecosystem functions, which exert benefits that translate into well-being for the population itself. These include the improvement of the structural and functional connectivity of green and blue areas, the increase of ecological integrity and sustainability, the increase of the number and (genetic) diversity of functional groups, and the reduction of the number of invasive species (Lozano et al., 2023).

As previously demonstrated, the environmental impacts of NBS can be profoundly positive, not only for the environment itself but also for the population. However, there can also be negative impacts from their use if the planning of them is not carried out correctly. If, for example, unsuitable plants are used for the implementation of greenery, the cooling function could be compromised or it could generate problems with invasive species and unwanted diseases that could spread (Lozano et al., 2023). With regard to vegetation with the function of reducing air pollutants, it is advisable to select vegetation that does not produce VOCs or allergens but is able to absorb the maximum number of pollutants. Furthermore, the location of trees should be considered to ensure that pollutants are not concentrated in areas frequented by people (Lozano et al., 2023).

In the context of air pollution reduction, the selection of tree species that do not produce volatile organic compounds (VOCs) and allergens but absorb a maximum amount of air pollutants is crucial. However, the location of trees must be carefully considered and studied to ensure that pollution is not captured and retained in areas frequently visited by humans (Ghasemian et al., 2017; Yli-Pelkonen et al., 2017). Furthermore, the transportation and emissions resulting from maintenance operations must be taken into account during the construction phase, as well as other potential adverse impacts (such as gentrification, noise, and the nature of the intended use) (Ghasemian et al., 2017).

It can therefore be said that the benefits that can be derived from NBS, i.e. ecosystem services, vary depending on the context of application. Indeed, natural areas can provide many ecosystem services, but not to the same extent (Panduro et al., 2021). For example, in dry and hot climates, green roofs not only contribute to the well-being of occupants, but also reduce and mitigate heat. In cold and wet climates, green roofs can regulate water flow in cities. However, if we compare these NBS with wooded green spaces, which provide the strongest ecosystem services of all types and are therefore the NBS with the highest potential, green roofs perform poorly in all respects. However, given the property costs associated with large green areas, green roofs may be the best option in some situations. In the table below (Table 7), we can see an analysis of the real benefits we can derive from the application of certain NBS according to the type of problem they can improve (Lozano et al., 2023).

TABLE 7 – EXPERT ASSESSMENT OF THE EFFECTIVENESS OF URBAN NATURE AREAS (SOURCE: PANDURO ET AL., 2021)

OBJECT CATEGORY	AIR POLLUTION	NOISE	HEAT	WATER QUALITY	WATER FLOW	CARBON	BIODIVERSITY	WELLBEING
Woodland (other)	Very high	Very high	Very high	Very high	Very high	Very high	Very high	High
Green space								
- Pocket park	Low	Low	Low	Low	Low	Low	Low	Low
- Urban park	Medium	High	High	Very high	Very high	Low	High	High
- Sports field	Low	Negligible	Negligible	Negligible	Low	Low	Negligible	Medium
Street tree	High	Low	Medium	Low	Low	Medium	Low	Medium
Green roof	Low	Low	Low	High	High	Low	Low	Negligible
Green wall	Medium	Medium	Negligible	Negligible	Low	Low	Negligible	Medium
Permeable paving	Negligible	Negligible	Negligible	High	High	Negligible	Negligible	Negligible
Blue space								
Wetland	Medium	Low	Medium	Very high	Very high	Medium	Medium	Medium
River/stream	Low	High	Medium	Low	Low	Low	High	Very high
Pond	Low	Medium	Medium	Low	Low	Medium	High	Very high
Lake	Low	Medium	Medium	Low	Low	Medium	High	Very high
Reservoir	Low	Medium	Medium	Low	Low	Medium	High	Very high

The effect of NBS on biodiversity is determined by the type and number of species used. In theory, NBS offer a wide range of opportunities for biodiversity conservation, as many NBS species are continuously introduced and conserved worldwide. However, the lack of in-depth knowledge among NBS practitioners on how to effectively sustain declining species and the failure to utilise the scientific literature that provides adequate guidance on biodiversity sustainability result in unintended consequences. The most recent relevant literature (Lozano et al., 2023) indicates that NBS should be based on native species in a broad geographical sense, taking into account climate change scenarios and plant origins. In a warming scenario, this could mean that species emerge in warmer conditions, but as close as possible to the location of the NBS from which the species is migrating. It is possible that NBS could benefit from assisted migration, which would protect species that are threatened by climate change and provide new suitable habitats for plant and animal populations affected by climate change.

It is therefore of paramount importance to emphasise that NBS are not the sole solution to address global environmental and social challenges. In order to achieve sustainability, it is necessary to complement these with other actions and regulations at different spatial levels, addressing the underlying causes rather than just the symptoms (Lozano et al., 2023).

Category 5 | Socio-economic impacts

The application of NBS can result in the generation of positive externalities, which have the potential to spill over into society and the economy. Consequently, it can be argued that there is an economic return on investment from the implementation of these solutions, as they provide ecosystem services that generate social and economic value (Lozano et al., 2023).

First and foremost, there is an increase in economic opportunities and employment. Indeed, NBS can mitigate social fragilities and foster inclusive economic growth by creating environmental employment and green business opportunities. This includes the adaptation of traditional or local practices to create green jobs. NBS projects that promote diversification of employment activities further contribute to reducing social vulnerability and enhancing economic resilience, e.g. through crop diversification and implementation of agroforestry systems. Furthermore, NBS can assist in reducing economic hardship by facilitating equitable access to food production, improving food security, strengthening the link to natural environments, reducing health costs, enhancing ecotourism and increasing natural capital, social return on investment and reducing insurance premiums. Furthermore, NBS have a positive impact on physical and psychological health. They offer stress relief, reduce depression, improve mental health and facilitate more opportunities for physical activity. Consequently, their implementation enhances the health and well-being of citizens. In fact, NBS projects involving the planting of trees and vegetation can reduce heat-related mortality and morbidity (Lozano et al., 2023).

As previously stated, NBS can facilitate the achievement of the SDGs outlined in the New Urban Agenda 2030. Goals such as promoting equality, inclusion and environmental justice can be attained through the implementation of these NBS. Indeed, NBS integrate socio-economic benefits by promoting equality, social cohesion and inclusion, with a focus on diversity and social exclusion. The creation of green spaces accessible to all fosters a greater sense of community, trust and participation, thus contributing to greater safety and reduced crime. Furthermore, NBS can also be used in support of SDG 7, which looks at the transition to clean and affordable energy and thus support a successful energy transition. Indeed, NBS investments bring benefits such as improved sustainable food patterns, reduced energy poverty and energy savings through reduced consumption, including the potential for lower energy prices. This also encompasses the promotion of sustainable transport patterns, which may entail reducing vehicle use and transport distances (Lozano et al., 2023).

Furthermore, NBS are capable of providing the population with natural recreational spaces for play and entertainment. These solutions foster a sense of belonging in citizens and the establishment of social relationships, particularly among the child population. Therefore, it is essential to create corridors to facilitate access to these green areas. Nevertheless, some NBS are susceptible to intensive recreational use. For instance, some green areas or coastal areas lack paths and walkways, which could result in irreversible impacts on the biodiversity that has been created. It can therefore be posited that the utilisation of green areas for recreational activities is beneficial for humans. However, these spaces must be planned with due consideration for the natural environment, as human activities may have long-term detrimental effects. Consequently, even the economic efforts made to implement NBS may be in vain (Lozano et al., 2023).

3.6 STATE OF THE ART OF THE EVALUATION METHODS OF NBS

In recent years, NBSs have been increasingly recognised as a key tool to address the challenges of achieving urban sustainability. In order to apply NBSs in project contexts, it is essential to have an understanding of the costs of implementation and the resulting environmental, social and economic impacts. In order to gain insight into the manner in which NBSs impact the social and environmental spheres, a comprehensive literature review was conducted. This review aimed to provide an overview of the most commonly used environmental, economic and social assessment methodologies deemed appropriate for the design, construction and implementation of NBSs. The review also examined the shortcomings and challenges associated with these methodologies. Subsequently, a literature review was conducted on existing monetary, non-monetary and software methodologies for NBS evaluation.

An Initial overview of evaluations In the three spheres was conducted, followed by a general keyword search on Scopus in 2024. This initial overview revealed that the subject of environmental, social and economic evaluation is not yet fully addressed in the literature.

TABLE 8 – CONTRIBUTIONS FOUND ON THE GENERAL SPHERES AND NBS (SOURCE: AUTHOR ELABORATION)

QUERY	KEYWORDS	NUMBER OF RESULTS
1	“NBS” AND “Economic evaluation” AND “Environmental”	3
2	“NBS” AND “Environmental evaluation”	1
3	“NBS” AND “Economic evaluation” AND “Social”	1
4	“NBS” AND “Social evaluation”	0
5	“NBS” AND “Economic evaluation” AND “Monetary”	2

A second case of literature review was conducted by Assumma et al (2023). This involved an analysis according to three key methodologies. The first consisted of identifying the most widely used methodologies in the environmental field. The second examined the economic field, analysing existing methodologies capable of estimating the feasibility of NBS in both financial and socio-economic terms. Finally, the third review examined the social field, examining the different evaluation frameworks and summarising the relative impacts of NBS implementation. As the analysis was conducted in 2023, the research results were updated to the current year, 2024.

In the context of the literature review in the environmental field, which was limited to the years 2003 to 2024, it became evident that the assessment of environmental indicators is more applied than that of socio-economic indicators. This observation highlighted a deficiency related to the collection and availability of socio-economic data. The Scopus search in 2024 revealed approximately 36 articles analysing quantitative and qualitative methods of environmental assessment in urban contexts. The articles in question deal more with the concepts of urban resilience, the mapping of different ecosystem services, and the perception of risk by different stakeholders in promoting NBS. However, there is still a lack of methodological frameworks for incorporating climate change factors into NBS impact assessments related to biological impacts, and research on this topic is limited (Assumma et al., 2023).

Research in the field of economics has demonstrated that this issue has not yet been addressed in relation to the environmental and social spheres, despite the fact that in recent years it has been recognised that the implementation of NBS represents a good value for money trade-off. These years represent a moment of great opportunity, because while the economy offers secure and predictable returns despite global economic uncertainty, concerns about loss, damage and consequences are not equally distributed across the spatial and social spheres. To ascertain the extent to which the issue of economic valuation of NBS has been addressed in the literature, a search on the Scopus platform was conducted using the following keywords (Table 9). The following table corroborates the assertion that, despite the high interest in the field, the literature search demonstrated that the economic aspect has not yet been sufficiently explored in relation to environmental and social aspects. Indeed, despite the modification and/or addition of keywords to the queries, the results were not particularly significant (Assumma et al., 2023).

TABLE 9 – CONTRIBUTIONS FOUND ON THE ECONOMIC SPHERE ON THE NBS (SOURCE: AUTHOR RE-ELABORATION FROM ASSUMMA ET AL., 2023)

QUERY	KEYWORDS	NUMBER OF RESULTS
1	“NBS” AND “economic evaluation”	20
2	“NBS” AND “economic evaluation” AND “financing”	1
3	“NBS” AND “monetary” AND “decision making”	3
4	“NBS” AND “cost-effectiveness” AND “co-benefits”	8

Upon analysis of the literature pertaining to the social sphere, it becomes evident that the literature is relatively recent, and that qualitative evaluation methods are frequently proposed, whereby a sample of individuals is subjected to questionnaires or interviews. The search questions for the literature analysis were submitted to the Scopus platform, utilising a combination of the following keywords to select only journal articles (Table 10) (Assumma et al., 2023).

TABLE 10 – CONTRIBUTIONS FOUND ON THE SOCIAL SPHERE ON THE NBS (SOURCE: AUTHOR RE-ELABORATION FROM ASSUMMA ET AL., 2023)

QUERY	KEYWORDS	NUMBER OF RESULTS
1	“Nature-based solutions” AND “social impacts”	26
2	“Nature-based solutions” AND “evaluation” AND “social impacts”	4
3	“Nature-based solutions” AND “stakeholders’ participation”	28

The relative scarcity of research in this area is due to several factors. Firstly, the issue has only recently been explored, and thus there is a paucity of data. Secondly, stakeholder involvement in NBS implementation is often more appreciated in a community context. Thirdly, even if a solution is environmentally beneficial, it may not be accepted by society. Finally, it should be noted that most social issues in NBS are evaluated using an ES approach (Assumma et al., 2023). Despite the high level of interest in this area, research in the literature has revealed that the economic aspect in environmental and social contexts is still little studied. Indeed, despite the modification and addition of search terms, few results have been found and most contributions focus on the estimation of NBS benefits, negative costs, avoided costs and the complexity of the value monetisation process. The dearth of financial instruments, the high transaction costs associated with small projects, and the lack of monitoring of financial activities have served to heighten awareness of the challenges associated with NBS investments. Furthermore, the priorities of governments and the financial strength of countries around the world influence budget availability, and in some cases, serve to widen the gap between developed and developing countries. Finally, the literature review demonstrated that the assessment of the impact of NBS is complex and challenging, underscoring the necessity to develop a comprehensive evaluation framework that encompasses all aspects of NBS implementation (Assumma et al., 2023).

As previously stated, the economic sphere has not been addressed in the same manner as the environmental sphere. Consequently, a literature review was conducted on the principal economic valuation methods employed in the context of NBS. Both non-monetary and monetary valuation methods were considered in this review.

TABLE 11 – CONTRIBUTIONS FOUND ON THE MOST RELEVANT ECONOMIC EVALUATION METHODS FOR NBS (SOURCE: AUTHOR ELABORATION)

QUERY	KEYWORDS	NUMBER OF RESULTS
1	“Nature-based solutions” AND “Environmental Impact Assessment”	29
2	“Nature-based solutions” AND “Travel cost”	3
3	“Nature-based solutions” AND “Hedonic prices”	2
4	“Nature-based solutions” AND “Benefit transfer”	6
5	“Nature-based solutions” AND “Contingent valuation”	10
6	“Nature-based solutions” AND “Cost-benefit analysis”	95
7	“Nature-based solutions” AND “Costs-Incomes Analysis”	0

The results demonstrate that the most prevalent methodology is cost-benefit analysis (CBA), which enables a direct comparison of the implementation and maintenance costs of a project, in this case, NBSs, with the economic benefits generated. This provides a comprehensive economic picture of the economic value of NBSs. In contrast, the Environmental Impact Assessment (EIA) is referenced 29 times. This is a non-monetary evaluation that assesses the effects of NBSs on the environment through the inclusion of aspects that are not easily monetised. Contingent valuation is a useful method when estimating environmental goods that do not have a direct market. Finally, the benefit transfer method, travel cost method and hedonic price method are referenced infrequently. The benefit transfer method is still not widely used, while the travel cost method and the hedonic price method are less frequently employed.

A further analysis was conducted o” the’extent to which software for the economic valuation of ecosystem services resulting from NBS implementation is actually used.

TABLE 12 – CONTRIBUTIONS FOUND ON THE MOST RELEVANT SOFTWARE FOR THE ECONOMIC EVALUATION OF SE FROM NBS IMPLEMENTATION (SOURCE: AUTHOR ELABORATION)

QUERY	KEYWORDS	NUMBER OF RESULTS
1	“Nature-based solutions” AND “InVest”	51
2	“Nature-based solutions” AND “i-Tree”	20
3	“Nature-based solutions” AND “SimulSoil”	0

This analysis indicates that the economic evaluation of Ses is predominantly conducted using the InVest software, with i-Tree being employed to a lesser extent. This may be attributed to the fact that i-Tree is only applicable to a subset of states, whereas InVest is more widely used. Finally, Simulsoil is a software that has not been referenced, likely due to its obsolescence.

3.7 COST CATEGORIES RESULTING FROM NBS IMPLEMENTATION

The implementation of NBS entails financial costs to be borne by the various stakeholders involved, ranging from potential project funders to the community itself. These costs include all the expenses required for their implementation, from the initial investment to the transactions for their implementation and maintenance over time (Lozano et al., 2023).

In order to understand how much it might actually cost to implement a given NBS, a literature review was conducted in Scopus, Web of Science and also in the grey literature. This analysis showed that it is difficult to find this information, in fact only a few articles were found that deal with a real economic estimate. Among them, Panduro et al. in the paper “Cost-effectiveness of NBS in the urban environment WP N°2 Challenges and fostering NBS for smart, green and healthy urban transitions in Europe and China”, published in 2021, provides an overview of the costs of implementing NBS and presents an application of cost estimation in the cost-benefit analysis of potential NBS in urban areas (Lozano et al., 2023).

We can therefore divide the NBS into ‘generic’ categories, which include all those cost categories that we can consider relevant to the realisation of the project, and ‘specific’ categories, which cover all initial investments and expenses incurred before the project starts operating. General costs include: I) construction costs, II) maintenance, administration and operation costs, III) monitoring costs, IV) financing costs, V) opportunity costs and VI) indirect costs. Specific costs include: (a) fundraising campaigns, events and meetings with (potential) funders and the community at large, (b) feasibility, technical and planning studies to assess risks and cost analyses prior to implementation, (c) architectural and engineering design, (d) research and development (R&D) and innovation activities, I site or land acquisition, (f) legal fees, and (f) construction, installation and implementation costs of the NBS project, such as excavation or creation of blue-green infrastructure; (g) contingency margin for contingencies and unforeseen costs during construction or installation; (h) relocation/reconfiguration of existing land use infrastructure; h) labour costs (i.e. wages and benefits) and staff costs; i) labour costs (i.e. wages and benefits) and staff training; j) stakeholder engagement costs, such as workshops, meetings, interviews, surveys, food, accommodation, promotional and educational activities; k) purchase of capital equipment, facilities, machinery and office supplies (e.g. software, hardware, branding, furniture, chairs); and l) utilities costs, i.e. electricity, water, waste disposal, heating, air conditioning, sewerage, etc. (Lozano et al., 2023).

However, in addition to the above-mentioned expenses, one should also consider maintenance, administrative and operational costs, i.e. those expenses incurred after the start of the project operation. These encompass: a) labour wages and training of on-site and off-site personnel, b) insurance policies (e.g. health, life) and taxes (e.g. property), c) ongoing research and development (R&D) and innovation activities, d) expenses related to ongoing stakeholder engagement, including promotion, participation, involvement and education, e) land lease payments, f) maintenance, repair and replacement of capital assets, e.g. IT equipment, machinery, intangibles, software licences, furniture, office supplies and other physical equipment, g) depreciation of capital assets, h) utilities, i) travel and transport costs, j) legal advice, audits and support staff, including audit fees and salaries of external staff (Lozano et al., 2023).

In addition, monitoring costs and financing costs must also be taken into account. The former are the costs of observing and analysing the performance and impact of the NBS intervention, i.e. the collection of information, data or measurements in the field, which may be collected, recorded and periodically updated for analytical and sampling purposes. There may also be costs associated with the development of monitoring protocols. Whereas financing costs are expenses related to loans, such as interest, fees, transaction costs and lease payments (Lozano et al., 2023).

Finally, it is also appropriate to list opportunity costs, i.e. benefits lost because they are associated with other land uses such as housing, industrial activities, sport, recreation and other competing land uses, and indirect costs, i.e. all those costs of unintended disturbances, side effects and impacts of the NBS project, e.g.: a) residual damage, b) agricultural losses, and c) degradation of air/water/soil quality (Lozano et al., 2023).

We can therefore conclude that, in the ex-ante design phase of projects integrating NBS solutions, the cost items just mentioned and shown schematically in the table below (Table 13) should be taken into account in order to assess the feasibility of the project itself, not only in the implementation phase, but also in the ex-post maintenance phase to ensure the continued proper provision of ecosystem services (Lozano et al., 2023).

TABLE 13 – COST CATEGORIES FOR THE IMPLEMENTATION OF NBS (SOURCE: LOZANO ET AL., 2023)

GENERIC COST CATEGORIES	SPECIFIC COST CATEGORIES
I) Costs of establishment	a) Fundraising
	b) Feasibility and planning studies
	c) Architectural and engineering design
	d) Research and development (R&D)
	e) Site and/or land acquisition
	f) Construction and installation
	g) Allowance for contingencies
	h) Relocation and/or removal of existing land-use infrastructure
	i) Labour and training
	j) Stakeholder involvement
	k) Capital (Equipment, facilities, machinery, and office supplies)
	l) Utilities
II) Maintenance, administrative and operation costs	a) Labour and training
	b) Insurance and taxes
	c) Ongoing research and development (R&D)
	d) (Continued) Stakeholder involvement
	e) Land rent
	f) Capital (Equipment, facilities, machinery, and physical endowments)
	g) Capital depreciation

(*Continued next)*

	h) Utilities
	i) Transport and travel expenses
	j) Legal counselling, audit and supporting staff
III) Monitoring costs	[Costs of tracking and observation ex-ante and ex-post]
IV) Financing costs	a) Interests
	b) Fees, transactions costs and commissions
	c) Lease payments
V) Opportunity costs	[Foregone benefits associated with other land uses such as housing developments, industrial activities, sports, recreation, and other competing land uses]
VI) Indirect costs	a) Residual damages
	b) Agricultural loss
	c) Reduced air / water / soil quality

PART II | METHODOLOGY

This section of the thesis will provide an overview of the different methodologies for the economic valuation of natural capital, with a detailed analysis of the techniques used. Both monetary and non-monetary techniques, which quantify the value of natural capital in financial terms, and non-monetary valuation techniques, which focus on qualitative aspects that cannot easily be translated into economic terms, will be examined.

Next, we will take a closer look at Spatial Multicriteria Analysis (SMA), a tool that combines MCA and GIS analysis into one and will be used in the final project to support complex decisions by evaluating various spatial and environmental criteria.

Furthermore, an in-depth analysis of indicators in the literature will be conducted, which are used to draw up vulnerability maps. These maps are an invaluable tool for identifying the areas most at risk and for planning interventions aimed at the conservation and management of natural capital.

4. Economic evaluation of natural capital

Before describing the different methodologies used for the economic valuation of natural capital, it is considered appropriate to provide an overview of the characteristics of environmental goods. A first important classification to clarify is that goods or services used by the community in its socio-economic system can be divided into public goods and private goods. Public goods, or goods for collective consumption, can be enjoyed by many people at the same time without increasing production costs or reducing individual utility; an example of a public good would be a park. In contrast, private goods, or goods for individual consumption, are characterised by competition in consumption, i.e. the use of a good by one individual excludes others from using it, e.g. a car. We can therefore say that a fundamental difference between a public good and a private good is non-excludability, i.e. the impossibility of excluding an individual from the use of a good, and this exclusion can only occur in cases of technical or financial limitations that prevent an individual from using certain goods or services, and rivalry in consumption, which gives rise to so-called "mixed goods". The latter combine the characteristics of public and private goods; for example, a park may be accessible to all (cannot be excluded), but if it becomes too popular it may become a bottleneck (competition for consumption). Mixed assets may be managed by both public and private entities, often for different purposes. However, the provision of goods or services can generate externalities, which are the side effects of producing or consuming goods that are not reflected in market prices. Externalities can be positive, such as improved temperatures due to the addition of a green space, or negative, such as pollution caused by cars. An externality is a market failure because neither producers nor consumers are fully included in the costs or benefits (Stellin & Rosato, 1998).

Over the years, the community has become increasingly aware of the value of environmental resources to their lives and the benefits they bring, and have therefore increased their use and research. This phenomenon is due to a number of socio-economic factors, such as an increase in economic well-being, a rise in the level of culture and an increase in the availability of leisure time. As a result, the protection of natural ecosystems and cultural heritage has become a common priority, both from the threats posed by productive activities and from the consequences of excessive recreational use. This new awareness has highlighted the need to implement more effective strategies for environmental resources, aimed at both their conservation and their sustainable use in the economic sphere. To achieve these goals, it is important to study not only the physical and historical aspects of these resources, but also the economic effects of their use. The monetary valuation of environmental goods and services is difficult because of their public goods nature. However, the absence of a market price does not mean that these goods have no economic value; on the contrary, the growing demand for the benefits they provide, combined with their increasing scarcity, underlines their economic importance (Roscelli, 2014).

Over the years, the economic valuation of environmental assets has undergone numerous developments, leading to the definition of the concept of Total Economic Value (TEV). Indeed, having recognised the limitations of the traditional reference to exchange value, it has been necessary to develop a broader concept of value that takes into account the multiple reasons why these assets are valued in society. TEV seeks to capture the intrinsic and multidimensional value of environmental resources, going beyond mere monetary quantification (Stellin & Rosato, 1998).

Some of the components of VET are directly related to the use of an asset (use value) while the others are independent of its use (non-use value). From this distinction, four value categories can be distinguished (Roscelli, 2014):

- Direct use value, refers to the benefit deriving from a specific use of a resource and is therefore consistent with the concept of opportunity cost.
- Option value, correlated to the concept of wanting to ensure the availability of a good in the future; this value item indicates, therefore, the additional expenditure that an individual is willing to face in order to be able to guarantee a certain good or service in the future.
- Bequest value, stems from the awareness of guaranteeing for future generations the enjoyment of certain environmental resources;
- Existence value, stems from the awareness that a certain good or service exists and will continue to exist; this value is therefore related to ethical, moral and ideological points of view.

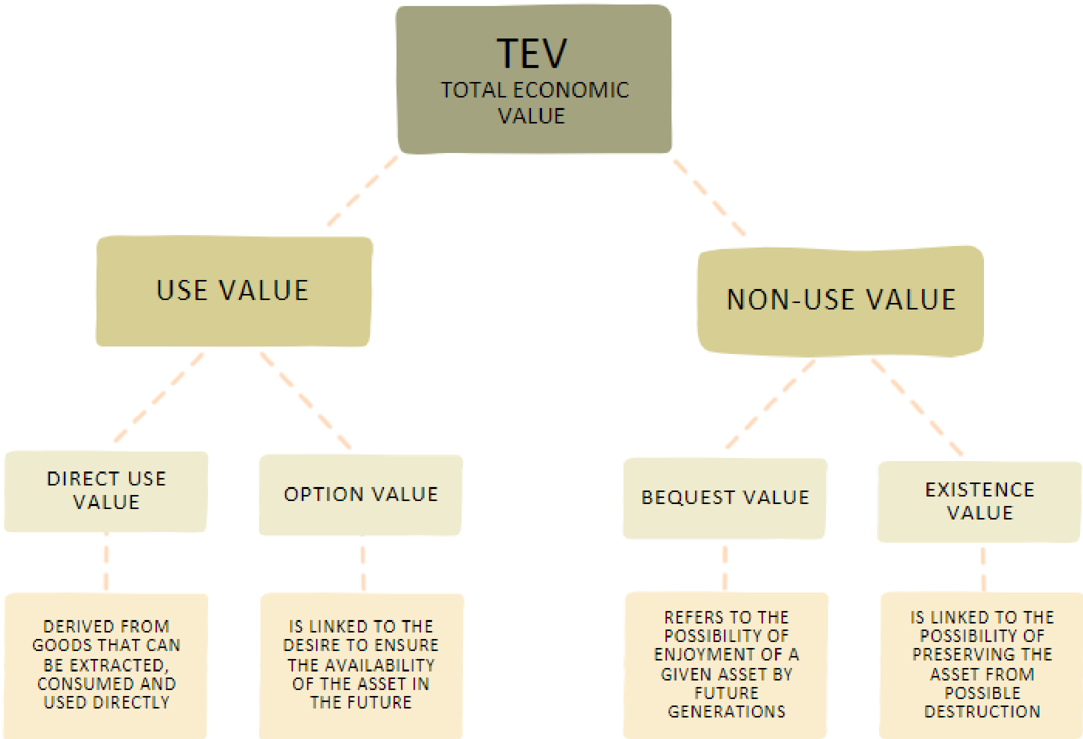


FIGURE 22 – TOTAL ECONOMIC VALUE (SOURCE: AUTHOR RE-ELABORATION FROM ROSCELLI, 2014)

NBS are now seen as an important technique for addressing current environmental issues in the context of socio-economic challenges. They are also useful for integrating the environmental benefits of their implementation with the related economic benefits. The economic and monetary assessment of the costs and benefits associated with incorporating NBS solutions is a crucial aspect of understanding the tangible and intangible values associated with ecosystems. This assessment includes both the use values associated with

NBS and the non-use values. The use of both values ensures a comprehensive assessment of the benefits that can be provided by natural solutions. In addition to these values, there are also the general installation, maintenance and opportunity costs associated with implementing the NBSs themselves, which were discussed in detail in Section 3.6. Therefore, in order to determine the total net cost of NBS projects, it is necessary to integrate the costs just mentioned with the economic benefits that can be obtained (Croci et al., 2021).

To make TEV more comprehensive, several economic valuation methods are being developed to also understand the relationship between ecosystem services (ES), value types and methods. Three types of ecosystem services can be identified (Lozano et al., 2023):

- Supply services (e.g. timber, food, fresh water, fibre, genetic resources, medicinal plants)
- Regulation and maintenance services (e.g. climate regulation, water purification, disease regulation, maintenance of physical conditions)
- Cultural services (e.g. recreation, tourism, education, aesthetic value, spiritual value, religious value)

Therefore, applying VET to the valuation of NBS, we can define use values as the benefits that people derive from the direct, indirect or potential use of NBS. Examples include tangible goods and services that have a market price, such as the value of timber, agricultural products or water supply services generated by an NBS, or the indirect benefits that people derive from the SE provided by NBS, such as improved air quality or the cooling of certain urban areas by green spaces. On the other hand, optional values related to NBS can be, for example, how much a homeowner would be willing to pay for the maintenance of a medium-sized park in front of his house. Looking at the non-use values applied to NBS, we can say that existence values are those values that individuals attach to the existence of a particular NBS for moral or ethical reasons, while bequest values are those values that the current generation attaches to the preservation of biodiversity and the functioning of ecosystems for future generations (Lozano et al., 2023).

Methods of economic valuation of environmental goods can be monetary and non-monetary (Table 14). In the following paragraphs, these methodologies will be described in more detail.

TABLE 14 - CLASSIFICATION OF VALUATION METHODS FOR ENVIRONMENTAL ASSETS (SOURCE: STELLIN & ROSATO, 1998)

Type of evaluation	Units of Measurement	Evaluation method	
Non-monetary	Technical Parameters	Environmental Impact Assessment (EIA)	
Monetary	Valori convenzionali	Technical coefficients applied at market prices	
	Market prices (traditional valuation)	Production value Supplementary value Subrogation value Transformation value	
	Consumer surplus	Indirect	Travel cost (TCM)
			Hedonimetric method (HP)
			Benefit Transfer
		Direct	Contingent valuation (CV)

4.1 Non-monetary evaluation method

4.1.1 Environmental Impact Assessment (EIA)

The Environmental Impact Assessment (EIA) is a decision-making tool that aims to proactively identify, describe and assess the environmental impact of certain public or private projects. It is a technical-administrative procedure whose purpose is to systematically evaluate the compatibility of the work or intervention with the environment, based on an analysis of the impact of the work or intervention on the relevant environmental and socio-economic components. It is precisely for this reason that the EIA is considered to be a valuable tool in environmental policy, since it moves away from the creation of projects and takes into account their preventive effects, according to an integrated approach (Roscelli, 2014).

EIA considers impacts on all aspects of the environment, and through this process it is possible to identify the least environmentally damaging of the various project options, and to make changes to the project to mitigate or compensate for negative impacts. The key concepts that summarise the EIA process are (Roscelli, 2014):

1. Prevention: a preliminary analysis of all possible consequences of human activities in order to protect and improve the environment and the quality of human life.

2. Integration: taking into account the interactions and different possible impacts of all environmental components. Impact assessment is integrated into the planning of projects and policies in the main economic sectors.

3. Comparison: Collection, analysis and use of scientific and technical information to provide a basis for information, dialogue and feedback between planners and authorities with a view to mutual cooperation.

4. Participation: the evaluation process is open to the active contribution of citizens, ensuring greater transparency of planning proposals and the work of the public administration.

EIA was first implemented in the United States in 1969 through the National Environmental Policy Act (NEPA), where national policies oriented towards environmental sustainability were defined. Subsequently, in 1985, the EIA was introduced in the European context with Directive 85/337/EEC, concerning the assessment of the environmental impact of certain public and private projects, leaving subsequent implementation to the Member States. The Italian state transposed the legislation with Legislative Decree no. 152 of 3 April 2006, known as the Consolidated Environmental Act. This document establishes that for works and interventions under state jurisdiction, the preliminary investigation for the EIA is carried out by a technical-consultative commission for environmental assessments, set up by the Ministry of the Environment and Land Protection (Roscelli, 2014).

4.2 Monetary evaluation method

This type of method is based on analysing the behaviour of individuals in the market to understand their preferences in terms of ecosystem services. Within these consumer analyses, we can analyse the value of a piece of land, travel costs, etc. To better understand how this consumer-based methodology works, a case study was conducted (Mutulu et al., 2023) to investigate the willingness of homeowners to pay for NBSs that provide flood protection and environmental benefits. The study assessed homeowners' willingness to pay using the hedonic pricing model, which we will see in detail below, by analysing changes in property value over time and estimating the reduction in flood risk associated with the introduction of NBS (Lozano et al., 2023).

Thus, indirect methods allow for the analysis of trade-offs between the benefits associated with NBS and those associated with other goods and services with which people interact or consume. By analysing how people allocate their resources and make choices, revealed preference methods describe the relative importance and value of NBS. In addition, they take into account the context and specific characteristics of the markets studied, allowing for a more personalised and contextualised assessment of the value of NBS, taking into account local preferences and circumstances. However, this type of model is based on observable market transactions and behaviour, which may not fully capture the value of NBS, and ignores non-market values that are not reflected in the observed market options. Critical market problems, such as externalities or missing information, can lead to biased or incomplete valuation results that do not fully take into account the social and environmental externalities associated with NBS, which may underestimate their true value. Furthermore, in some cases, information on market behaviour and choices related to NBS may be limited or difficult to obtain, which may prevent the application of revealed preference methods and negatively affect the accuracy and reliability of valuation results (Lozano et al., 2023).

4.2.1 Indirect methods

Indirect methods (travel cost method, hedonic method) use the relationships between environmental goods and private goods created during consumption activities. In this case, the use of environmental goods is often possible because it complements the consumption of private goods whose price is easily observable. For example, to visit a holiday destination, it is usually necessary to pay for travel, eat out and possibly buy a ticket. By constructing a demand curve for private goods and services associated with the use of an environmental resource, it is possible to derive the demand function for the latter. The methods under consideration may be effective in determining the use value of the resource, but estimates based on the use value of the actual use of the good are not (Stellin & Rosato, 1998).

4.2.1.1 Hedonic Pricing Method (HP)

The hedonic pricing method is used for the economic valuation of environmental assets, public assets and the property market. In the latter case, it is used to assess the market value of a property and how each individual property characteristic affects its value. Hedonic pricing is also used to assess how negative externalities can negatively affect market value (Lozano et al., 2023).

The method was introduced in 1938 by Andrew Court in the automobile industry. It is based on the axiom that each good is characterised by its own attributes and therefore the value of each good is based on the attributes that a particular good possesses. The consumer then chooses one good over another on the basis of the characteristics of the good or service in order to derive a specific utility from it. Hedonic prices are therefore based on the fact that each good is characterised by different attributes and the consumer chooses the one that has the attributes that will maximise his utility (Lozano et al., 2023).

This means that if I have two identical goods that differ in one characteristic, the difference in price is the difference in that characteristic. However, the Court of Justice does not use the term 'price' but the term 'value'. The term 'price' was later introduced by specifying that the price of each good is a function of the characteristics of that good, and thus the difference in price is given by the difference in characteristics. Hedonic pricing began to be used in the real estate sector in the 1960s, when it was recognised that the real estate market was a diverse market in which the traded goods had different attributes: intrinsic, i.e. intrinsic to the property (e.g. surface area, number of floors, etc.) and extrinsic, such as neighbourhood, presence or absence of public services, proximity to goods that can increase consumer welfare (Lozano et al., 2023).

Hedonic prices are based on utility theory, introduced by Lancaster, which shows that a consumer can choose one good over another on the basis of characteristics and the utility derived from those characteristics. In property market studies, market values reflect these same characteristics. For example, properties located near a park or with a beautiful landscape often have a higher market value, and the price difference may be due to the value of the ecosystem services provided by the park or landscape concession (Lozano et al., 2023).

Furthermore, hedonic prices are based on regression analysis, which is used to identify the relationship between two variables: dependent, such as market value, and independent (e.g. the area of a property). Regression analysis makes it possible to determine the relationship between the dependent variable and its characteristics, i.e. if one of the independent variables changes, the dependent variable will also change. Ultimately, the evaluation is based on the identification of the role that each independent variable plays in defining the market value inherent in the case being studied; in economic terms, it then determines the influence that each characteristic has on the final price (Lozano et al., 2023).

4.2.1.2 Travel Cost Method (TCM)

The travel cost method is used to estimate the recreational value of a natural area. It is based on the principle that the value of an area is measured by how much visitors would be willing to pay to reach and use it, taking into account, for example, transport and time costs.

This type of information is obtained through surveys of visitors to a given area; they are asked, for example, about the number of visits made, the number of kilometres travelled and the time taken to reach the site, the type of transport used, etc. This information is essential to build up a detailed picture of the behaviour and preferences of users of a given site. Travel costs are calculated on the basis of the distance travelled and the means of transport used, while the time taken to reach the site is considered an opportunity variable, since it could also be used for other leisure activities; to understand this last variable better, the value of the time spent travelling is analysed on the basis of income, since the time "lost" on the way has an economic cost linked to the possible gain or use of that time. In order to estimate the demand for a given area, the travel costs and the number of visits are evaluated in order to see how the travel costs vary with the number of visits. From this relationship between variables it is possible to derive the average willingness to pay of visitors (Metodo del costo di viaggio come utilizzare il comportamento di viaggio per stimare il valore dei siti ricreativi nell’analisi costi benefici - FasterCapital, 2024).

4.2.1.3 Benefit Transfer

The benefit transfer methodology has been developed to estimate the economic value of ecosystem services by transferring available information from studies already carried out in another location or scenario. The aim is to estimate the benefits of a good or service by adapting it to an estimate derived from a different context. This method is used when another type of study would be too costly or the time available is very limited (Benefit Transfer Method, n.d.).

Benefit transfers are of two types: value transfers and function transfers. The first type of transfer uses a single value taken from another similar or previously assessed scenario, while the second type uses the aggregation or average of values from previous studies and is then applied to the scenario for which the value estimate is sought. While the first type requires the two scenarios being compared to be very similar in terms of the demographic and physical characteristics of the area, the second allows the economic value to be analysed in relation to non-similar case studies by calibrating values based on the population or physical characteristics of the study area. In recent years, greater importance has been attached to the functional transfer typology, which is considered more reliable from a statistical point of view, since it is able to reduce as far as possible the differences between the two contexts compared (Boutwell & Westra, 2013).

In both methodologies, however, two types of error can occur (Boutwell & Westra, 2013):

- Measurement errors: these are mainly related to the assumptions made by the researchers in the primary study and how the measurement of these can lead to discrepancies between the estimate of the true value in the primary study and the true value of the scenario with which the comparison is made. These types of errors can be limited by more careful selection of the studies to be compared.;

- Transfer or generalisation errors: these arise in the very act of transferring values because of differences between the study site and the compared site, or in the methodology used to transfer values. These errors are measured by a convergent validity test that compares an out-of-sample prediction of a transferred value with a primary empirical analysis of the hypothetical site.

Today, benefit transfer is also used to estimate the economic value of ecosystem services provided by natural solutions. It has also been used extensively to assess the economic benefits of many strategies, such as floodplain restoration, afforestation or ecosystem-based management practices. The method is applied by identifying relevant studies that have valued and quantified NBS and similar ecosystem services, and then transferring and adapting these values to the real-world scenario.

4.2.2 Direct methods

Direct methods measure the user's willingness to pay for a given environmental benefit by direct reference to his or her explicitly stated preferences in real or hypothetical situations. Direct methods can be divided into two groups: observable direct methods, where changes in people's well-being are estimated on the basis of actually expressed preferences, and hypothetical direct methods (Stellin & Rosato, 1998).

Direct hypothetical methods, of which contingent valuation is the best known, involve the creation of a hypothetical market in which consumers directly express their preferences. These markets are simulated through interviews in which a representative sample of the target population is asked to express their willingness to pay (WTP) to continue using, finance improvements to, or simply save environmental resources, or the compensation they would be willing to pay (WTA) to give up using them. Hypothetical direct methods estimate the value of a good by 'simulating' a market in which users of the resource can quote prices directly, without an actual exchange taking place. These methods are based on the assumption that the behaviour of individuals in a hypothetical market is similar to that in a real market. It is therefore assumed that respondents do not behave strategically and are not influenced by the research methods or the interview process. From the extensive literature on the subject, it can be concluded that although the hypothetical nature of the market may affect the quality and reliability of the valuation, prospective valuation can provide reasonable financial estimates of the natural and built environment (Stellin & Rosato, 1998).

4.2.2.1 Contingent Valuation Method (CVM)

This method is used to place an economic value on certain goods for which there is no target market, by conducting a direct survey to understand consumer preferences. In order to assign an economic value to this type of good or service, a hypothetical market is simulated through surveys of the relevant part of the population, which evaluates the willingness to pay (WTP) for an increase in well-being or the willingness to accept (WTA) the renunciation of this good or service (BankPedia, n.d.). It was Ciriacy-Wantrup who proposed this method in 1947 to estimate the positive economic externalities of projects to prevent soil erosion. It was applied for the first time in 1963 and was later used to assess non-use values, particularly in environmental contexts (BankPedia, n.d.).

However, this methodology is critical in that both willingness to pay and willingness to accept lack validity and reliability in estimation because they assess people's individual preferences. This criticality arises from the fact that people interpret the loss of value differently from the gain in value. In order to avoid these problems, the contingent valuation methodology must be studied and implemented by including analyses of socio-economic information and the use of real and applicable questionnaires. In addition, the sample of people included in the analysis must be representative and meaningful, and the interviews or surveys conducted must be face-to-face with the sample, rather than relying on remote collection. The steps in applying this methodology must therefore begin with the definition of a hypothetical market, then the selection of the sample to be analysed, the study and design of the questionnaire to be administered to the sample, and the analysis of the results (BankPedia, n.d.).

4.3 Ex-ante evaluation tool

The ex-ante evaluation of a project is conducted prior to its implementation and is crucial for decision-makers to select the most compatible project with their objectives and to define related strategies. The evaluation methods employed in this phase can be monetary or non-monetary, and both can be used to assist in the formulation of a project and the definition of strategies. The most commonly used methodologies are stakeholder analysis and SWOT analysis to assess the application context; multi-criteria analysis for an evaluation of different alternatives; and cost-benefit analysis to provide prior input on the economic, social and environmental feasibility of the project. Once more, decision support approaches can be combined to provide a more realistic and comprehensive assessment for decision-makers of the costs and benefits to be derived from NBS. It is crucial to conduct preliminary assessments, as the selection of an optimal investment option may necessitate a trade-off between different objectives. For instance, a scenario may arise where low investment costs are achieved at the expense of higher environmental impacts, or vice versa. It is therefore necessary to identify the optimal balance between the actual objectives and the necessary trade-offs to achieve them, in support of the decision-makers themselves (European Commission, 2013).

4.3.1 Monetary tools

Monetary tools are economic-financial analyses that evaluate a project from a purely cost perspective. This section presents the most significant monetary methodologies for NBS analysis.

4.3.1.1 Cost-Benefit Analysis (CBA)

A cost-benefit analysis (CBA) is a methodology that is employed to compare the costs generated by the implementation and possible maintenance of NBS projects with the possible benefits they will generate. This is done in order to assess the feasibility and complexity of the intervention. In order to have a structured and objective overview of the feasibility assessment of the interventions that will support the decision-makers, both market and non-market values are to be considered. The CBA prioritises NBSs based on their net benefits and helps to allocate resources more effectively towards projects that bring the greatest benefit to society. However, considering also non-market values may prove to be a limitation, as it is not always easy to assign correct values to intangible assets, which are also subject to personal interpretations of the individual evaluating them. Moreover, the CBA's focus on minimising future costs and benefits may lead to a conflict between short-term and long-term objectives and generate ethical and equity concerns. Indeed, the CBA may not adequately take into account disparities or inequalities in the distribution of benefits and costs of a possible NBS project between different segments of the population (European Commission, 2013).

4.3.1.2 Cost-effectiveness analysis (CEA)

CEA is employed to ascertain which of the NBS options is most conducive to the achievement of the environmental objectives. This methodology entails a comparison of the costs associated with each NBS, followed by an assessment of their efficacy in delivering the anticipated benefits while minimising their implementation costs. Furthermore, it permits a direct comparison of various NBS interventions in terms of costs and results obtained, thereby enabling decision-makers to select the option most aligned with their objectives. This is made possible by the pragmatic approach to decision-making that this methodology offers. In particular, CEA is suitable when limited resources are available, as it helps to direct the evaluation towards more efficient and affordable solutions to achieve the set objectives. However, CEA is constrained by its narrow scope, which encompasses a limited number of outcomes while overlooking crucial non-monetary and long-term NBS outcomes. Moreover, as this methodology prioritises cost-effectiveness, some objectives may be overlooked as being less cost-effective according to the methodology itself (European Commission, 2013).

4.3.1.3 Life-cycle analysis (LCA)

Life cycle assessment (LCA) is a comprehensive methodology employed for the estimation of ecosystem services. During the assessment, this methodology considers the entire life cycle of NBSs and provides a holistic understanding of their contribution to ecosystem services. Through this, LCA is able to identify potential issues and impacts that NBSs may generate during their life cycle and, through the implementation of mitigation measures, is able to prevent them. Moreover, the application of this methodology enables the comparison of different solutions in order to identify the most sustainable and congruent with the objectives. However, the application of LCA requires a wide range of data, and, in particular, in NBS projects, these are not always readily available. Moreover, a crucial aspect for the generation of accurate and comparable results is the definition of boundaries. This entails focusing on one or more specific phases of the NBS life cycle, as well as on the functional unit, which is the measure that quantifies the inputs and outputs of the analysed system. Finally, a further fundamental step concerns the weighing of the different environmental impacts detected. However, this may not always be reliable, as the assessment may be subjective and therefore not guarantee complete reliability of the results (Larrey-Lassalle et al., 2022).

4.3.2 Non-monetary tool

Non-monetary tools comprise strategic assessments designed to identify the optimal scenario without quantifying the associated costs. This section will examine the most significant non-monetary methodologies for NBS analysis.

4.3.2.1 SWOT Analysis

The analytical framework was developed by Albert Humphrey, an American economist, between the 1960s and 1970s. Its origins lie in the context of business. Its potential was recognised, and it was subsequently employed to create alternative development scenarios for the public sector, thus influencing urban planning. The framework is represented by a matrix divided into four main quadrants. The first two elements, Strengths and Opportunities, deal with the positive aspects of a decision problem. The second two elements, Weaknesses and Threats, encapsulate the negative aspects of a project. The further difference between these four elements is that they can be classified as endogenous (internal) elements that are part of the decision problem under consideration. These are the strengths and weaknesses on which one can directly act to solve or mitigate them. In contrast, opportunities and threats are considered as exogenous (external) factors over which one has no direct control (Wheelen & Hunger, 1995).

The analysis can be developed according to two distinct procedures: Desktop analysis, which is conducted remotely and involves the analyst collecting information and organising the matrix independently, and Participatory analysis, where the main stakeholders are involved in the decision-making process and each is asked to provide a rationale for the four points. At the conclusion of these analyses, the analyst synthesizes the information and produces the SWOT analysis. It is possible to develop analysis at different stages of the decision-making process, not only in the ex-ante phase. In fact, the ex-ante phase is carried out first to support project drafting, in the in-itinere phase, on the other hand, the SWOT is useful to monitor project progress, and in the ex-post phase, i.e. after project implementation, it is useful to better contextualise the results of a certain evaluation (Hill & Westbrook, 1997).

The SWOT analysis enables the construction of project strategies. The rationale is that, once the SWOT is completed, the project strategy is one that enhances strengths, minimises weaknesses, increases opportunities and controls risks. Based on the results of the SWOT, the analyst and planner can define a strategic framework (Hill & Westbrook, 1997).

The methodology for conducting a SWOT analysis differs from that of other forms of analysis. The first step is to collect data concerning the project and the area in question. This is followed by the identification of the components of the project, plan or programme. A preliminary classification of exogenous and endogenous factors is then carried out. Finally, possible strategies can be selected to enhance strengths, minimise weaknesses, increase opportunities and control related risks. The SWOT analysis is a flexible approach that can accommodate a wide range of information, including data of varying types. It is also conducive to participatory procedures, which enhances its openness. However, it is a qualitative analysis, which can be a limitation because subjective factors can sometimes be more influential than objective ones (Wheelen & Hunger, 1995).

4.3.2.2 Stakeholders Analysis

This type of analysis allows us to organise the complexity of a decision-making process by examining the underlying issues that may arise due to the involvement of multiple interests in the decision-making process. The analysis aims to identify which actors can participate and contribute to the development of a given project, plan, or programme. This depends on the interests of the actors and the level of action of the stakeholders. It is also necessary to consider the preferences of stakeholders with regard to the solution to be implemented, as these preferences relate to their own interests and objectives (Dante, 2014).

The analysis may be performed using three main methodologies: the Power-Interest Matrix, the Stakeholder Cycle Methodology and Social Network Analysis. In the Power-Interest Matrix, the different stakeholders are mapped using a matrix identified by Mendelow, which is composed of four quadrants (Yang, 2013):

1. "*keep player*" quadrant, high power and high interest, these individuals can formally make decisions;
2. “*key player*" quadrant, high power but low level of interest;
3. "*minimal effort*" quadrant, low power and low interest;
4. "*keep informed*" quadrant, high level of interest but low level of power, such as citizens.

With regard to the aforementioned quadrants, the x-axis represents the level of interest, while the ordinates indicate the level of power. Consequently, the level of power and interest allows for the mapping of each stakeholder's position and the definition of their role. The evaluation of each stakeholder is based on the perception of power and interest, which is produced through the index and defined to prioritise the stakeholder list. The stakeholder cycle methodology enables the identification of a stakeholder's position within a project and the prioritisation of key players (actors) to facilitate the identification of objectives and the establishment of a balance, thereby enhancing communication and the management of decision-making processes. The elements classified for each of the stakeholders are as follows: power, which refers to the extent to which each stakeholder can influence the outcome of the project; proximity, which indicates the proximity of the stakeholder to the project's objective; and urgency, which indicates whether the necessary resources are present to achieve the predetermined objective. The aforementioned representations permit the prioritisation of the actors under analysis, with the evaluation of each actor being conducted through the perception of their power, proximity and urgency with respect to the project. This produces an index for each stakeholder. However, this analysis is rarely applied, as the result is difficult to interpret. Finally, social network analysis represents the information derived from the exchange of resources between the various stakeholders. This is important because within a complex decision-making process, there are various actors who participate and exchange resources. In this case, the actors are mapped by structuring a network through nodes, where each node represents a stakeholder, and arrows, which correspond to the resources exchanged between the different actors (Yang, 2013).

The resulting network can be examined quantitatively through indices of complexity, density and centrality. The first of these indices assesses the existence of a plurality of viewpoints within the process and involves the creation of a matrix that shows the level, type of actor and size of interest. This matrix then allows us to identify the actors and see at what level they operate. The more cells are filled, the more complex the network becomes. If all cells are filled, the highest level of complexity is reached. This index is calculated by multiplying the number of lines by the number of columns; the index varies between 0 (minimum complexity) and 1 (maximum complexity). Density, on the other hand, provides information with respect to the intensity of the relationships exchanged between the different actors. In this context, the density index refers to the number of relationships exchanged between the different actors and is measured through a formula that considers the number of relationships and the number of actors. The index varies between 0 (minimum density) and 1 (maximum density). Finally, centrality, which does not refer to the network per se but refers to a specific actor, provides information regarding the fact that one or more actors may be prevalent and thus monopolise the decision-making process. The index is calculated on the basis of the number of relationships for each actor, with values ranging from 0 (minimum centrality) to 1 (maximum centrality) (Yang, 2013).

4.3.2.3 Multi-Criteria Analysis (MCA)

MCA is an economic evaluation methodology that analyses different criteria and economic, social and environmental spheres in order to evaluate and compare different NBS studies or projects. The aim of this application is to identify the most suitable solution that best meets the objectives set. Different criteria and alternatives are defined, and a process of weighing and assigning values is employed to evaluate which of the alternatives is preferable to the identified criteria. This methodology is described in more detail in the following section (Department for Communities and Local Government, 2009).

4.3.3 MULTI-CRITERIA ANALYSIS (MCA)

Multi-criteria analysis (MCA) is an evaluation technique that considers various aspects of system complexity. A narrow focus on costs and revenues is insufficient for addressing the issue of sustainability in urban contexts. Holistic approaches that encompass multiple complexities are necessary to fully understand the dynamics of urban development. The objective is therefore to assess a number of attributes simultaneously, both qualitatively and quantitatively, in order to identify the different perspectives of the stakeholders involved. MCA is able to provide decision-makers with a rational basis for choice problems that, in reality, are increasingly characterised by a multiplicity of objectives/criteria, often in conflict with each other (Simon, 1960).

The MCA was initially developed within the context of mathematical and operational research, with its earliest applications occurring during the Cold War (1947). However, over the past three decades, there has been a significant acceleration in the pace of research and practice development. This has led to the MCA being applied not only within the mathematical domain, but also across a range of other fields where decision-making challenges are prevalent. Since the 1960s, there has been a growing realisation that real decision-making problems are by their very nature increasingly complex and characterised by a multidimensionality of objectives, often interacting with each other according to non-linear dynamics, and a multiplicity of possible solutions, which could not be processed by means of one-dimensional approaches (such as CBA analyses). In the 1980s, CBAs began to be applied in Italy in contexts such as Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), urban project assessments and other areas (Department for Communities and Local Government, 2009).

Following the Second World War, the emergence of new social, political and ecological problems necessitated the development of a multidisciplinary approach that would permit the analysis of all these effects and enable them to be addressed in an integrated manner. The imponderability of some factors and the existence of non-linear relations between system components, such as those in a territorial context, make it clear why attention has shifted towards methodologies better suited to grasping and reflecting the complexity and multidimensionality of problems. Techniques of Multi-Criteria Analysis are one such methodology. According to various scholars of MCA, when reasoning about real processes, it is often uncertain whether there is an optimal solution that can fully maximise or minimise all aspects of the transformation. There is no plan that can be considered optimal by all the stakeholders involved. Therefore, it is necessary to select the best decision among the existing ones that can reduce as much as possible the potential conflict between the different actors involved and guarantee a balance between all the aspects at stake. The initial approach of the MCA was oriented towards identifying the most satisfactory alternative, which was not necessarily the best option. However, more recently, a more solution-oriented approach has emerged that must be justified. In particular, the approach of the 'justified' choice assumes particular relevance in the context of multi-criteria analyses and participatory planning processes. These contexts facilitate the explicit definition and justification of subjective perspectives, thereby enabling them to be subjected to public debate. In the context of spatial transformation interventions, Multi-criteria Analysis techniques serve as a valuable support tool in the ex-ante phase of assessment. This phase is becoming increasingly important as a means of identifying potential transformation alternatives and their associated advantages and disadvantages (Department for Communities and Local Government, 2009).

The MCA methodology can be classified in several ways, depending on the content and purpose of the evaluation (Department for Communities and Local Government, 2009):

1. According to the number of alternatives:
    a. Discrete multi-criteria methods, where the number of alternatives is finite
    b. Continuous multi-objective methods, where an infinite number of alternatives is considered
2. According to the nature of the information
3. According to the level of compensation

Classification according to the number of elements that are dealt with refers to discrete multi-criteria methods, when the number of elements is finite, or continuous multi-target methods, when the number of elements is infinite. When considering discrete problems, there are four different types of analysis that can be implemented in order to provide meaningful support to the decision maker (Department for Communities and Local Government, 2009):

- The construction of a ranking order of alternatives from best to worst (ranking) is a numerical vector.
- Classification or sorting the alternatives into predefined homogeneous groups. This is followed by the allocation of the alternatives to the appropriate classes.
- Identification of the optimal alternative or selection of a limited number of optimal alternatives (choice).
- Identification of the main distinguishing features of the alternatives.

With regard to the classification of techniques according to the nature of the information processed, three types can be distinguished: quantitative (hard), qualitative (soft) and mixed.

- *Quantitative techniques* employ numerical and measurable data, which are considered objective and precise. These techniques are used to analyse phenomena that can be measured with precision. Quantitative techniques can utilise compensatory methods, such as the Analytic Hierarchy Process (AHP) or Analytic Network Process (ANP), partially compensatory methods, and non-compensatory methods.
- *Qualitative techniques* utilise what is commonly referred to as 'soft information', which is defined as data that is challenging to quantify due to its inherent nature. These techniques are typically employed in the context of complex situations, with the objective of gaining an understanding of the perspectives and perceptions of individuals. In practice, this encompasses methodologies such as interviews and focus groups.

- *Mixed techniques* combine both quantitative and qualitative techniques in order to obtain a more complete and precise result.

Finally, in the classification according to the level of compensation, two methodologies are distinguished according to the procedure adopted to reveal the decision maker's preference: the outranking method and multi-attribute utility theory. The former employs a procedure based on the construction of binary relationships between pairs of elements, whereas the latter is characterised by being simpler than the former, as it is applied whenever indices are aggregated through a weighted summation (Department for Communities and Local Government, 2009).

The process of conducting an MCA analysis comprises a number of distinct stages (Department for Communities and Local Government, 2009):

1. *Definition of the decision-making context*
   The objective of this phase is to insinuate the objectives of the MCA and to define the decision-makers and key actors. A clear definition of the objective of the MCA helps to establish the tasks and phases of the evaluation and to maintain transparency in the analysis process. It is also important to define the actors participating in the evaluation, which are chosen in such a way as to include in the evaluation the key viewpoints and perspectives for the analysis of the problem under consideration. These individuals are often referred to as stakeholders, defined as individuals or groups of people who have an interest in the decision-making problem. Typically, MCA evaluations are developed through the organisation of workshops and focus groups, with the use of interviews and questionnaires to define the so-called socio-technical reference system.

2. *Identification of alternatives*
   Once the decision context has been defined, it is necessary to identify the finite set of alternatives to be considered in the evaluation. This set of alternatives is typically provided to the analyst in charge of the AMC. However, during the development of the evaluation, it may be necessary to modify the set of alternatives or to add new options to the evaluation model.

3. *Identification of objectives and criteria*
   To reflect the values associated with the consequences of each option under consideration, a set of criteria and sub-criteria are identified that represent the performance measures against which the alternatives are assessed. In defining the set of criteria, it is necessary to consider the points of view of all stakeholders, as well as to examine regulatory and legislative references and information that can be derived from a review of the scientific literature. Furthermore, the maximum number of sub-criteria that can be identified for each criterion should not exceed seven or nine, respectively. In order to be considered valid, the criteria and sub-criteria must fulfil several characteristics:
   - *Completeness*, i.e. that they take into account all aspects considered in the evaluation to achieve the objective;

- *Redundancy*, i.e. the criteria must not be repetitive or measure similar aspects
- Operationality, i.e. the criteria must be measurable, both in quantitative and qualitative terms;
- *Size*, it is important that each alternative can be evaluated from the perspective of each criterion. The evaluation may be objective (physical, measurable quantities...) or subjective (intangible aspects requiring expert judgement);
- *Diachronic impacts*, with respect to which one must avoid considering too many criteria, as the development of the evaluation and the communication of the final results may become difficult;
- *Organisation of evaluation criteria*, since in many decision-making problems, especially public ones, decisions may refer to medium- to long-term impacts or benefits.

Normally, the criteria and sub-criteria are organised according to a hierarchical structure, which is referred to as a decision tree (Figure 23). This structure allows for the objective of the evaluation to be identified at the first level of the hierarchy. The second level of the hierarchy identifies the evaluation criteria, while the next level relates to the sub-criteria of the evaluation. This process continues until the lowest level of the hierarchy is reached.

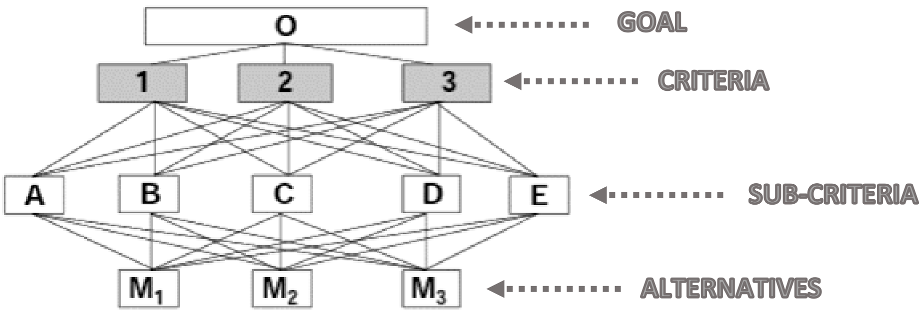


FIGURE 23 – MULTI CRITERIA DECISION MAKING TREE (SOURCE: AUTHOR RE-ELABORATION FROM SUNER ET AL., 2017)

4. *Definition of action performance*

   Once the criteria have been established, it is necessary to estimate the performance of each alternative from the perspective of these criteria. The evaluation is normally developed according to a multi-criteria evaluation matrix. This matrix is represented by a table where the rows are the alternatives and the columns the criteria (Figure

24). Each cell of the matrix defines the performance evaluation of an alternative against a specific criterion.

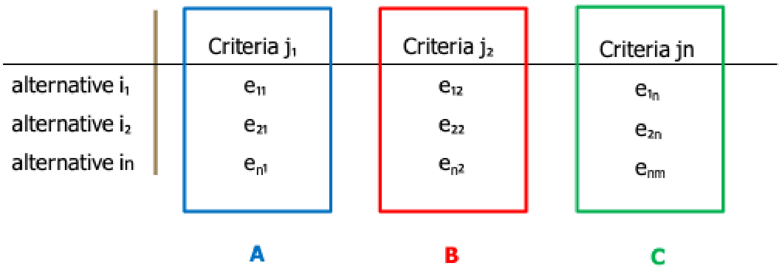


FIGURE 24 - PERFORMANCE MATRIX (SOURCE: AUTHOR RE-ELABORATION FROM CINELLI ET AL., 2020)

5. *Weighting*
   The assignment of weights to evaluation criteria is a crucial aspect of decision-making, as it reflects the relative importance of different factors within the decision problem. There are various methodologies for assigning weights, which depend on the multi-criteria techniques employed. These include the SWING method (Multi Attribute Value Theory), pairwise comparison (AHP, ANP) and SRF: Simos-Figueira - Roy (ELECTRE). With regard to the pairwise comparison methodology, the method requires only two criteria to be considered at a time.

6. *Combination of weights and performance*
   In order to develop this step, it is typical to utilise specific calculation software. To illustrate, if the overall preference for a specific action is represented by the weighted average of the different scores, the estimation value 's' for each alternative can be obtained by summing the scores eij with the respective weights of the criteria, as expressed by the following equation:

$$s_i = e_{ij1}w_{j1} + e_{ij2}w_{j2} + \ldots + e_{ijJ}w_{jJ} = \Sigma e_{ij}w_J \quad [1]$$

7. *Analysis of result*
   Once the results have been obtained, it is advisable to share the results of the evaluation with key stakeholders in order to discuss the outcomes of the model and attempt to reach a consensus on the alternative chosen.

8. *Sensitivity Analysis*
   This phase is useful for validating the results obtained in the evaluation and is based on hypothetical questions. It is particularly useful for understanding whether variations in the identified set of weights lead to changes in the final ranking of alternatives. Sensitivity analysis can play a key role in resolving any disagreements among stakeholders in the process under consideration.

In conclusion, MCAs represent a methodology for addressing complex decision-making problems. They facilitate the evaluation of alternatives by different stakeholders, enabling the assessment of a range of criteria. This methodology is now widely employed in a variety of fields, including urban planning, environmental impact assessment and natural resource management.

4.3.4 Analytic Hierarchic Process (AHP)

As previously stated, this methodology belongs to the AHP family and is one of the most widely used methodologies. AHP was developed by the American mathematician T. Saaty between 1977 and 1996 and is defined as a discrete multi-criteria methodology, i.e. one that presents a finite number of options, qualitative and mixed, i.e. one that allows the use of both qualitative and quantitative information. Furthermore, this methodology is compensatory and ranking in nature, whereby the result obtained is a ranking of alternatives. In order to apply this methodology, specific software is required. In the case of this thesis work, the SuperDecision software will be used (Saaty, 2000).

The three fundamental principles of AHP are as follow (Saaty, 1987):

1. The principle of decomposition involves the decomposition of the complexity of the problem by first identifying the objective, which is then broken down into different criteria. At the end of the hierarchy, the candidate projects are identified (see Figure 4).
2. The principle of comparative judgements stipulates that all elements of the hierarchy (the criteria) are expressed in pairs against the level above (the objectives). The most commonly used techniques for implementing this principle are:
    a. The Saaty scale varies from 1 (equal importance) to 9 (one element is significantly more important than the other);
    b. Pair-wise comparison matrices are drawn up for all levels of the hierarchy. At this stage, the matrix is square and has the same elements (criteria or alternatives) on its rows and columns. At each crossing, the judgements obtained are placed. The diagonal always consists of values equal to 1 and is symmetrically reciprocal. The case of inconsistent values is assessed through the consistency index, which must always be less than 0.1. If the consistency index is less than 0.1, there is a consistency problem, and therefore the analysis must re-evaluate the comparisons.
3. Priority synthesis: A vector is extracted from each matrix, synthesising the information entered therein. This vector is calculated by calculating the main eigenvector of the normalised matrix (the sum of which is equal to one). The combination of these vectors gives the final priorities.

As with the MCA, a sensitivity analysis is conducted at the conclusion of the AHP using evaluation models. This analysis is of the "what if..." type, where the weights of the first-level criteria are varied and how these are reflected in the final result is examined. If, by varying the weights of the alternatives, the chosen alternative always remains the chosen alternative, this indicates that the model is stable and thus the results are not susceptible to attack (Saaty, 2000).

4.4 Selection of the most appropriate economic evaluation methodology

The variables that affect the decision of which economic valuation model for natural systems is most suitable are numerous. These include the specific context, data availability, type of ecosystem services, timeframe and budget available, among others. In order to make the assessment more realistic and complete, several methodologies and integrated approaches can also be used in combination. This allows for the consideration of different economic, social and environmental variables when assessing the overall benefits and costs associated with implementing NBSs in projects. Consequently, when determining the most suitable economic methodology for a case study, a number of steps must be taken into account (Lozano et al., 2023):

1. Definition of objectives: Understanding the scope and purpose of the assessment and determining which aspects of NBS will be assessed and which ecosystem services to include in the assessment.
2. Identification of ecosystem services, costs and benefits: this step may involve a literature review, consultation with experts or stakeholder engagement to ensure a clear understanding of the service. It will also be necessary to understand the variables of costs and benefits, whether they are of use or non-use value, and also to consider which risks will actually be reduced and the potential benefits, on the other hand, that will be derived from the project.
3. Assessment of data availability and quality: the types of data may be economic, social, environmental, technical, hydrogeological, etc.
4. Selection of the appropriate valuation method: the aim is to understand which valuation is most likely to capture the economic value generated by the ecosystem services identified in point 2. It will also be necessary to assess which economic method best suits the case study in terms of time, cost and data available. An initial selection can be made according to the ecosystem services identified and the type of value to be captured (Table 15). Subsequently, a second selection can be made according to the availability of data, the budget for carrying out the valuation itself, the time required, etc. (Table 16).

TABLE 15 - COMPARISON OF ECONOMIC VALUATION METHODS THAT CONSIDER ECOSYSTEM SERVICES AND VALUE TYPES (SOURCE: LOZANO ET AL., 2023)

			Quantitative methods					Qualitative methods
			Market-based methods	Cost-based methods	Revealed preference methods	Stated preference methods	Value transfer	Participatory approaches
Ecosystem Service		Provisioning	✓	✓	✓	✓	✓	✓
		Regulating and Maintenance			✓	✓	✓	✓
		Cultural			✓	✓	✓	✓
Type of value	use value	Direct use value	✓	✓	✓	✓	✓	✓
		Indirect use value	✓	✓	✓	✓	✓	✓
		Option value			✓	✓	✓	✓
	non-use value	Existence value				✓	✓	✓
		Altruistic value				✓	✓	✓
		Bequest value				✓	✓	✓

Furthermore, as previously stated, it is possible to select multiple evaluation methodologies and combine them in order to obtain an evaluation encompassing several dimensions, thereby increasing the evaluation's completeness and reliability.

TABLE 16 - COMPARISON OF ECONOMIC VALUATION METHODS ACCORDING TO VALUATION FACTORS (SOURCE: LOZANO ET AL.., 2023)

Evaluation criteria	Quantitative methods					Qualitative methods
	Market-based methods	Cost-based methods	Revealed preference methods	Stated preference methods	Value transfer	Participatory approaches
Data need	Low to Moderate	Moderate	Moderate to High	Moderate to High	Low to Moderate	Moderate
Costs	Moderate	Moderate	Moderate to High	High	Low to Moderate	Moderate to High
Time requirement	Moderate	Low to Moderate	Low to Moderate	High	Low to Moderate	High
Technical expertise	Moderate to High	Moderate	Moderate to High	High	Low to Moderate	Low to Moderate
Ease of implementation	Moderate	Moderate	Moderate	Moderate	High	Moderate to High
Stakeholder involvement	Low	Low to Moderate	Moderate to High	High	Low to Moderate	High
Inclusivity	Low	Low to Moderate	Moderate	Moderate to High	Low to Moderate	High

4.5 SPATIAL MULTICRITERIA ANALYSIS (SMCA)

Compared to MCA, SMCA represents an important advancement, as it is capable of integrating Geographic Information Systems (GIS) into its analysis. Designed and introduced in the 1990s, SMCA improves the approach to complex decision-making for all issues that involve a geographical perspective, by integrating the spatial dimension into the analysis.

The method of spatial multi-criteria analysis (SMCA) is distinguished by its capacity to integrate spatial data with multiple evaluation criteria, thereby generating suitability maps that illustrate the relative desirability of different areas. In contrast to traditional multi-criteria analysis, which employs numerical values as input and generates a ranking of alternatives, SMCA employs spatial representation through mapping to illustrate the spatial variability of each criterion. This approach allows the results to be visualised in an intuitive and understandable way, thus facilitating informed decision-making. The integration of GIS and multi-criteria analysis offers a number of advantages. Firstly, GIS enables efficient management, analysis and visualisation of spatial data. Secondly, multi-criteria analysis techniques provide a methodological framework for the evaluation of alternatives based on multiple criteria. This synergy enables the direct and effective addressing of problems that spatial decision-making might generate, thus facilitating the formulation of more comprehensive and sustainable decisions (Asare et al., 2023).

SMCA appears to be highly adaptable and, as a result, suitable for a range of contexts, including spatial planning and environmental management. As an example, this methodology can be employed to assess the suitability of a list of candidate areas for a specific land use, like evidenced in the work of Tecnica (2024), focused on the selection of the most suitable areas for green spaces.

One of the principal advantages of the SMCA is its capacity to integrate the sustainability dimension into decision-making. This systemic approach enables the assessment of the environmental, social and economic impacts of decisions, thereby promoting sustainable development. Furthermore, SMCA enhances the transparency and objectivity of decision-making by providing a flexible problem-solving environment where a decision-making problem can be explored, understood and redefined (Tecnica, 2024).

The SMCA employs multiple methodologies to integrate various criteria and generate suitability maps. Among these, the Analytic Hierarchy Process (AHP) constitutes a structured approach that decomposes the decision-making process into hierarchically structured subproblems, facilitating pair-wise comparisons and the calculation of weights based on the comparisons. Another methodology is weighted overlay, whereby spatial layers of criteria are combined by assigning them weights based on their respective relative importance. The integration of these techniques with the advanced functionalities of GIS facilitates the performance of complex spatial analyses and enables the visualisation of results in a clear and detailed manner.

4.5.1 Literature review: spatial analysis techniques used to generate a vulnerability map

After analysing all the most informative methodologies for the case study of this research paper, a literature review was carried out, focusing on finding articles that could provide guidelines for the development of a spatial vulnerability map. The search, conducted between 2007 and 2023 on Scopus, revealed that this topic has not yet been fully addressed. Below is the table showing the results of the research (Table 17). The publication trend shows that there has been a slight improvement in the number of publications on this topic over the last five years, although they remain scarce.

Table 17 - Contributions found on the most relevant spatial analysis techniques used to generate a vulnerability map (source: author elaboration)

QUERY	KEYWORDS	NUMBER OF RESULTS
1	"MC-SDSS" AND "Multicriteria Spatial Decision Support System" AND "GIS" AND "Geographic Information System"	17

A review of the literature revealed the use of different techniques to combine the indicators and arrive at an overall index. In particular, the articles cited illustrate the different approaches to assessing the contribution/impact/weight of each indicator in the calculation of the overall index. Among the different methods listed in Table 18, the most important are Fuzzy Analytic Hierarchy Process (F-AHP), AHP, Multicriteria Spatial Decision Support System (MC-SDSS) and TOPSIS. For AHP and MC-SDSS, please refer to sections 4.1 and 4.5, respectively. F-AHP represents a variant of AHP that incorporates fuzzy logic for the purpose of handling uncertainty and ambiguity in judgements. Finally, TOPSIS is a methodology that is based on the concept that the positive chosen alternative must have a longer distance than the ideal but negative solution. This value is obtained through a normalisation of criteria and the calculation of geometric distances.

TABLE 18 - REFERENCE OF SPATIAL ANALYSIS TECHNIQUES AND AHP METHODOLOGY ON VULNERABILITY MAP GENERATION (SOURCE: AUTHOR ELABORATION)

	TITLE	AUTHOR	JOURNAL	YEAR	METHODOLOGY	CITATION
1	From Traditional to Electrified Urban Road Networks: The Integration of Fuzzy Analytic Hierarchy Process and GIS as a Tool to Define a Feasibility Index—An Italian Case Study	Nodari, C., Crispino, M., Toraldo, E.	World Electric Vehicle Journal	2022	Fuzzy Analytic Hierarchy Process (F-AHP), GIS	3
2	Addressing complex challenges in transformations and planning: A fuzzy spatial multicriteria analysis for identifying suitable locations for urban infrastructures	Caprioli, C., Bottero, M.	Land Use Policy	2021	Fuzzy Spatial Multicriteria Analysis, GIS	29
3	Multi-criteria spatial decision support system for identifying strategic roads in disaster situations	Ghavami, S.M.	International Journal of Critical Infrastructure Protection	2019	Multicriteria Spatial Decision Support System (MC-SDSS), GIS	23
4	Land suitability evaluation for agro-forestry: Definition of a web-based multi-criteria spatial decision support system (MC-SDSS): Preliminary results	Modica, G., Pollino, M., Lanucara, S., Di Fazio, S., Fichera, C.R.	Lecture Notes in Computer Science	2016	Web-based Multicriteria Spatial Decision Support System (MC-SDSS), Analytical Hierarchy Process (AHP)	34
5	An application of MC-SDSS for water supply management during a drought crisis	Jeihouni, M., Toomanian, A., Alavipanah, S.K., Shahabi, M., Bazdar, S.	Environmental Monitoring and Assessment	2015	Multicriteria Spatial Decision Support System (MC-SDSS), Analytical Hierarchy Process (AHP), Fuzzy Logic	9

(*Continued next*)

	TITLE	AUTHOR	JOURNAL	YEAR	METHODOLOGY	CITATION
6	Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: Method, implementation and case study	Demesouka, O.E., Vavatsikos, A.P., Anagnostopoulos, K.P.	Waste Management	2013	Analytic Hierarchy Process (AHP), TOPSIS, Ideal Point Methods	141
7	Multicriteria spatial decision analysis in web GIS environment	Karnatak, H.C., Saran, S., Bhatia, K., Roy, P.S.	GeoInformatica	2007	Web-based Multicriteria Spatial Decision Analysis, Analytic Hierarchy Process (AHP)	81

4.6 Analysis of indicators to produce a climate change vulnerability map

One of the objectives of this work is to produce a map of vulnerability to climate change in the city of Milan. However, before being able to proceed with the specific case of Milan, it is necessary to carry out a search of the existing literature with the aim of identifying case studies that have produced a map of vulnerability in urban areas through research and the use of specific indicators. However, this analysis did not reveal a significant number of case studies, even though they all date from very recent years. This trend could mean that the issue is becoming increasingly topical and relevant. The search was conducted in Scopus using keywords such as 'vulnerability index', 'vulnerability map', 'urban heat island', 'vulnerability indicator'. A total of four valid results were obtained, divided into three main dimensions: social, economic, environmental (Table 19).

Table 19 - References of indicators used for the creation of a vulnerability map (Source: Author elaboration)

DIMENSION	INDICATOR	DESCRIPTION	TYPE	SOURCE
SOCIAL	Deprivation Index	composed of income deprivation, employment and education deprivation, health deprivation and disability, housing and services accessibility, and living environment deprivation and crime	Numb	(Acosta & Haroon, 2021)
	Health index	composed of diabetes, ischemic heart disease, breast and cervix cancer, tuberculosis, infant deaths, traffic accident, and homicide	Numb	(Acosta & Haroon, 2021)
	Proportion of households that are 1-person households	Percentage of families composed by only one person	%	(Tapia et al., 2017), (Zha et al., 2024)
	Proportion of households that are lone-parent households	Percentage of families composed by a lone-parent	%	(Tapia et al., 2017)
	Proportion of households that are lone-pensioner households	Percentage of families composed by a lone-pensioner	%	(Tapia et al., 2017)
	Lone parent households per 100 households with children aged 0–17	Number of lone parent households per 100 households with children between 0 and 17 years old	Numb	(Tapia et al., 2017)

(*Continued next*)

	INDICATOR	DESCRIPTION	TYPE	SOURCE
	Number of deaths per year under 65 due to diseases of the circulatory or respiratory systems per 1000 inhabitants	Number of deaths every year under 65 from circulatory and respiratory diseases per 1000 inhabitants	Numb	(Tapia et al., 2017)
	Population growth rate over the period 2004–2012	Rate of population growth in the period from 2004 to 2012	Numb / %	(Tapia et al., 2017)
	Population density: total resident pop. per sq. Km	Population density: the total number of inhabitants per square kilometre	Numb	(Tapia et al., 2017), (Zha et al., 2024), (Huynh et al., 2020)
	Non-EU foreigners as a proportion of population	Number of foreign people	Numb	(Tapia et al., 2017)
	Proportion of population aged 0–4 years	Percentage of population under 4 years	%	(Tapia et al., 2017)
	Proportion of population aged 75 years and over	Percentage of population over 75 years	%	(Tapia et al., 2017)
	Population < 14 and > 65	Percentage of population under 14 years and over 65 years	%	(Zha et al., 2024)
	Female population	Percentage of female population on the total of it	%	(Zha et al., 2024), (Huynh et al., 2020)
	Illiteracy rate	Percentage of population that can read and write	%	(Zha et al., 2024)
	Number of households with bathing facilities	Number of households with bathing facilities in the census tract	Numb	(Zha et al., 2024)
	Water use per capita	Average of the quantity of water used by one person every day	l/person.day	(Huynh et al., 2020), (Tapia et al., 2017)
	Poverty rate	Percentage of poor population	%	(Huynh et al., 2020)
	Unemployment rate	Percentage of population without a job/incomes	%	(Huynh et al., 2020)
	Working-age population	Labour force population	Numb	(Huynh et al., 2020)
ECONOMIC	Median Household Income	Median Household Income per Census Track 2010 in 2018	Numb	(Acosta & Haroon, 2021)
	Price of domestic water	Price of a m3 of domestic water – Euro	€	(Tapia et al., 2017)
	Per capita income	Income level of population	Numb	(Zha et al., 2024)
	Number of air conditioners	Number of air conditioners per 100 households	Numb	(Zha et al., 2024)
	Number of hospitals	Density of medical service institutions	Numb	(Zha et al., 2024), (Huynh et al., 2020)
	Density of built-up area	Number of buildings per square kilometre	Numb	(Zha et al., 2024)
	Number of schools	Number of schools per square kilometre	Numb	(Huynh et al., 2020)
	Number of different industrial activities	Number of different industrial activities	Numb	(Huynh et al., 2020)

(*Continued next*)

DIMENSION	INDICATOR	DESCRIPTION	TYPE	SOURCE
ENVIRONMENT	Average of the maximum daily temperature	Average of the maximum daily temperature across the 2006 heatwave	Numb	(Acosta & Haroon, 2021), (Huynh et al., 2020)
	Urban Heat Island	positive temperature differential over time between an urban census tract	Numb	(Acosta & Haroon, 2021)
	Flood risks zone	Percentage of the area under flood risk	%	(Acosta & Haroon, 2021)
	Number of days with extreme concentrations of ozone O3	Number of days ozone O3 concentrations exceed 120 ug/m3	Numb	(Tapia et al., 2017)
	Number of days with extreme concentrations of PM10	Number of days particulate matter PM10 concentrations exceed 50 ug/m3	Numb	(Tapia et al., 2017)
	Accumulated ozone concentration	Accumulated ozone concentration in excess 70 ug/m3	Numb	(Tapia et al., 2017)
	Annual average concentration of NO2	Annual average concentration of NO2 (ug/m3)	Numb	(Tapia et al., 2017)
	Annual average concentration of PM10	Annual average concentration of PM10 (ug/m3)	Numb	(Tapia et al., 2017)
	Mean soil sealing	Percentage of soil sealing of UMZ 2006 of core city (EEA 2012)	%	(Tapia et al., 2017)
	NLST	Average nighttime land surface temperature	Numb °C	(Zha et al., 2024)
	NHTF	Nighttime High-temperature frequency	Numb	(Zha et al., 2024)
	Greenspace proportion	The proportion of green space in the total area of each census tract %	%	(Zha et al., 2024)
	Distance to greenspaces	The average distance of each census tract to the nearest green space in km	Numb in km	(Zha et al., 2024)
	Greenspace area	The area of greenspace in each census tract in km2	Numb in km2	(Zha et al., 2024)
	Per capita greenspace area	Supply of green space per capita m2	Numb in m2	(Zha et al., 2024)
	Water area	The area of water in each census tract km2	Numb in km2	(Zha et al., 2024)
	Distance to water bodies	The average distance of each census tract to the nearest water body in km	Numb in km2	(Zha et al., 2024)
	Average number of storms and tropical depressions	Average of storm water and tropical depression events per year (2013)	Numb	(Huynh et al., 2020)
	Average number of floods	Average number of floods events per year (2013)	Numb	(Huynh et al., 2020)
	Heavy rain	Number of heavy rain events per year (2013)	Numb	(Huynh et al., 2020)
	Change in potential evaporation compared with a baseline period	Change in potential evaporation compared with a baseline period of the sea level	%	(Huynh et al., 2020)
	Change of annual rainfall	Percentage of change of annual rainfall events per year	%	(Huynh et al., 2020)
	Area of forest	Number of km of the forest area (ha)	Numb	(Huynh et al., 2020)

PART III | APPLICATION

This section will examine the design details, which represent the focus of this thesis. First, an overview of the case study of the city of Milan will be presented, analysing how it has evolved over time and identifying the environmental problems that characterise the area. Next, an overview will be presented of how the Region of Lombardy and the city of Milan have implemented the strategies and directives of the upper areas analysed in the first part of the paper.

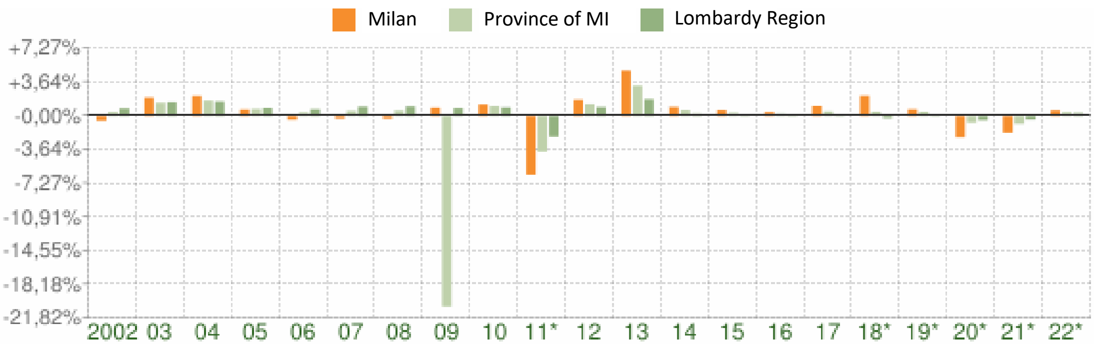
The second part of the thesis will focus on the creation of a UHI vulnerability map of the city of Milan. This will be achieved through the use of QGIS combined with Spatial Multi-Criteria Analysis (SMCA) and SuperDecision software. Once the map has been created, a disused green area located in a highly vulnerable zone will be selected for further analysis. This will be analysed at the regulatory level and a solution will be proposed for its redevelopment to reduce the effects of UHI through the implementation of NBS.

Finally, the economic benefits generated by the NBS will be assessed through a cost-benefit analysis, which will also consider the implementation and maintenance costs of the NBS solution, defined by consulting the Prezzario della Regione Lombardia updated to 2024.

5. CASE STUDY: THE CITY OF MILAN

The city of Milan is located in the North-West of Italy, in the region of Lombardy. Situated in the Po Valley, the city covers an area of approximately 181.67 square kilometres and is strategically located about 25 kilometres east of the Ticino River and west of the Adda River, which, along with other watercourses, cross the territory. The climate in this area is temperate, with wet and cold winters and hot and humid summers, while rainfall peaks in the autumn and spring seasons (Wikipedia, 2024).

Milan is the second most populous city in Italy, with a total population of 1,358,420 in 2023 (Comune di Milano, 2023) within the city limits and a population density of approximately 7 inhabitants per square kilometre. The demographic evolution of the city has been very variable in the last 20 years: from 2003 to 2005 there was an increase of about +2%; from 2006 to 2008 there was a slight decrease of about -0.4%, followed by a slight increase until 2010; 2011, on the other hand, was characterised by a strong decrease, reaching peaks of even -7%. From 2012 to the present, the population of Milan continued to grow until the period of the Covid-19 pandemic (2020-2021), when there was a large loss with a fluctuation of about - 2%; in the following years, the population grew again (Population of Milan (2001-2022) Graphs based on ISTAT data, n.d.-b).



** post-census*

FIGURE 25 - PERCENTAGE DEMOGRAPHIC VARIATION OF MILAN, MILAN PROVINCE AND LOMBARDY REGION (SOURCE: COMUNE DI MILANO - ISTAT DATA AS OF 31 DECEMBER EACH YEAR - PROCESSED BY TUTTIITALIA.IT)

In order to better understand the demographic change in Milan, migration balances both from other municipalities to Milan and vice versa, and from foreign countries to the city, were also assessed.

TABLE 20 - MIGRATION BEHAVIOUR FROM 2002 TO 2022 (SOURCE: COMUNE DI MILANO - ISTAT DATA AS OF 31 DECEMBER EACH YEAR - PROCESSED BY TUTTIITALIA.IT)

YEAR	INSCRIBED: FROM OTHER MUNICIPALITIES	INSCRIBED: FROM ABROAD	INSCRIBED: OTHER MEMBERS	CANCELLED: FOR OTHER MUNICIPALITIES	CANCELLED: FOR ABROAD	CANCELLED: OTHER CANCELLATIONS	FOREIGN MIGRATION BALANCE	TOTAL MIGRATORY BALANCE
2002	24,655	12,153	1,806	36,456	2,244	4,061	9,909	-4,147
2003	19,127	11,903	61,233	33,533	2,265	29,317	9,638	27,148
2004	23,71	35,105	7,659	34,601	2,16	1,343	32,945	28,37
2005	24,152	20,109	5,642	35,482	2,166	1,36	17,943	10,595
2006	21,194	13,353	3,18	36,82	2,11	3,084	11,243	-4,287
2007	24,093	10,629	1,828	36,566	2,485	902	7,783	-4,648
2008	24,948	11,104	1,197	35,741	2,961	993	8,143	-2,456
2009	25,198	20,302	1,125	29,406	2,566	1,754	17,736	12,899
2010	29,153	20,813	1,109	28,938	2,945	1,504	17,868	17,688
2011 (¹)	13,553	17,865	783	20,638	2,251	1,827	15,614	15,986
2011 (²)	6,455	5,134	277	5,631	856	918	4,278	-1,529
2011 (³)	22,999	1,06	25,669	3,107	8,745	19,892	14,261	\
2012	31,202	17,255	18,39	32,552	4,498	5,825	17,957	23,972
2013	34,13	17,238	59,94	25,554	4,714	19,568	17,524	61,472
2014	30,036	17,086	25,081	4,773	19,465	11,499	11,47	
2015	28,155	12,973	3,972	25,357	5,033	3,129	7,94	11,581
2016	30,227	10,211	3,42	26,703	4,981	4,43	5,32	7,744
2017	31,3	17,391	3,211	26,611	4,623	4,43	17,509	17,55
2018 *	32,197	12,718	2,644	26,713	4,122	870	8,596	13,854
2019 *	37,631	15,867	2,343	33,352	5,885	2,664	9,982	13,941
2020 *	28,658	15,867	2,343	31,583	4,882	5,637	6,719	6,746
2021 *	30,415	13,852	1,591	30,54	5,275	5,387	8,577	3,079
2022 *	31,945	18,393	3,42	36,191	4,131	5,83	14,262	-1,016

(¹) pre-census 2011 demographic balance (1 January to 8 October)
(²) post-census 2011 population balance (9 October to 31 December)
(³) 2011 demographic balance (1 January to 31 December). This is the sum of the two previous rows.
(*) post-census population

The latter is calculated by subtracting the number of enrolled individuals who have relocated from abroad from the number of enrolled individuals who have relocated to foreign cities (Table 20). A comparison of the year 2003 with 2020 reveals that the migration balance has decreased by approximately 3% since 2003. This decline can be attributed to a number of factors, including changes in migration policies, economic crises, and pandemic events. Conversely, an analysis of the national migratory balance, defined as the movement of individuals from one municipality to another within the Italian state, reveals a notable increase in immigration over the period from 2003 to 2022. Milan (2003: 24,655 inhabitants; 2022: 31,945 immigrants) (Milan population (2001-2022) Graphs on ISTAT data, n.d.-b). The growing influx of immigrants serves to illustrate the city's considerable allure. Among the factors contributing to this appeal are the job and economic opportunities that Milan offers, given its status as the country's most significant financial hub. Additionally, the city's high quality of life, which is enhanced by the excellent services it provides and the numerous cultural centres it hosts, is a further draw. Indeed, Milan is traversed by five metro lines, thereby facilitating interconnectivity and rapid transportation to any destination (Navigli, 2024).

However, while the quality of life in the city of Milan is high in terms of the services provided, the city does not excel in environmental quality. In fact, Milan is one of the most polluted cities in the state and one of the areas most subject to fine dust pollution in Europe (Greenpeace Italy, 2024). This situation, which will be discussed in greater detail in the subsequent section, represents a significant challenge for urban planning in Milan. It is a matter of great concern to the city's residents, who are particularly vulnerable to the adverse effects of air pollution on their health. The configuration of the Po Valley, which acts as a natural barrier to air circulation, allows pollutants to accumulate, resulting in the formation of large concentrations of PM10, which are detrimental to human health (Arsuffi, 2024).

A further challenge for the city is the management of water resources and the risk of flooding along the Seveso and Lambro rivers. The risk of flooding along these rivers is attributed to the reduction in river sections and the siltation of some of them resulting from the continuous expansion of urbanised areas. It is important to note that between 1975 and 2023, there were approximately 118 floods of the Seveso River (an average of approximately 2.5 floods per year). These floods caused significant inconvenience to the population due to flooded infrastructures, homes, and businesses. Once more, the city of Milan is focusing its urban planning on the issue of mitigating these floods in order to enhance the city's safety and liveability for its citizens through investments (Lombardy Region (PGRA), 2023).

Furthermore, the problem of Urban Heat Islands (UHI), caused by the high percentage of sealed areas, needs to be addressed. In 2022, only 13.8% of the city's surface area consisted of green areas, which is significantly less than in other cities, such as Rome (35.8%) and Naples (31.5%). The surplus of sealed soil and buildings intensifies temperatures drastically, thus posing health risks to the population and increasing energy expenditure for cooling. Furthermore, high temperatures favour the formation of air pollutants, which are exacerbated by the lack of green areas. In this thesis, a project will be proposed in the following paragraphs that shows how reusing brownfields can mitigate the effects of UHI through the implementation of green areas. Indeed, brownfield sites in the city of Milan are numerous, and the reconversion of all of them into permeable soil with the implementation of NBSs would mitigate both the air quality and the UHI problem, thereby improving the quality of life of citizens.

This is due to the rapid expansion of urban areas since the 1950s that has made the Milan region one of the most important metropolitan areas in Europe. This has been accompanied by significant structural changes in urban and suburban landscapes and the fragmentation of previously contiguous green corridors with the introduction of new urban forms such as housing and transport infrastructure. It is worth noting that the metropolitan area of Milan is characterised by a number of factors, including: large urbanisation, a high degree of soil compaction, a highly fragmented but still productive agricultural economy and the impact of climate change. It is also important to acknowledge that politicians first realised in the late 1970s that it was necessary to address the loss of green spaces, and over time, this led to the introduction of new policies and laws. These policies included the Milan Metropolitan Parks approach, which has led to the establishment of numerous urban forests that have become an invaluable asset in the creation and maintenance of Green Infrastructure (GI). In recent decades, new forests and green areas have appeared on a total of 10,000 hectares, which is a testament to the success of this approach. We might consider Bosco in città and Parco Nord Milano as the most notable examples of this approach, which has the goal of redeveloping some of Milan's peripheral areas and creating mixed-use green spaces (woods, grasslands, wetlands, river corridors and urban gardens) on previously industrial or uncultivated land (Sanesi et al., 2016).

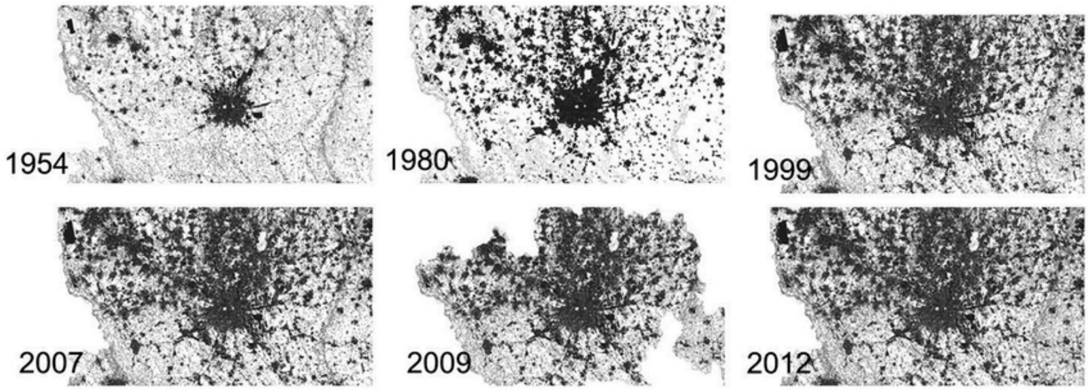


FIGURE 26 - URBAN EXPANSION IN THE MILAN METROPOLITAN AREA SINCE 1954 (SOURCE: SANESI ET AL., 2016)

The following section will provide a more detailed account of the manner in which the Lombardy region and the city of Milan have implemented national and European strategies for climate change mitigation and adaptation.

6. LOMBARDY REGION AND MILAN LEVELS - HOW THEY HAVE RESPONDED TO CLIMATE CHANGE CHALLENGES

Following an examination of the manner in which strategies for mitigating and adapting to the consequences of climate change have been formulated at the international and national levels (Chapter 1), it is deemed pertinent to provide a detailed account of the manner in which the Lombardy region and the city of Milan have implemented these plans and directives.

6.1 LOMBARDY REGION

Over time, the Lombardy region has developed and implemented various strategies to address the challenges of climate change. This section will analyse those that have had the greatest impact.

6.1.1 REGIONAL CLIMATE CHANGE ADAPTATION STRATEGY (SRACC)

The SRACC is a document that was drafted in 2021 in close collaboration with the Fondazione Lombardia per l'Ambiente (FLA) and was developed in accordance with the directives established by various European institutions and in alignment with the Italian National

Strategy for Adaptation to Climate Change, as outlined in Directorial Decree m. 186/2015 (Legambiente, 2022). The strategy was devised with the objective of furnishing guidance to the stakeholders of the Lombardy region on the means of adapting to the impacts of climate change. This was to facilitate the formulation of quantitative assessments of sectoral impacts and vulnerability analyses. The intention was to establish a relationship between impacts, general adaptation objectives and specific measures for each of the sectors analysed. These sectors are as follows (Climate Change Adaptation: The Regional Strategy, n.d.):

- Water resources
- Ecosystems and biodiversity
- Air quality
- Built environment and soil protection
- Transport and spatial planning
- Energy - Tourism
- Agriculture and animal husbandry

The vulnerability of these sectors is assessed through a structured and methodical process (Adaptation to Climate Change: The Regional Strategy, n.d.):

1. An analysis of the fundamental principles of climate change, including an examination of past and current climate variations and a forecast of future developments.
2. Quantitative Assessment of Sectoral Impacts: This is achieved by analysing the scientific bibliography, which allows for the collection and synthesis of data from sources in order to build a more complete picture of the specific impacts of climate change in different sectors.
3. Vulnerability Analysis: This analysis is conducted for all eight sectors previously mentioned. It identifies the sectors' most vulnerable points and areas most susceptible to the effects of climate change.
4. The functional relationship between impacts, targets and measures across sectors, taking into account all existing or planned sectoral policies and interventions.
5. The undertaking of stakeholder consultation through the utilisation of internal consultation mechanisms with the objective of ensuring the dissemination of vulnerability assessments and adaptation measures.
6. The utilisation of specific indicators to monitor and assess the vulnerability and resilience of different sectors in order to ascertain the efficacy of applied adaptation measures.

The anticipated outcomes of the implementation of the SRACC are twofold. Firstly, the region's society, economy and environment will become more resilient to the effects of climate change. Secondly, these strategies will be integrated into sectoral policies at the levels below, laying the foundations for a future Regional Action Plan.

6.1.2 Regional Action Document on Climate Change Adaptation

The document, which was drafted in accordance with the SRACC, was approved by the Regional Council No. 6028 of 19 December 2016 (Dgr Lombardia 19 December 2016, No. 6028). The principal objective of this document was to identify all areas where action in the field of adaptation to climate change is of paramount importance. In this case, 30 measures have been identified for priority areas, which include tourism and sport, water management, soil and land protection, human health, air quality, and so forth (Legambiente, 2022).

The document is based on the principle of mainstreaming, which posits that adaptation should be integrated into sectoral policies in terms of both interventions and resources. As in the case of the previously analysed document, the FLA collaborated in the drafting of this document by acting as a mediator between local authorities, territorial agencies, businesses and for-profit entities in order to identify the most effective mitigation and adaptation strategies (Fladmin, 2023).

These elaborated strategies are integrated into sectoral policies through different stages (Adaptation to Climate Change: The Regional Strategy, n.d.-b):

1. It is necessary to consult with regional stakeholders in order to verify that the measures developed are consistent with existing and future policies.
2. A vulnerability and sectoral impact analysis is conducted to establish a concrete relationship between objective impacts and specific measures. This analysis takes into consideration the stakeholder consultations that took place in the previous phase.
3. Integration into planning policies through Strategic Environmental Assessment (SEA) to ensure that these considerations are incorporated into the decision-making process in a more comprehensive manner.
4. The implementation of specific measures for priority areas that are designed with the intention of being integrated into existing policies.
5. Multi-level governance between the region, metropolitan city and municipalities to ensure coordination and coherence between all existing administrative levels with the aim of facilitating even more policy integration at all levels.
6. Cross-sectoral collaboration is essential to reduce conflicts of interest and ensure that these policies are both synergistic and complementary.
7. Monitoring and evaluation to ascertain the efficacy of the aforementioned policies and, should the necessity arise, to implement updates based on newly acquired data.
8. The implementation of financial resources to support the implementation of projects that integrate the aforementioned measures developed in urban sectoral policies.

The document devotes particular attention to the topic of water resources management, with a view to reducing the conflicts of interest of the actors involved in the management of these resources through enhanced inter-sectoral and inter-regional collaboration. The stated objectives are to reduce the hydraulic risk caused by flood flows, implement the resilience of water-demanding and vulnerable areas, and guarantee the water demand required for the various sectors (Legambiente, 2022).

Despite the efforts and strategies outlined in this document, recent events in the Lombardy context have demonstrated the necessity for more concrete actions and investments to mitigate the effects of climate change. In light of this, the Lombardy region has planned a new call for approximately 10 million euros for Lombardy municipalities by the end of 2024 with the objective of increasing adaptation and mitigation measures in urban public areas (Lombardy News Online, 2024).

6.1.3 Regional Plan of Air Quality Interventions (PRIA)

The update of the PRIA was approved by D.G.R. XII/1754 of 15/01/2024. This planning and programming tool looks at improving air quality in Lombardy's territories through the development of measures to prevent and reduce emissions of pollutants into the atmosphere. The plan was developed in accordance with national and regional regulations, in particular Legislative Decree No. 155 of 13 August 2010 and Regional Law No. 24 of 11 December 2006 (Piano Regionale Interventi per La Qualità Dell'Aria (PRIA), n.d.). The update of the PRIA was particularly concerned with the agricultural and forestry sectors, industrial plants and energy, and transport and mobility (Lombardy, Air Quality: Start of Strengthening PRIA, n.d.).

The primary objectives of this plan are twofold: firstly, to ensure that air pollutant values remain within the established maximum limits in areas where these values are typically exceeded, and secondly, to maintain air quality in areas where pollutant values are below the maximum limit. The document is structured into two sections: Cognitive territorial regulatory framework and identification of areas of intervention and measures to be implemented (Regional Plan for Air Quality Interventions (PRIA), n.d.).

The main measures developed to achieve the objectives are numerous (Permanent Measures to Improve Air Quality, n.d.):

1. Limitation of the circulation of more polluting vehicles
2. A prohibition on the utilisation of wood-fired generators for domestic heating, accompanied by temperature limitations in residential and commercial premises of no more than 19°C.
3. The allocation of approximately 30 million euros has been made for the purpose of investing in the renewal of heating systems and vehicles on the road.
4. Reducing emissions from industrial plants by promoting the use of renewable energy resources.
5. Improvement of air quality monitoring systems
6. Development of provisional measures in the event of PM10 limits being exceeded for several days.
7. Investments in the expansion of urban green spaces.
8. Investment in information campaigns aimed at citizens to make them aware of these issues and their importance.

Notwithstanding the measures implemented as part of this plan, the air quality within the region has not yet reached the desired level of improvement. Indeed, recent air quality reports indicate that numerous cities in Lombardy, particularly those situated in the Po Valley, continue to experience air pollution levels that exceed the legal limits (Il Giorno, 2024).

6.1.4 Regional Energy Environment and Climate Programme (PREAC)

This is a strategic initiative that was deliberated by DGR 7553 in 2022 and elaborated to promote the economic and social sustainability of the Lombardy region. This programme was developed in response to higher-level policies such as the Green Deal (Regional Programme for Energy, Environment and Climate (PREAC), 2022). Among its objectives is the decarbonisation of the regional electricity production from renewable sources, which is to be achieved with a special focus on renewable heating, photovoltaics and heat pumps.

Furthermore, the programme aims to reduce final energy consumption by 35.2 per cent through increased efficiency in the various sectors. Finally, the programme also aims to reduce greenhouse gas emissions by up to 43.5 million tonnes (PREAC - ARIA S.p.A., s.d.).

In order to achieve these objectives, the PREAC initiative was developed on the basis of four guiding principles, as outlined in the Regional Programme Energy Environment and Climate (PREAC), 2022.

1. Reduction of consumption through increased energy efficiency in end-use sectors.
2. The development of renewable energy sources through the promotion of self-consumption and local renewable resources.
3. Expansion of the production system through the provision of funding for research and technological innovation.

Furthermore, the programme incorporates a number of implementation measures designed to facilitate the achievement of these objectives. These include the simplification of bureaucratic procedures to facilitate the introduction and use of sustainable technologies, the inclusion of new incentives for the promotion of energy efficiency, the integration of sustainability into spatial planning policies, and finally, the involvement of all stakeholders involved to ensure better participation in the decision-making process (Regions4, 2024).

6.2 MUNICIPALITY OF MILAN

The City of Milan, situated at the level below the Region of Lombardy, is required to integrate the various implementations and strategies elaborated and issued by the region into its urban planning. This section will analyse those that have had the greatest impact.

6.2.1 AIR AND CLIMATE PLAN (PAC)

The PAC, which was approved by the city council in 2022, represents a strategic tool for addressing the challenges of air pollution in the city of Milan. This plan is designed to protect the health of the Milanese population and also the environment in response to the current climate emergency. The most ambitious goal of this plan is to achieve zero climate-altering emissions by 2050 (Piano Aria E Clima - Comune Di Milano, 2022).

The PAC is structured according to five priority areas, as outlined in the Air and Climate Plan of the Municipality of Milan (2022):

1. A Healthy and Inclusive Milan: A Clean, Fair, Open, and Inclusive City
2. Connected and highly accessible Milan: a city that is able to move in a sustainable, flexible, active and safe manner.
3. Positive energy Milan: a city that consumes less and more efficiently
4. Cooler Milan: a greener, cooler and more liveable city that adapts to climate change.
5. Conscious Milan: a city that adopts conscious lifestyles

For each of the areas, a series of specific measures and actions have been identified to achieve the objectives set by the plan. In order to achieve these objectives, it was necessary to involve stakeholders and citizens themselves through participatory action using thematic workshops and dedicated online platforms. In addition, a permanent citizens' climate assembly composed of 90 citizens selected through a lottery was established to accompany the implementation of the plan until 2030 (Poliedra, 2024). The Agency for Mobility, Environment, Territory (AMAT) played a pivotal role in the formulation of the CAP. AMAT's primary focus was on matters pertaining to air quality and the reduction of greenhouse gas emissions into the atmosphere (Climate Air Plan - Agency Mobility Environment Territory, 2019).

In the context of Sphere Four, the city of Milan, the plan pays particular attention to the mitigation of the heat island effect and hydraulic risk. This is achieved through the elaboration of several actions, as outlined by Legambiente (2022c):

1. The implementation of urban forestation measures will serve to increase the amount of green areas and the spread of green-walled roofs.
2. The implementation of permeable surfaces is intended to mitigate the risk of flooding and overflows during heavy rainfall events.
3. The reduction of impermeable surfaces associated with public car parks.
4. It is recommended that a local climate profile be published and frequently updated in order to raise awareness among the citizens of Milan.

The aforementioned measures are designed to enhance the quality of life in Milan and fortify the city against the effects of climate change by improving urban thermal comfort.

6.2.2 Project '100 resilient cities' (100RC)

The 100RC is an international project initiated by The Rockefeller Foundation with the objective of assisting global cities in developing resilience to climate change. The city of Milan was selected to participate in this project in 2015 (The Rockefeller Foundation, 2023).

The initiatives undertaken by the city of Milan in the context of this project were as follows (Direzione Città Resilienti - Comune Di Milano - #Sicuriperdavvero, 2019):

1. The elaboration of specific projects on initiatives to transform urban areas into sustainable and resilient areas is of particular importance. Among these, it is essential to mention 'reinventing cities', a global competition to identify degraded and abandoned areas to be valorised and redeveloped (Reinventing Cities - Municipality of Milan, n.d.).
2. Global collaborations such as C40 Cities facilitate collaboration between cities facing similar challenges and goals. The city of Milan is currently facing a number of challenges, including the impact of the global financial crisis and the ongoing effects of the COVID-19 pandemic, in addition to its environmental vulnerability.
3. The development of resilient urban planning within resilience strategies, including urban regeneration and natural resource management.
4. Adaptation to climate change is achieved through the development of plans, such as the area and climate plan illustrated above.

As a result of the city of Milan's involvement in this global initiative, the city has been able to access a range of financial and material resources, which have enabled the development and implementation of innovative and sustainable projects.

6.2.3 Milan 2030 Land Use Plan (PGT)

In 2019, the Milan City Council approved the Piano di Governo del Territorio (PGT) Milano 2030 (Milan 2030 - PGT VIGENTE | PGT, n.d.) as a new spatial planning tool. The PGT's principal objectives are the creation of a vast metropolitan park, the inclusion of zero-emission buildings from 2020 and the introduction of a climate impact reduction index. Furthermore, the plan places significant emphasis on urban regeneration, with particular attention to brownfield sites and railway yards. Another objective of the plan concerns the suburbs and neighbourhoods, with the redevelopment of seven strategic squares and 13 interchange nodes. Finally, the plan addresses the issue of sustainable mobility through the development of public transport and soft mobility. Additionally, the TMP includes several analyses on climate dynamism related to weather variables, integrating climate change mitigation actions into urban planning. In order to achieve these objectives, the TMP has devised a series of strategies, including the reduction of land consumption through the promotion of urban regeneration, the reinforcement of the entire green network and ecological connections, and the development of an interconnected and polycentric city model (Spaces and Projects | TMP, n.d.).

In 2023, further amendments were made to the TMP, with the approval of a variant to the plan of rules. This modification sought to alter some implementation rules and to update the Seveso torrent's river belts. As can be observed, the TJP is a dynamic instrument that undergoes frequent revisions and updates, with a focus on environmental issues. In recent times, the critical issue of hydraulic risk management has emerged as a consequence of global events such as the pandemic. Furthermore, on 13 April 2023, the municipal authority initiated a new process of drafting the new services plan document and rules plan (Milano 2030 - PGT VIGENTE | PGT, n.d.).

6.2.4 Development and Consolidation of Geospatial Sustainability Services for Adaptation to Environmental and Climate Change Urban Impacts Project (DECUMANUS)

The DECUMANUS project was launched by the European Commission under the FP7 programme in 2013 for a period of 32 months with the aim of developing a set of sustainable services to enable stakeholders in urban areas to integrate Earth Observation (EO)-based geospatial products and services into their climate change resilience strategies. The cities participating in this project are helping to define the requirements, test the products, validate the results and act as ambassadors of the developed technologies for other cities not currently included in the project. The main objective is to bridge the gap that currently exists between user requirements and state-of-the-art technologies in order to improve the accessibility and use of already existing spatial products for non-expert users (Cordis, 2014).

The City of Milan participated in this project and had a significant impact in several respects. In fact, DECUMANUS contributed to (Milano Green Week. A future with 13 million square metres of green roofs in the city - City of Milan, 2019):

1. Mapping of green roofs, revealing that there are currently 970,000 square metres of all green roofs and identifying about 13 million square metres of roofs that could potentially be transformed into green roofs.
2. Providing tools for Milan's urban planning for climate change resilience, air pollution reduction and improved management of the urban area itself in the long term.
3. Improve city policies by using data to develop strategies to increase green roofs in the city itself.

4. Increasing environmental benefits as the introduction of large numbers of green roofs counteracts the heat island effect and energy loss in both summer and winter; further improvements are also linked to storm water management.
5. Integration of this project with other initiatives such as Horizon 2020 and CLEVER Cities.

Thanks to the participation of the City of Milan in this project, the Municipality has been able to develop incentives and regulations to promote the implementation of green roofs in urban areas, always with the aim of making the city more resilient to climate change and improving the quality of life of its citizens.

6.2.5 Project ForestaMi

Forestami is a project promoted by the City of Milan, the Municipality of Milan, the Lombardy Region, Parco Nord Milano, Parco Agricolo Sud Milano, ERSAF and the Fondazione di Comunità Milano. It is a project to plant 3 million trees by 2030 with the aim of cleaning the air, improving living conditions and preventing the effects of climate change. The project is the result of research carried out by the University of Milan with the support of the Falck Foundation and FS Sistemi Urbani (Forestami, 2024).

To date, around 427,475 trees have been planted, involving 62 municipalities in the city of Milan. The project also aims to raise awareness of environmental issues among young people through lessons at the 'ForestaMI School'. To cover the costs of planting trees, ForestaMI uses both public and private funds, thanks to the creation of the ForestaMI Fund, which has raised around 2.8 million euros (Fondo Forestami - Fondazione di Comunità Milano, 2023).

The difficulties encountered by this project are linked to the drought, which has slowed down and affected the reforestation process. Despite the criticism regarding the maintenance of these "forests", it has been amply demonstrated how the introduction of these trees has effectively mitigated the heat island problem (Gli alberi di Milano - qual è la verità? Forestami and the shortcomings of the city, 2023).

7. Application of the evaluation model

In this thesis, it has been used:

1. A methodology for the identification of urban areas particularly vulnerable to the UHI through the use of SMCA (see section 4.5)
2. The assessment of the economic impact of a mitigation measure on a specific critical/vulnerable area using the state of the art in literature

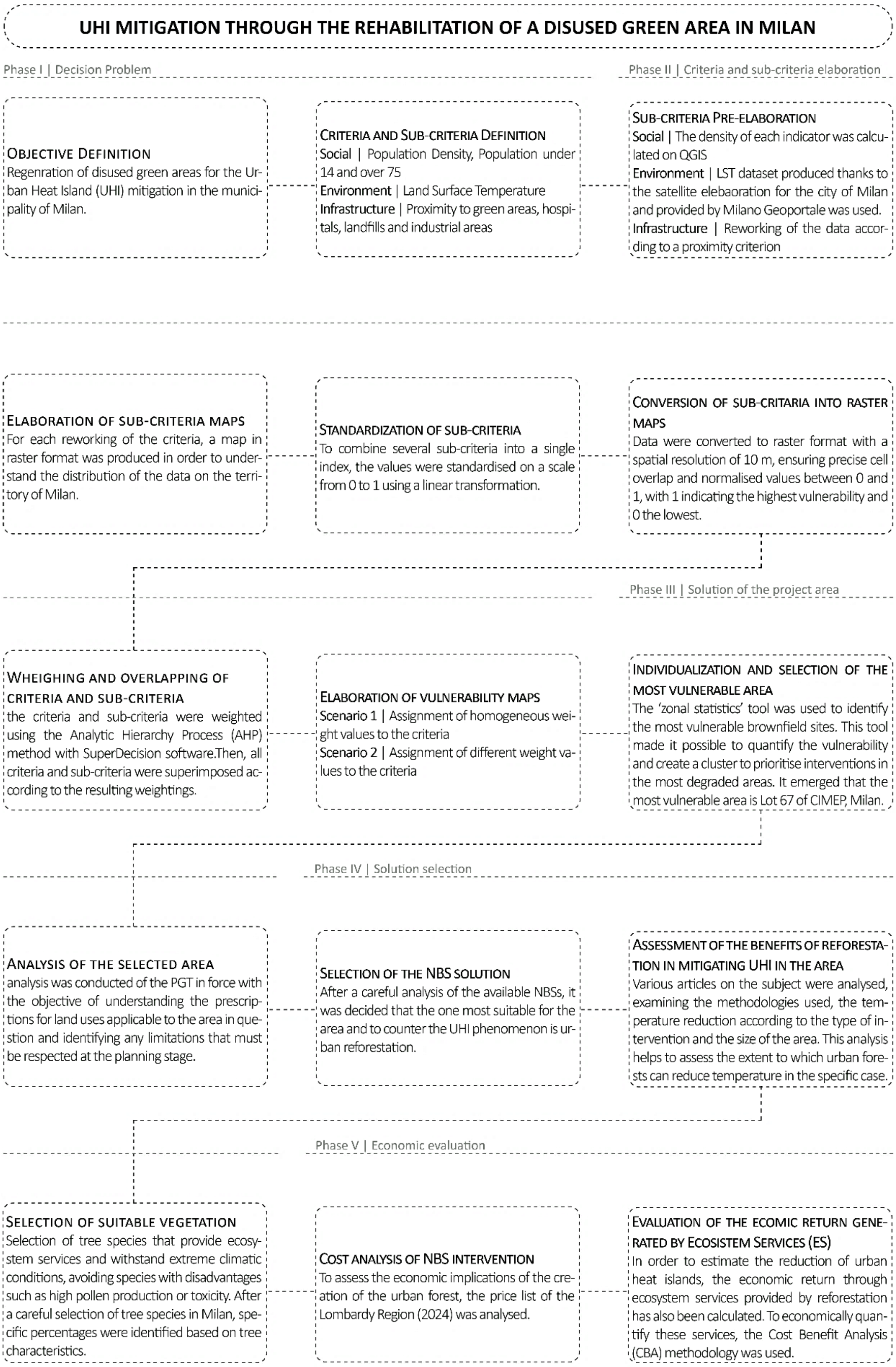


FIGURE 27 - METHODOLOGY SCHEMA (SOURCE: AUTHOR ELABORATION)

This study used QGIS software, an open-source platform for the analysis, visualisation and management of geospatial data. Once all the sub-criteria were entered into the QGIS platform, maps were generated for each of them according to the selected criteria and sub-criteria. Then, using the AHP evaluation method (see section 4.3), the maps were standardised and weighted according to the values derived from the hierarchical analysis performed with the SuperDecision software. The maps were then converted into a raster format to facilitate the processing of the results, and the sub-criteria belonging to each of the environmental, social and infrastructure criteria were aggregated. From this last aggregation, two vulnerability maps were obtained, one with weighted and homogeneous weights and one with deferred weights. All relevant steps are analysed in detail below.

7.1 STRUCTURE OF THE DECISION PROBLEM

In order to create a vulnerability map for the city of Milan, it is therefore necessary to define, according to a hierarchical structure, an objective, a number of criteria that will be used to evaluate the objective itself, and a number of sub-criteria that will be used to evaluate the criteria themselves. The objective of this study is to assess the problem of heat islands in the urban area of Milan and to try to mitigate its effects by recovering disused green areas within the city, identifying the most vulnerable areas in order to find the most vulnerable area and therefore subject to these effects. To achieve this objective, three macro areas or criteria have been defined: environmental, social and infrastructural.

7.1.1 INDICATOR SELECTION

The analysis of the literature, as presented in section 4.6, revealed a plethora of useful indicators for mapping the urban vulnerability to the UHI. This analysis helped to identify which of these indicators should be selected in order to construct the map. However, in the study area considered in this work, the Municipality of Milan, the search for data useful for constructing the indicators reported in the literature, carried out on regional and municipal geoportals, did not yield many results.

The indicators were therefore reduced and adapted to the available information in order to ensure their representativeness with regard to the three macro dimensions: social, environmental and infrastructure.

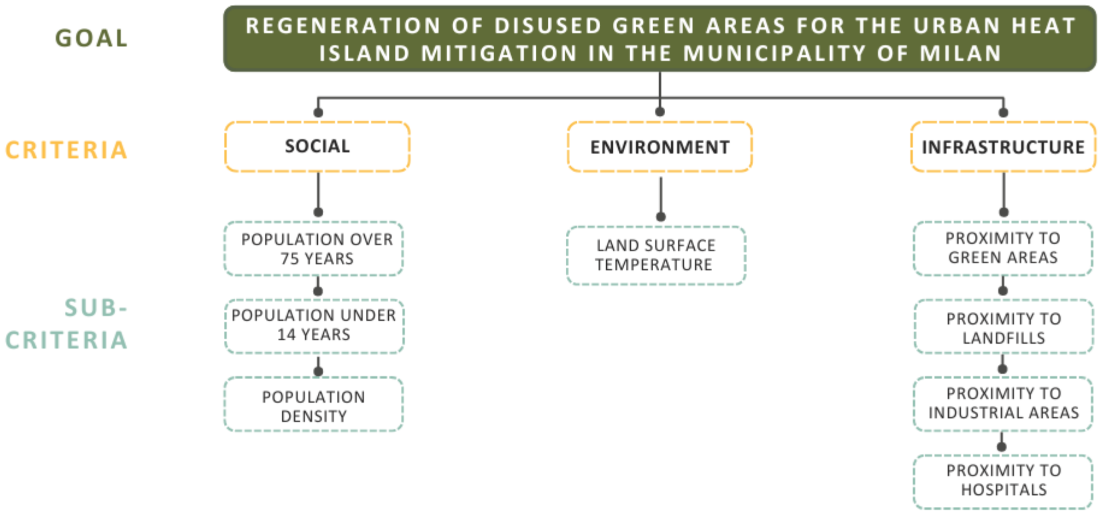


FIGURE 28 - SCHEMA OF GOAL, CRITERIA AND SUB-CRITERIA SELECTED FOR THE VULNERABILITY MAP OF MILAN (SOURCE: AUTHOR ELABORATION)

In order to define each criterion, sub-criteria were selected based on the indicators and data available for the city of Milan. Table 21 illustrates the relevance of the indicator and its contribution to the vulnerability assessment.

TABLE 21 - SELECTION OF SUB-CRITERIA AS AN INDEX OF VULNERABILITY (SOURCE: AUTHOR ELABORATION)

CRITERIA	SUB-CRITERIA	MOTIVATION OF VULNERABILITY
SOCIAL	Population over 75 years	1. Reduced ability to thermoregulate 2. Often subject to dehydration and heatstroke 3. Health conditions that can be easily aggravated by heat 4. Poor ability to move around in search of cooler places
	Population under 14 years	5. Reduced thermoregulatory capacity 6. Not independent in terms of hydration and heat shielding 7. Easily exposed to heat during outdoor play activities
	Population density	8. The higher the housing density, the more artificial surfaces can release heat 9. Less green areas that cool 10. Poor ventilation between buildings
ENVIRONMENT	Land Surface Temperature	11. Methodology for measuring surface temperatures 12. Distinguishing which areas are warmer and cooler
INFRASTRUCTURE	Proximity to green areas	13. Those not in the vicinity of green areas are more prone to extreme heat 14. 3-30-300 rule for good planning practice of green areas in urban areas
	Proximity to landfill	They generate additional heat due to the decomposition of waste
	Proximity to industrial areas	Large impermeable surfaces that increase heat release
	Proximity to hospitals	Individuals living far from hospitals do not have quick access to care in an emergency

Table 22 presents the data employed in the construction of the aforementioned indicators. It should be noted that the original data required some modifications prior to its utilisation as an indicator. All selected data were reprojected into the Projected Coordinate System (PCS) RDN2008 / Italy zone (E-N) in order to render them spatially processable within the GIS.

TABLE 22 - DESCRIPTION OF SUB-CRITERIA AND THEIR POSSIBLE RE-ELABORATION (SOURCE: AUTHOR ELABORATION)

CRITERIA	SUB-CRITERIA	DESCRIPTION	TYPOLOGY	YEAR	SOURCE	ELABORATION
ENVIRONMENT	Intra-Urban Spatial Distribution of Land Surface Temperatures (LST)	*Satellite thermal data to identify urban areas with high temperatures. A five-year time series (2013-2017) of diurnal LST satellite images with a resolution of 100 m (in °C) was used to generate a dataset of the spatial distribution of LST. The data used correspond only to the summer months (June, July and August) in order to capture the hotspots with the most significant impact.*	Shp	2018	[1]	*(UOM: °C)*
SOCIAL	Density of population over 75 years old per NIL	*Identification of NILs containing the largest vulnerable elderly population*	csv	2023	[2]	The figure for the number of residents over 75 was recalculated with the density of persons over 75 in the total resident population in 2023 per NIL (*UOM: inhab/sqm*)
	Density of population under 14 years old per NIL	*Identification of NILs containing the largest vulnerable young population*	csv	2023	[2]	The figure for the number of residents under the age of 14 was recalculated with the density of persons under 14 in the total resident population in 2023 per NIL (*UOM: inhab/sqm*)
	Population Density	*Incidence of severe crowding*	shp	2023	[2]	Calculated from the ratio of the resident population in 2023 to the total area of each NIL (*UOM: inhab/sqm*)
INFRASTRUCTURE	Proximity to Hospitals	*Useful distance of people within 1000 metres of a hospital facility*	shp	2023	[3]	The point figure of hospital units was recalculated by the author to estimate proximity by applying a 1000 m buffer on each facility *(UOM: meters)*
	Proximity to landfill	*Useful distance of people within 500 metres of a landfill*	shp	2022	[4]	The point data of the landfills was recalculated by the author to estimate proximity through the application of a 500 m buffer on each structure *(UOM: meters)*
	Proximity to Industrial, commercial, public, military and private units	*Useful distance of people within 500 metres of industrial, commercial, public, military and private units*	shp	2010	[5]	The point data of industrial, commercial, public, military and private units was recalculated by the author to estimate proximity by applying a 500 m buffer on each structure *(UOM: meters)*

(*Continued next*)

Proximity to Green Areas	*Useful distance of people within 300 metres of a green area*	shp	2010	[6]	The point data of green areas was recalculated by the author to estimate proximity by applying a 300 m buffer on each area *(UOM: meters)*

7.2 Sub-criteria pre-elaboration

7.2.1 Environmental criteria

The environmental criterion was based exclusively on ground surface temperature data. As the only indicator, the LST dataset produced thanks to the satellite elaboration for the city of Milan and provided by Milano Geoportale was used. For the processing of this data the AVG_LST column was used, present in the downloaded shapefile, which contains the average value of the surface temperature of the summer months from 2013 to 2017 aggregated on the zones of the Urban Atlas (Map 1).

The map below illustrates the average surface temperature trend in Milan. As can be observed, the critical temperatures correspond to the most urbanised areas, which are characterised by a greater abundance of impermeable soil. In contrast, the more peripheral areas exhibit lower temperatures due to the prevalence of numerous green areas, which are permeable soil. It is noteworthy that the temperature differential between the peripheral and central areas is approximately 10 °C, which is consistent with the phenomenon of the urban heat island (UHI).

This distribution also serves to illustrate the beneficial impact of green areas on the reduction of temperatures in their surrounding areas, thereby enhancing the quality of life of the citizens residing there.

[1] Geoportale SIT del Comune di Milano
https://geoportale.comune.milano.it/download/area_download/SIT/HeatData/avgLST_Milan_UrbanAtlas.zip

[2] Sistema Statistico Integrato, Comune di Milano
https://sisi.comune.milano.it/

[3] Geoportale Regione Lombardia
https://www.geoportale.regione.lombardia.it/en/metadati?p_p_id=detailSheetMetadata_WAR_gptmetadataportlet&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&_detailSheetMetadata_WAR_gptmetadataportlet_identifier=r_lombar%3°00bbd829-32e7-4f86-8e87-a9b0a1c8bae0&_jsfBridgeRedirect=true

[4] Geoportale Regione Lombardia
https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioServizio/servizi-e-informazioni/Enti-e-Operatori/Ambiente-ed-energia/Rifiuti/ser-catasto-impianto-rifiuti-online-versione-pubblica-ambcatasto-impianti-rifiuti-online-versione-pubblica/catasto-impianti-rifiuti-online-versione-pubblica

[5] Urban Atlas – Italy – Milan
https://sdi.eea.europa.eu/catalogue/srv/api/records/1f094908-264e-434b-9d1e-a7f5511018f3

[6] Urban Atlas – Italy – Milan
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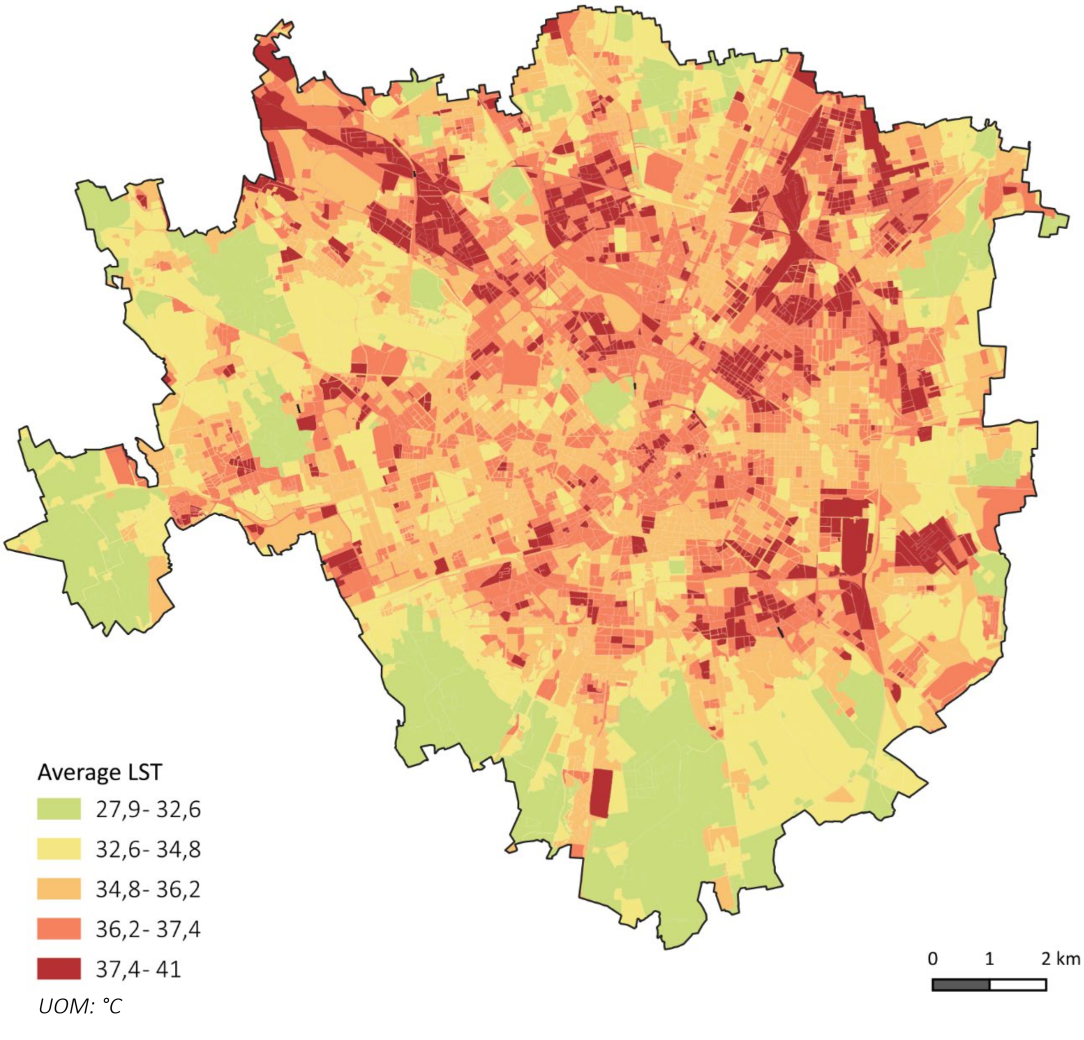


MAP 1 - LAND SURFACE TEMPERATURE (LST) (SOURCE: AUTHOR ELABORATION)

7.2.2 SOCIAL CRITERIA

The social dimension of the Milanese territory was evaluated using Local Identity Numbers (NIL) as a reference unit of measurement. In this section, the indicators were not considered in their absolute values but rather in terms of population density. To achieve this, the density of each indicator was calculated on QGIS by dividing the population by the area of each NIL, thus neutralising the areal dependency effects of the data. This processing enabled a more accurate representation of the population distribution to be achieved.

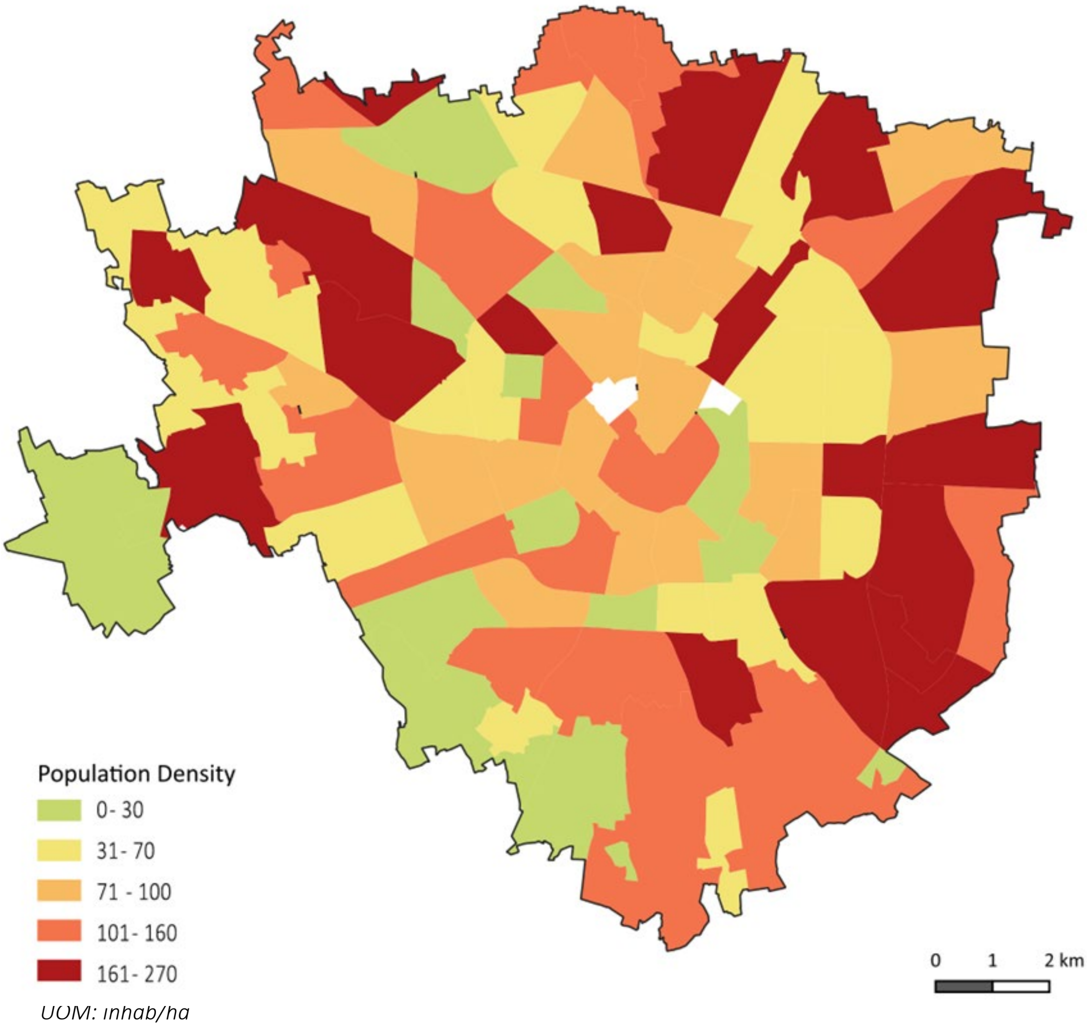
The social dimension is evaluated through the following indicators:

1. Population density in general (Map 2)
2. Density of the elderly population over the age of 75 (Map 3)
3. Under-14 population density (Map 4)

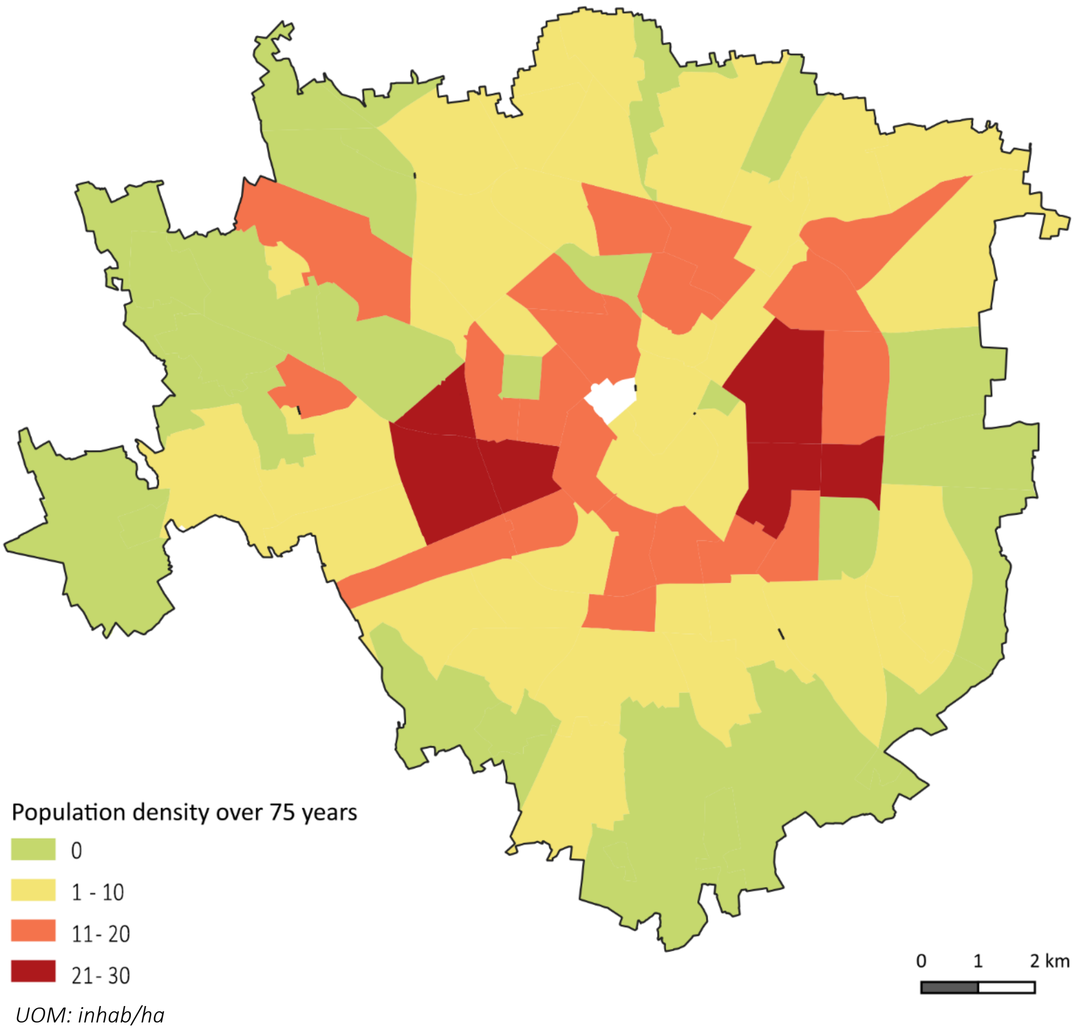
A review of the maps below reveals that the Milanese territory is characterised by a high overall population density. The majority of NIL exhibit a medium-high density, which reflects Milan's urban and metropolitan nature, characterised by high density in relatively small spaces.

Conversely, with regard to the population over the age of 75, it is evident that the areas surrounding the city centre and the inner city are the most densely populated in this age group. This phenomenon can be attributed to a number of factors, including the historical presence of long-term residents in these areas, the high availability of services and infrastructure suitable for this age group, and the potential influence of gentrification dynamics, which have led to the retention of this age group in the most central and expensive areas of Milan.

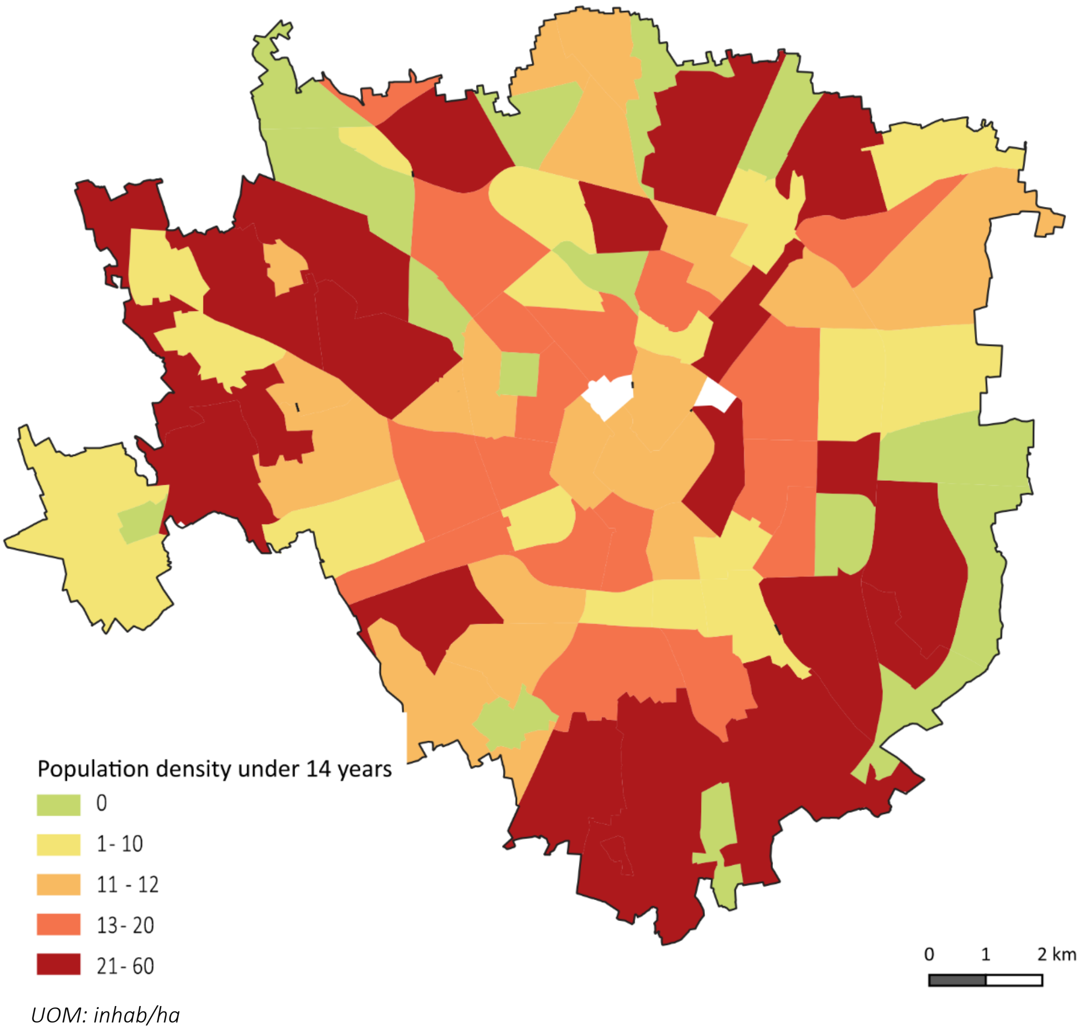
Conversely, with regard to the under-14 age group, a uniform distribution is observed across the territory, with high densities evident in the majority of NILs. Some neighbouring areas of the city represent an exception to this pattern. This distribution could be attributed to the pervasive presence of households with children, but also to potential discrepancies in household composition between the various NIL within the city.



Map 2 - Population Density Per Nil (Source: Author Elaboration)



Map 3 - Population Density over 75 years old per NIL (Source: Author elaboration)



MAP 4 - POPULATION DENSITY UNDER 14 YEARS OLD PER NIL (SOURCE: AUTHOR ELABORATION)

7.2.3 Infrastructure criteria

Finally, with regard to the infrastructural dimension, it was necessary to rework the data according to a proximity criterion. With regard to all sub-criteria belonging to this sphere, the following methodology was applied: the selection of areas of interest within the shapefile and the creation of a buffer of variable size according to type was undertaken.

The methodology employed involved the filtration of hospital data, with only hospital care facilities selected as they are considered to be the most important in an emergency. A buffer of 1000 m was then applied to the point data, outside of which access to the facility is deemed insufficient, making the area more vulnerable. Map 5 illustrates that the areas best served are those in the centre and west of Milan, while the areas south of Milan have fewer hospital facilities.

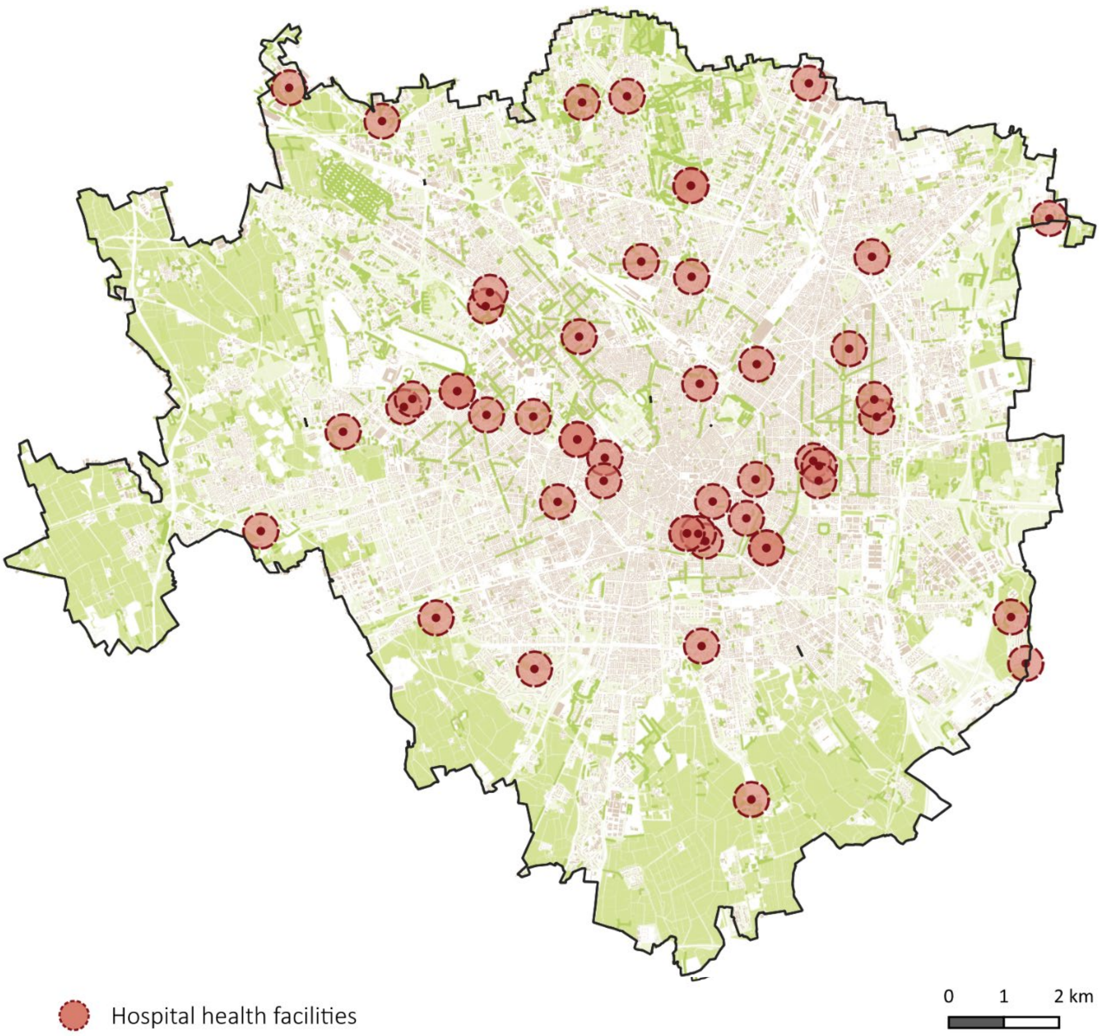
In contrast, the data on industrial, commercial, public, military and private areas was obtained using the data provided by Urban Atlas, which was filtered according to this category. A 500 m buffer was then applied to the point data, which identifies the areas close to these facilities and therefore more vulnerable to heat peaks. The areas outlined in map 6 have the highest vulnerability for this indicator. From map 6, it is evident that these sites are distributed homogeneously throughout the Milan area. The larger the area, the greater the heat capture by impermeable soil, resulting in elevated heat peaks. Furthermore, the majority of these areas are situated in the city's periphery.

The data on landfills was obtained by selecting within the shapefile named 'Waste Plants', provided by the Lombardy Region, only the 'landfill' type. This was considered to be more relevant in cases of heat peaks. A buffer of 500 metres was drawn up for this category, where the areas within it are considered particularly vulnerable. As the areas are distanced from these, the vulnerability decreases. In the city of Milan, only seven landfills were identified. Map 7 illustrates that these are predominantly situated on the municipal boundaries, with the exception of one landfill located towards the city centre.

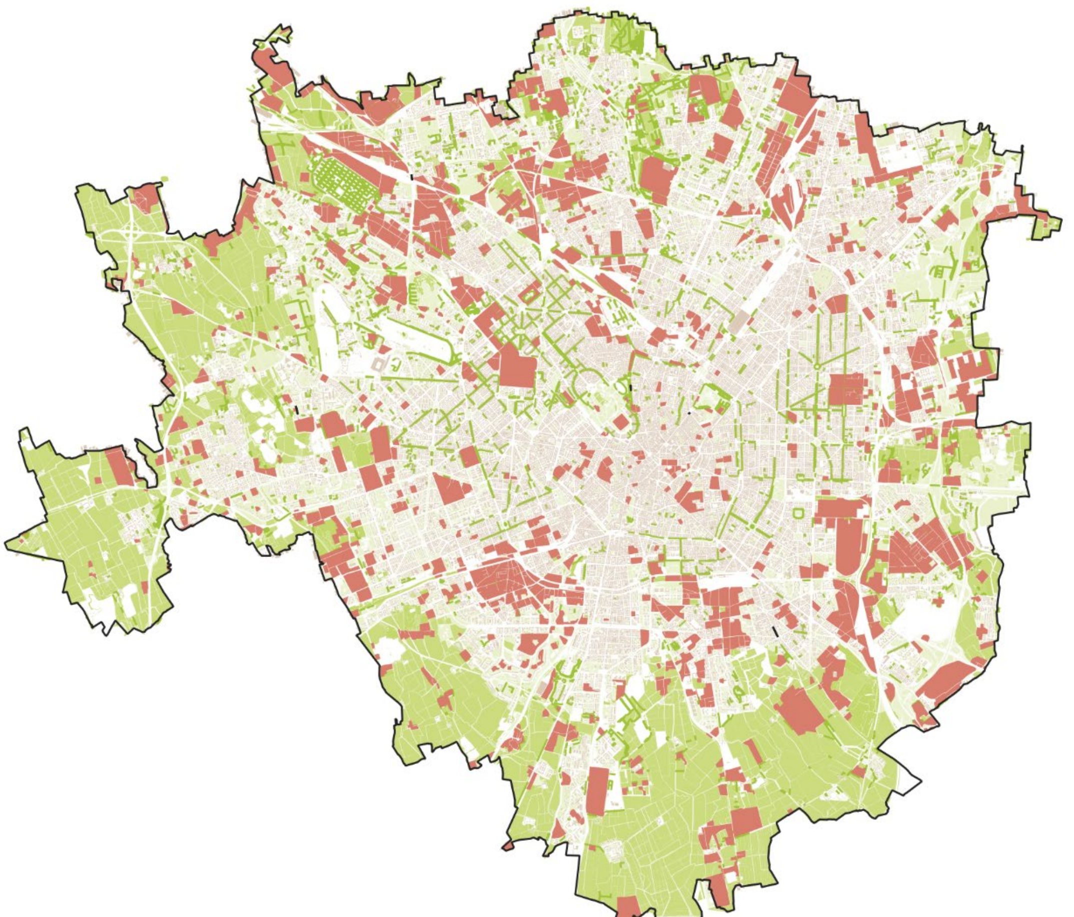
Finally, the proximity of green areas was analysed, which is a crucial factor in assessing heat peaks and the quality of life for citizens. According to the urban green planning guidelines devised by Professor Cecil Konijnendijk, the 3-30-300 rule was developed, which states that (Viganò, 2023):

1. A citizen should be able to see 3 trees from his home;
2. A neighbourhood should consist of at least 30% green areas;
3. Every citizen should have access to a green area within 300 m of his home.

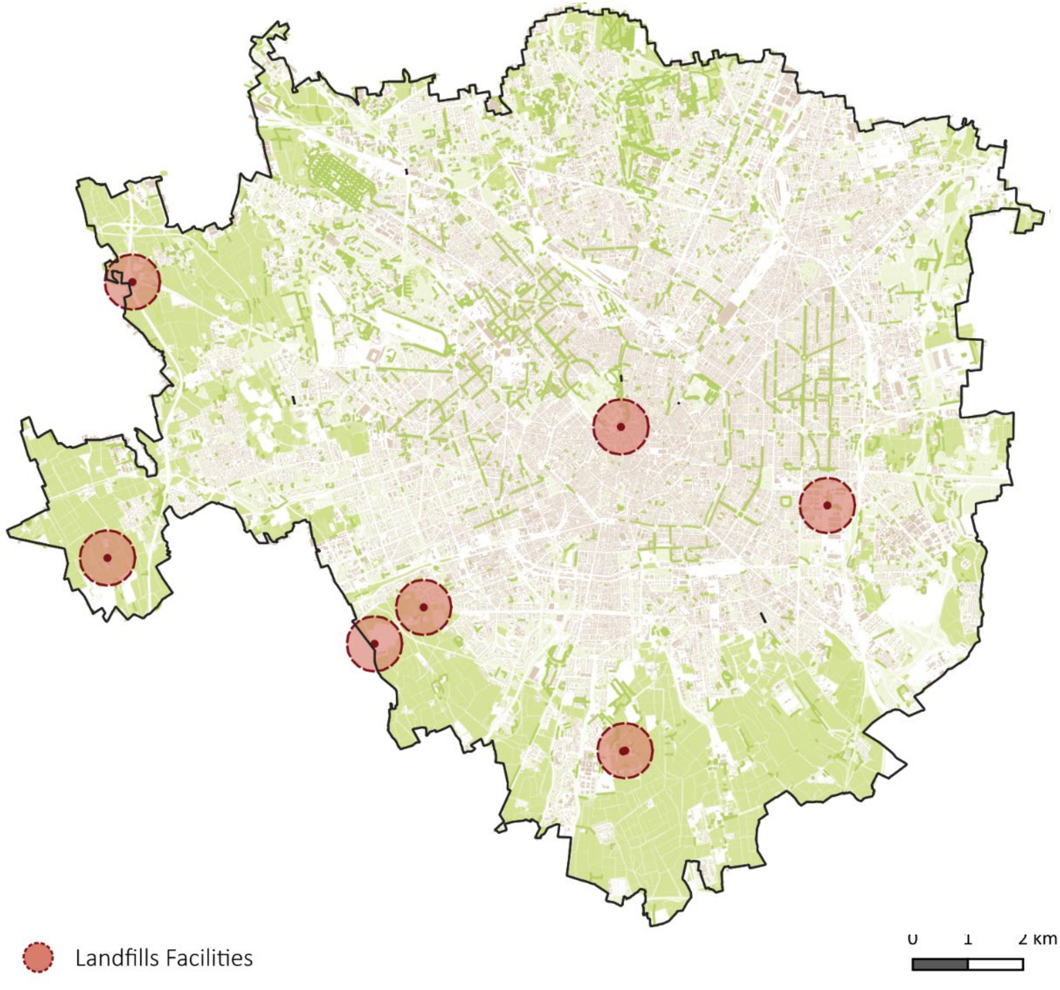
In this context of green areas, a figure was also elaborated by Urban Atlas, which considered urban green areas to which a 300m buffer was applied. This was based on the assumption that the population inside these areas is less vulnerable than those outside them. Map 8 illustrates that the largest areas are located in the most peripheral areas, with the exception of some located in the city centre.



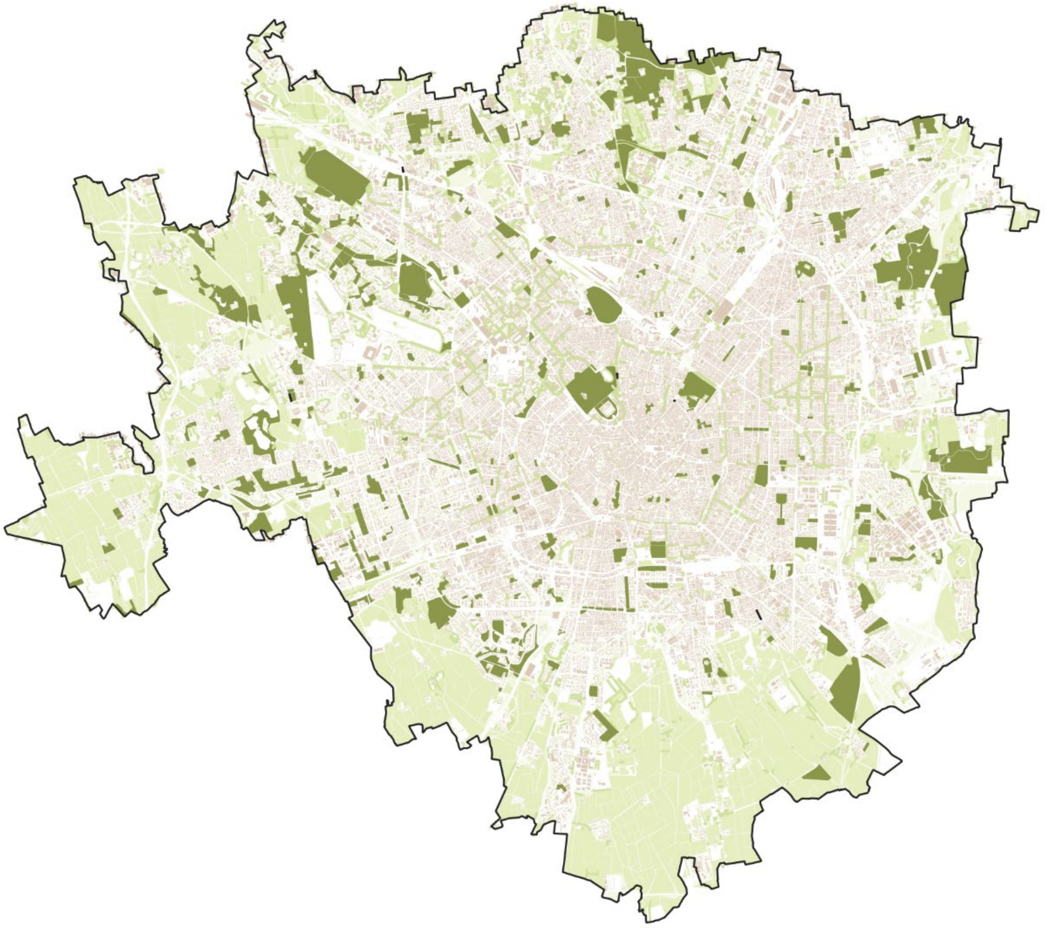
MAP 5 – LOCALIZATION OF HOSPITAL HEALTH FACILITIES (SOURCE: AUTHOR ELABORATION)



Map 6 – Localization of Industrial, commercial, public, military and private areas (Source: Author elaboration)



Map 7 - Localization of landfills facilities (Source: Author elaboration)



MAP 8 - LOCALIZATION OF URBAN GREEN AREAS (SOURCE: AUTHOR ELABORATION)

7.3 Standardization of sub-criteria

Each sub-criterion exhibits a distinct range of values, including both minimum and maximum values that cannot be directly compared with each other due to the differing units of measurement and resulting interpretations. In order to combine these factors into a single index, it is necessary to reclassify or transform them into a common ratio scale.

The decision was taken to standardise the values on a scale from 0 to 1, utilising a linear, increasing transformation function (Figure 29). The linear standardisation function is expressed by the following formula:

$$\frac{(x - x_{min})}{(x_{max} - x_{min})} \quad [2]$$

In this context, the variable x represents the column within the attributes table that contains the analysis data to be standardised. The variables x_{min} and x_{max} represent, respectively, the minimum and maximum values of the range. This transformation enables the conversion of any original value into a standardised value between 0 and 1.

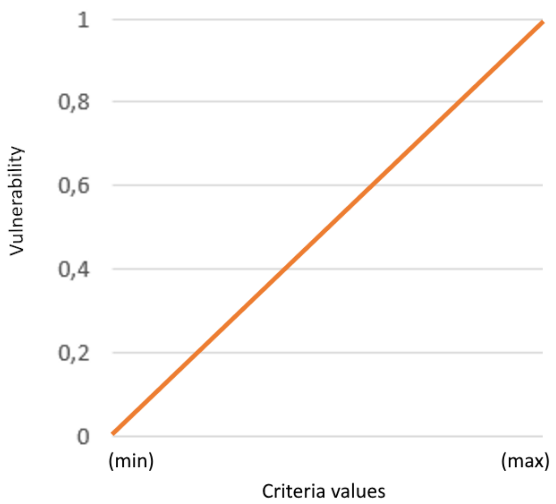


Figure 29 - Linear and increasing transformation function for standardization of indicators (Source: Author elaboration)

The standardisation of values allows for the maintenance of interpretative consistency between the different sub-criteria, facilitating the comparison and combination of these elements. A standardised value close to 0 indicates low vulnerability, while a value close to 1 is indicative of high vulnerability. This phase was preparatory for the subsequent aggregation of the sub-criteria and criteria in order to form a composite index for the vulnerability map of the city of Milan.

7.3.1 Environmental criteria

The standardisation of the Land Surface Temperature (LST) sub-criterion followed this process:

1. Creation of a new field: a new field named *'norm_LST'* was added to the attributes table, which will contain the standardised data
2. Application of the standardisation formula:

$$norm_{LST} = \frac{(avgLST - avgLST_{min})}{(avgLST_{max} - avgLST_{min})} \quad [3]$$

where:

- $avgLST$ is the average value of the LST for each area of analysis
- $avgLST_{min}$ is the minimum value of LST in the entire dataset
- $avgLST_{max}$ is the maximum value of LST in the entire dataset

The restitution of the data allows us to define that values close to 0 indicate low vulnerability to heat peaks, presenting relatively low temperatures compared to the rest of the analysed area. In contrast, values closer to 1 indicate high vulnerability, with soil temperatures significantly higher than in the rest of the analysed area.

7.3.2 Social criteria

In the case of the sub-criteria Population density, Population density over 75 and under 14 years, expressed as density (number of population per area), the values were standardised from 0 to 1 as described below:

1. Creation of a new field: a new field was added to the attributes table that will contain the standardised data:
   a. "norm_dens" for the total population density
   b. "norm_75" for the population density over 75
   c. "norm_14" for the population density under 14
2. Application of the standardisation formula:
   a. Population density

$$norm_{dens} = \frac{(densPop - densPop_{min})}{(densPop_{max} - densPop_{min})} \quad [4]$$

   b. Population density over 75

$$norm_{75} = \frac{(dens75 - dens75_{min})}{(dens75_{max} - dens75_{min})} \quad [5]$$

   c. Population density under 14

$$norm_{14} = \frac{(dens14 - dens14_{min})}{(dens14_{max} - dens14_{min})} \quad [6]$$

For all three standardised indicators, values close to 0 indicate low vulnerability, i.e. low density, while values close to 1, on the other hand, indicate high vulnerability, i.e. high density.

7.3.3 Infrastructure criteria

The sub-criteria concerning infrastructures have been elaborated differently from the previous sub-criteria. In fact, these are all binary/boolean, i.e. they only assume a maximum (1) or minimum (0) vulnerability, with no intermediate values.

With regard to the sub-criteria of proximity to hospital areas and green areas, the classification required the following steps:

1. From the creation of the buffer, the QGIS 'clip' tool was used to cut areas outside the buffer; areas resulting from this clip will have value 0
2. Then QGIS's 'union' function gives as input the buffer layer and the previously clipped Milan municipality area layer; the areas resulting from the union will have value 1

This means that buffer areas will have a value of 0, i.e. non-vulnerable as they are close to hospitals or green areas, while all external areas 1, or vulnerable as they are far from these.

On the other hand, with regard to the sub-criteria of proximity to landfills and industrial, commercial, public, military and private areas, the classification required the following steps:

1. From the creation of the buffer, the QGIS 'clip' tool was used to cut areas outside the buffer; the areas resulting from this clip will have value 1
2. Then QGIS's 'union' function gives as input the buffer layer and the previously clipped Milan municipality area layer; the areas resulting from the union will have value 0

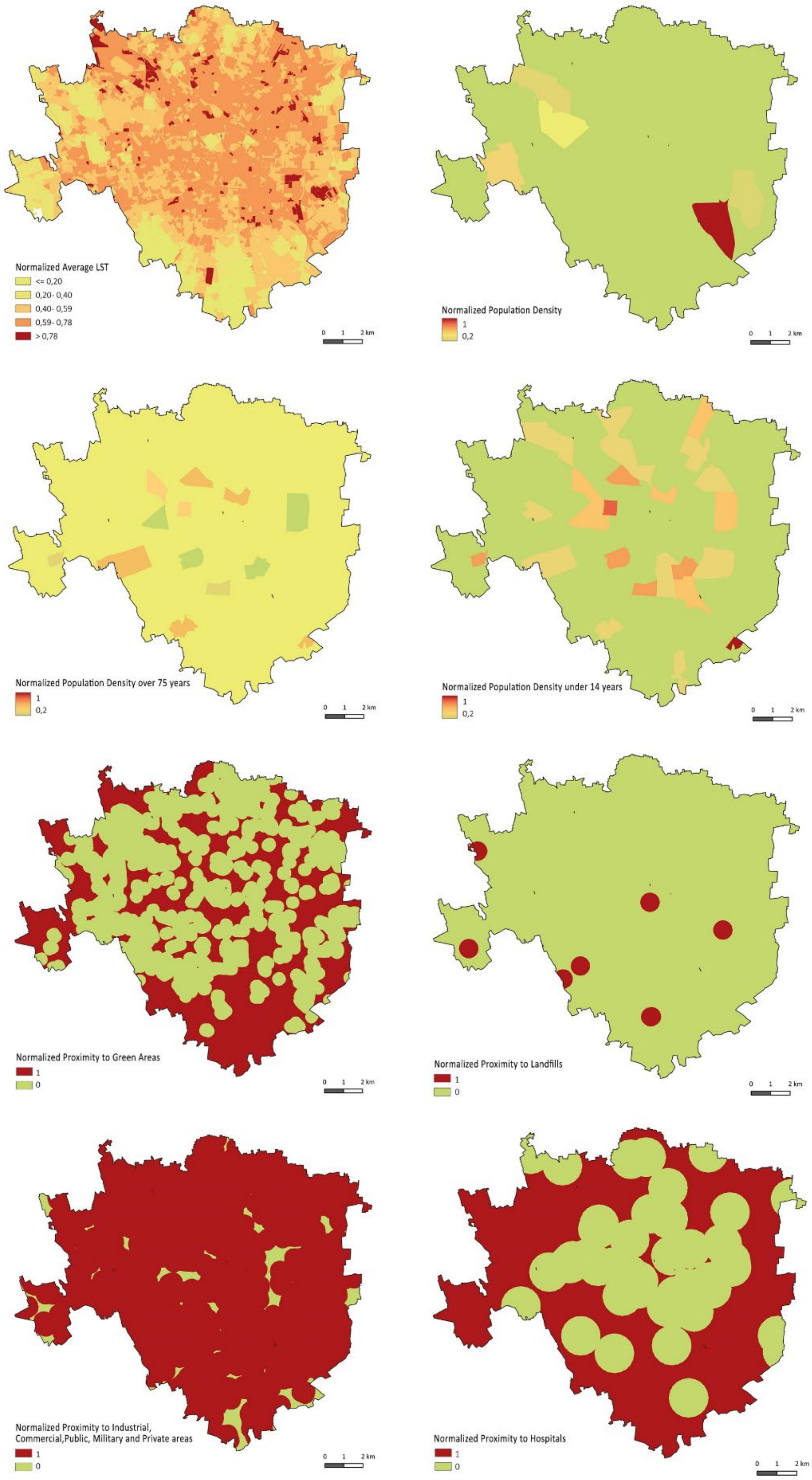
Compared to the previous case, the assignment of the values 0 and 1 has been reversed. This means that the buffer areas will have a value of 1, i.e. vulnerable as they are close to the sites mentioned above, while all external areas 0, i.e. non-vulnerable areas as they are far from these.

7.4 Conversion of sub-criteria into raster maps

Following the standardisation of the sub-criteria, the data was converted to raster format in order to reduce the area dependency of the data.

The rasters were created with a spatial resolution of 10 m and are based on the same spatial extent (the bounding box of the municipal boundary). This ensures that the cells of the different rasters are always coincident and perfectly superimposable. The cells of the rasters assume the value of the attribute normalised in the previous step and therefore vary from 0 to 1, where 1 represents the maximum vulnerability and 0 the minimum.

The following section presents the raster maps obtained for each indicator.



MAP 9 - SUB-CRITERION RASTER MAPS (SOURCE: AUTHOR ELABORATION)

7.5 Weighing and overlapping of sub-criteria and criteria through AHP

Once the maps had been transformed into rasters, the next step was to evaluate the importance of each criterion and sub-criterion with respect to the predefined objective. To perform this weighing, the hierarchical methodology of the Analytic Hierarchy Process (AHP) was used (see section 4.3.4). In order to understand which final result of the vulnerability map was most appropriate for the analysis of the specific cases, two different types of criteria weighting were carried out using the SuperDecision software[1]. In the first scenario, the criteria were weighted equally, thus generating homogeneous weightings, taking into account the three dimensions of sustainability, while the sub-criteria were then weighted according to the results of the literature review presented in section 4.6. In the second scenario, the criteria were weighted differently, giving greater priority to the environmental sphere, in line with the reason for implementing the NBS and the objective of this thesis, i.e. the reduction of the UHI. As for the sub-criteria in the second scenario, they were weighted differently in accordance with the literature review carried out in section 4.6.

As regards the practical act of weighing both criteria and sub-criteria, as already mentioned through the use of SuperDecision, this required the following steps:

1. *Creation of a matrix* for pairwise comparison where each criterion and sub-criterion was compared with all others by assigning an importance value between 1 and 9, according to the Saaty scale, where 1 indicates equal importance and 9 indicates that the criterion is extremely more important than the other. The analysis was carried out correctly using a consistency ratio (CR) of less than 10%.

   Below are the weighting values resulting from the pairwise comparison matrix.

Table 23 – Weighing sub-criteria derived from pairwise comparison (Source: Author elaboration)

CRITERIA	SUB-CRITERIA	WEIGHT
ENVIRONMENT	Intra-Urban Spatial Distribution of Land Surface Temperatures (LST)	1
SOCIAL	Density of population over 75 years old per NIL	0,4
	Density of population under 14 years old per NIL	0,4
	Population Density	0,2
INFRASTRUCTURE	Proximity to Hospitals	0,27807
	Proximity to landfill	0,16336
	Proximity to Industrial, commercial, public, military and private units	0,16336
	Proximity to Green Areas	0,39521

2. *Assignment of weights*. The raster maps obtained for each indicator were weighted according to the values determined by the AHP analysis. Each grid cell represents the normalised value of the indicator weighted according to its relative importance. In this case, two types of scenarios were developed:
   a. Homogenous weighting of environmental, social and infrastructure criteria;
   b. Diversified weighting in line with the objective of the work.

[1] *https://www.superdecisions.com/*

The thesis work deals with the mitigation of UHI in the city of Milan. In assigning different weights, greater importance was given to surface temperature than to infrastructure, as it can simultaneously mitigate or worsen the UHI phenomenon. Finally, the social criterion was used to assess the population at risk.

TABLE 24 - CRITERIA WEIGHING SCENARIOS (SOURCE: AUTHOR ELABORATION)

CRITERIA	HOMOGENOUS WEIGHT	DIVERSIFIED WEIGHING
ENVIRONMENT	0,33	0.81421
SOCIAL	0,33	0,07180
INFRASTRUCTURE	0,33	0,11398

Once the weighting phase is complete, it is possible to assign weights to the maps previously produced on the GIS. To do this, the "raster calculator" tool was used where the weights of all sub-criteria belonging to each criterion were first assigned (Table 25).

TABLE 25 - WEIGHT ASSIGNMENT WITH THE FORMULA RASTER CALCULATOR (SOURCE: AUTHOR ELABORATION)

CRITERIA	SUB-CRITERIA	WEIGHT	RASTER CALCULATOR FORMULA
ENVIRONMENT	Intra-Urban Spatial Distribution of Land Surface Temperatures (LST)	1	("LST raster@1" * 1)
SOCIAL	Density of population over 75 years old per NIL	0,4	*("Density raster@1" * 0.2) + ("Pop under 14 raster@1" * 0.4) + ("Pop over 75 raster@1" * 0.4)*
	Density of population under 14 years old per NIL	0,4	
	Population Density	0,2	
INFRASTRUCTURE	Proximity to Hospitals	0,27807	*("Prox hospitals raster@1" * 0.27807) + (" Prox Industrial raster@1" * 0.16336) + ("Prox landfill raster@1" * 0.16336) + ("Prox green areas raster@1" * 0.39521)*
	Proximity to landfill	0,16336	
	Proximity to Industrial, commercial, public, military and private units	0,16336	
	Proximity to Green Areas	0,39521	

Next, the criteria were weighed against each other:

1. *Scenario 1*: Assignment of homogeneous weight values

$$("Environment\ raster@1"\ *\ 0.33)\ +\ ("\ Social\ raster@1"\ *\ 0.33) + ("Infrastructures\ raster@1"\ *\ 0.33) \quad [7]$$

2. *Scenario 2*: Assignment of different weights

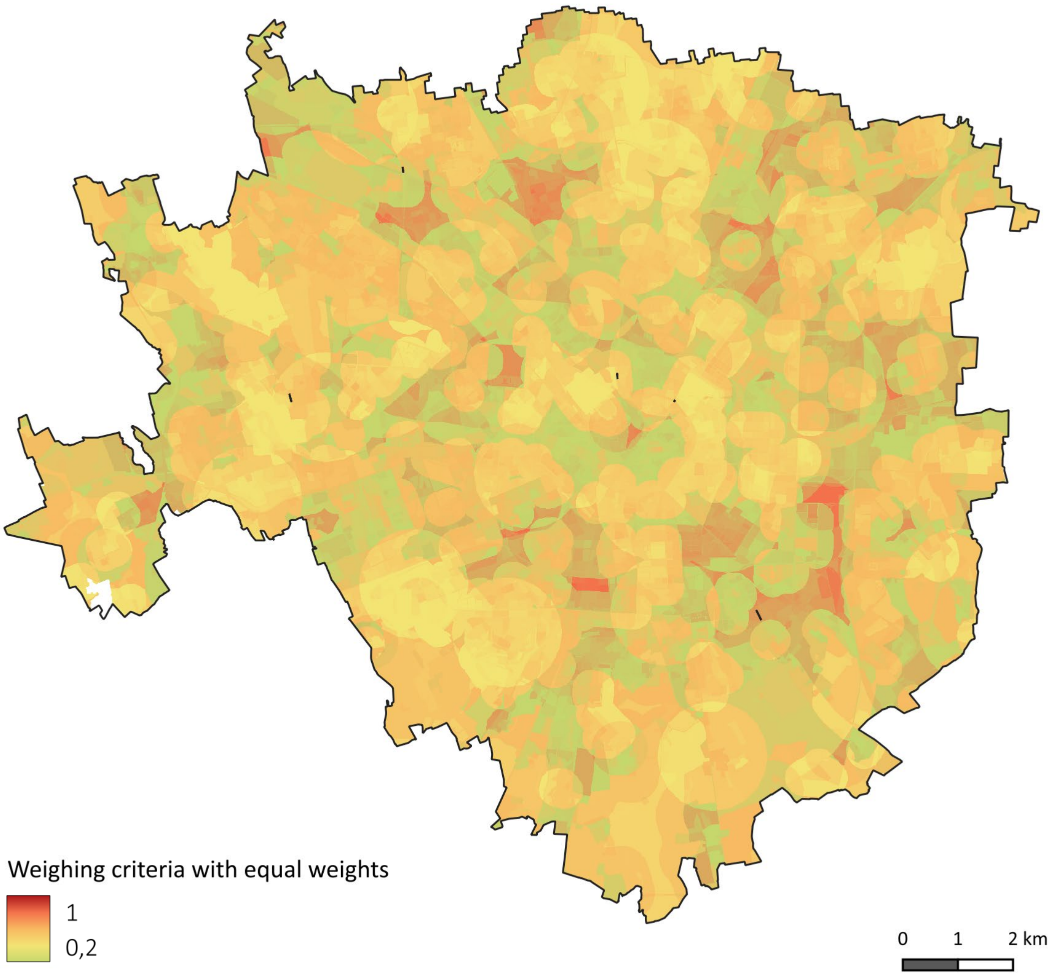
$$("Environment\ raster@1"\ *\ 0.81421)\ +\ (\text{Social raster@1} * \ 0.07180) + (“Infrastructures\ raster@1"\ *\ 0.11398) \quad [8]$$

7.6 ANALYSIS OF VULNERABILITY MAPS AND SELECTION OF BROWNFIELD SITES

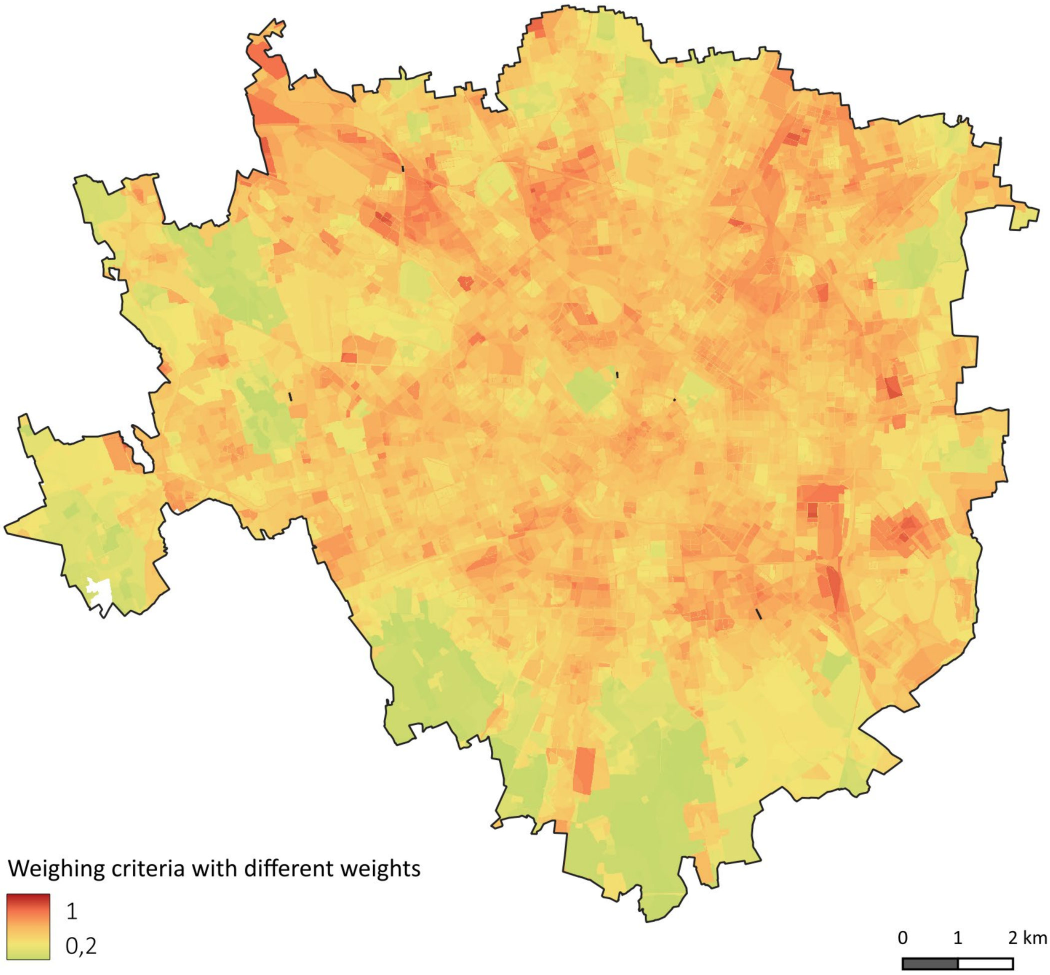
The result of the two scenarios that were obtained as a final result are different; in fact, the return of the weights shows two maps that, when compared, are different in terms of class diversification and homogeneity.

The first scenario (Map 10) was obtained by giving equal weight to the environmental, social and infrastructure criteria. It shows a very homogeneous distribution of vulnerable areas in the city of Milan. In this case, the impact of the buffer areas on the territory can be seen very clearly, given the importance given to the impact areas, which give a uniform representation of the vulnerability of the Milanese territory. Furthermore, the map shows that the distribution of the classes does not show a strong internal diversification, indicating a homogeneous situation without extreme vulnerability situations.

The second scenario, on the other hand, was achieved by assigning different weights to the different criteria analysed. In this scenario, the environmental criterion of LST (Land Surface Temperature) emerges as the criterion with the most significant weight. Even in this case, the impact of the buffers is still visible, but less significant than in the previous case. This implies that the map is more internally diversified, which allows a better classification of the vulnerable areas to be identified. This internal diversification allows a better and more direct identification of hotspots or particularly resilient areas. For this reason, it was decided to use the Scenario 2 map for the subsequent analysis, where different weightings were assigned to the criteria (Map 11).



MAP 10 – RESULT OF WEIGHING CRITERIA WITH EQUAL WEIGHTS (SOURCE: AUTHOR ELABORATION)



Map 11 - Result of Weighing criteria with different weights (Source: Author elaboration)

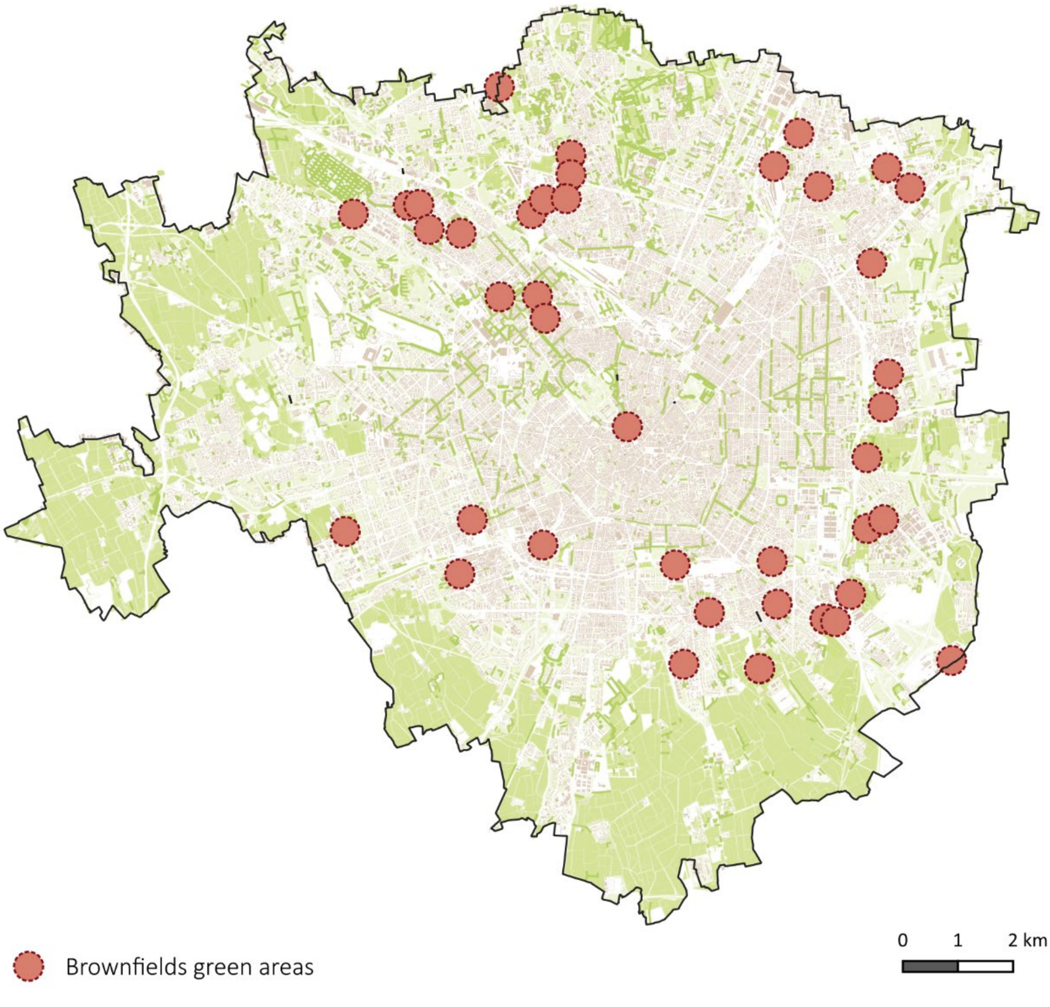
The final result of this overlapping process is the vulnerability map of the city of Milan, which serves as a fundamental tool for the accurate identification of the most vulnerable areas of Milan's urban fabric. As previously stated, the objective of this thesis project is to identify within the boundaries of Milan the disused green areas located in contexts that are highly vulnerable to UHI.

The next step was to identify brownfield sites in Milan. Two types of point data were used in this case (Table 26).

TABLE 26 - DESCRIPTION OF BROWNFIELDS AND DECAY AREAS IN MILAN (SOURCE: AUTHOR ELABORATION)

Name	Description	Typology	Year	Source
Buildings and areas in decay	Point identification of abandoned and degraded privately-owned buildings on the territory of Milan, which pose a danger to safety or public health and safety, or inconvenience to urban decorum and quality	Shp	2019	Geoportale di Milano (https://geoportale.comune.milano.it/sit/dettagli/?uuid=c_f205%3APUG_M201900001%3A20190529)
Brownfield sites	Areal identification of brownfield sites in the municipality of Milan	Shp	2022	Department of Architecture and Urban Studies (DASTU) Politecnico di Milano Mapping and Urban Data Lab

These data encompass both buildings, mixed areas and green spaces. As this thesis work will only consider disused green areas, we proceeded with a data cleansing process, removing all non-green data from the attributed tables (Map 12).



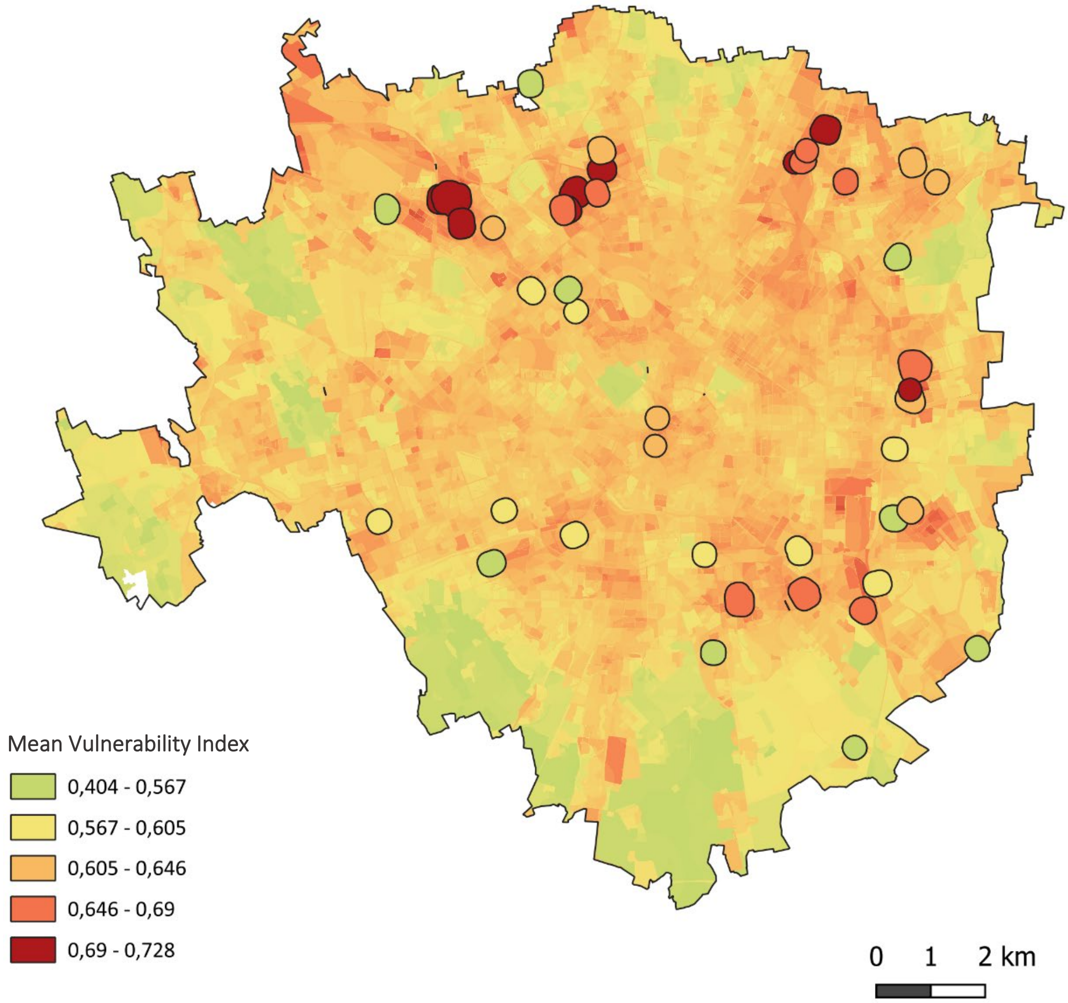
Map 12 – Localization of brownfields green areas in Milan (Source: Author Elaboration)

In order to achieve the objective of this work, the vulnerability map with different weightings (scenario 2) was superimposed on Map 12. In order to identify the most vulnerable disused green areas, a buffer of 200 metres was created and the average vulnerability value within the buffer was subsequently assessed using the 'zonal statistics' tool (Map 13).

Zonal statistics is a spatial analysis tool that allows the calculation of statistics on the values contained in the pixels of a raster image, but within areas defined by vector layers. Using this tool, it was therefore possible to quantify the vulnerability resulting from the Scenario 2 map (Map 11). This tool allowed us to have an objective basis for prioritising interventions to be carried out in degraded green areas, thanks to the creation of a cluster. This cluster allowed us to understand that where there is a higher concentration of red areas, the area is more vulnerable and therefore requires some improvement interventions within a shorter timeframe.

From this framework, it was possible to determine that the green area that most closely reflects the vulnerability criteria is the area of the CIMEP Area Lot 67 (Via Pannunzio/Oriani/Montefeltro/Trapani), located north-west of Milan. This choice is motivated by the fact that it is an area of adequate size, allowing a more complete evaluation of the benefits generated by ecosystem services (ES), an evaluation that would be less exhaustive on smaller areas.

The details of the selected area will be discussed in the next section.



MAP 13 – IDENTIFICATION OF AVERAGE VULNERABILITY VALUE WITHIN THE BUFFER OF 200M (SOURCE: AUTHOR ELABORATION)

8. Analysis of the area

The area selected for redevelopment using NBS solutions is the void created by the closure of the C.I.M.E.P. Comprensorio - Lot 67 (Consorzio Intercomunale Milanese Edilizia Popolare) in the City of Milan.

The area is located north-west of Milan in the NIL 71 area called Villapizzone - Cagnola - Boldinasco in the Varesina district at the intersection of Via Pannunzio, Via Oriani, Via Montefeltro and Via Trapani. It covers an area of 46794 square metres, currently in a state of decay and disuse, with open spaces and uncultivated green areas (Figure 30). The site is part of the C.I.M.E.P. consortium (Consorzio Edilizia Sociale Intercomunale Milano), responsible for the design and construction of low-cost and social housing in the Milan area (Martinelli, 2016).

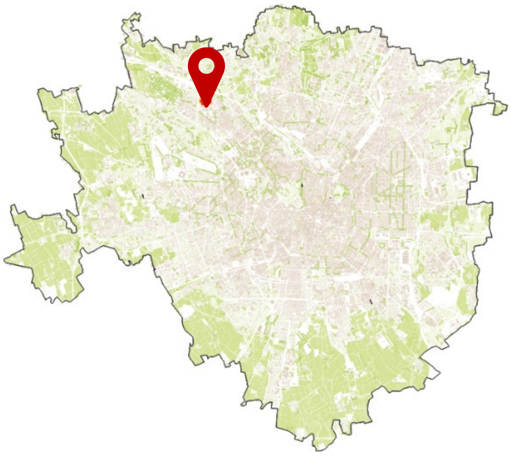


FIGURE 29 – LOCALIZATION AND CURRENT STATE OF THE AREA EX-COMPRENSORY CIMEP - LOT 67 (SOURCE: AUTHOR RE-ELABORATION FROM GOOGLE STREET MAP)

Subsequently, an analysis was conducted of the PGT in force with the objective of understanding the prescriptions for land uses applicable to the area in question and identifying any limitations that must be respected at the planning stage (Table 27).

TABLE 27 - PGT ANALYSIS (SOURCE: (MILANO 2030 - PGT IN FORCE | PGT, 2019)

Section	Table	Indication	Source
Plan Document (DdP)	D01 Draft Plan	Urban greenery: Newly planned urban greenery (indirect appurtenances): project greenery	https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=c68c444302684f27a9876a9908a6b316
	D02 Landscape Map	Recently formed urban fabric: Areas of recent Master Plans: Urban landscape prevalence area	https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=8adc4e7e7b674450b4b21b3e3fd25204
	D03 Outline of Municipal Ecological Network	Areas of Regeneration - Newly planned urban green (indirect appurtenances)	https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=12iD3XhCQfYF5sf6FaMrzrGFxzrKJ4u85L
Rules Plan (PdR)	R02 Town planning indications	Areas characterised by high levels of accessibility to public transport networks	https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=19be140b81aa4d5f8936d4b4540005f7
	R03 Morphological indications	TERRITORIAL ENDOWMENTS: Limit exemption territorial endowments (art. 11.3 Services Plan)	https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=829bf9940c1d4dcd88099a6acf3b91a8
	R10 Soil consumption map	SOIL COMPONENTS (LR 28-11-2014 n. 31): agricultural or natural soil	https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=57b8f90f9603404ebd53e2a06d6a7ae2
	Map of landscape sensitivity of places	Areas of enhancement: Area of prevalence of urban landscape and Landscape sensitivity: 2 - Landscape sensitivity low	https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=1a2c5ad07b6543cd84b7fda9bad0be37

The preceding analysis indicates that the forecasts for this area favour the incorporation of new green spaces into a recently established urban context with favourable accessibility. Furthermore, the area is distinguished by a relatively low landscape sensitivity, yet it is also classified as agricultural or natural land, which necessitates a meticulous design approach to its preservation and transformation.

From an environmental standpoint, the area is not distinguished by hydrogeological concerns, yet it is situated in an area that is highly susceptible to UHI. As illustrated in the subsequent image, the study area is positioned in an area with an average LST of 38.5 °C, in comparison to neighbouring areas that have average temperatures around 28 °C (Figure 30).

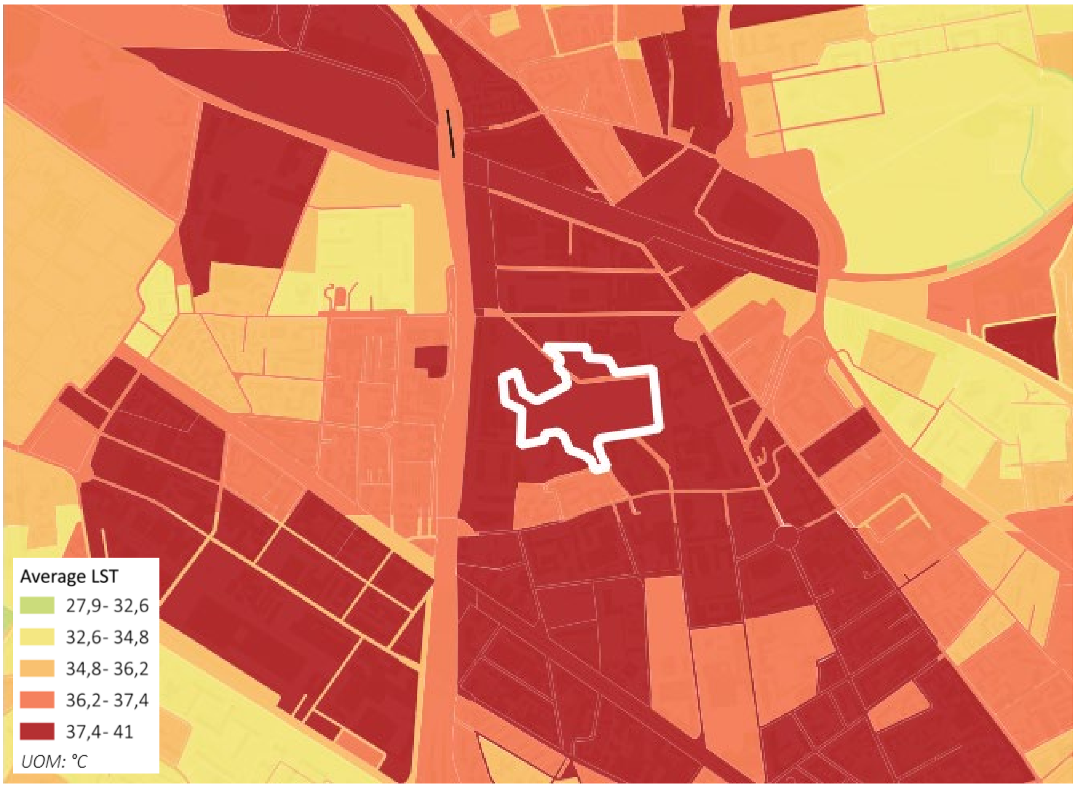


FIGURE 30 - LST ANALYSIS FOR EX- COMPRENSORY CIMEP - LOT 67 (SOURCE: AUTHOR ELABORATION)

The area is particularly vulnerable (Figure 31) because it contains large sealed infrastructures, such as the Ghisallo flyover to the left of the study area, which then leads to the Viale Certosa motorway junction, and the railway line to the north. The area surrounding the district also has small green areas that do not contribute to cooling the environment, some large commercial areas without vegetation and several industrial areas. As for the population density of the area, it is quite high, with a prevalence of elderly people over 75. All these factors contribute to making the area effectively critical.

FIGURE 31 – SCENARIO 2 ANALYSIS FOR EX- COMPRENSORY CIMEP - LOT 67 (SOURCE: AUTHOR ELABORATION)

The following section will present a discussion of potential solutions that could be applied to this context.

9. SELECTION OF THE REFORESTATION NBS SOLUTION FOR UHI MITIGATION

The potential of NBS to mitigate climate change has frequently been undervalued, resulting in its omission from urban regeneration strategies. Nevertheless, numerous instances have demonstrated the capacity of NBS to address the multifaceted challenges posed by climate change.

Following the analysis presented in Chapter 3, which discusses NBSs in terms of classification and benefits, and the planning and strategic framework of Milan outlined in Section 6.2, it was decided to implement urban reforestation using ForestaMI as a general reference project in order to bring all the scientific evidence to bear on our case study. As already mentioned, the ForestaMI project is an initiative aimed at reforesting the city of Milan, with the goal of planting approximately 3 million trees by 2030.

9.1. THE CONTRIBUTION OF URBAN FORESTS AND TREES TO THE AGENDA 2030

The urban reforestation solution contributes to the achievement of several SDGs, both directly and indirectly. While the strategy primarily focuses on SDGs 11, 13 and 15, its indirect benefits also extend to SDGs 1, 3, 6 and 7 (Borelli S., Forestry Officer, FAO, 2020). The following table provides a detailed analysis of these.

TABLE 28 - CONTRIBUTION OF FORESTATION TO ACHIEVE SDGS (SOURCE: AUTHOR ELABORATION)

SDG	SDG NAME	REFORESTATION ACTION	SOURCE
	No Poverty	Urban forests generate jobs, provide resources to entrepreneurs, reduce urban infrastructure costs, provide ecosystem services to all people, improve living environments and increase property values, ultimately supporting the region's green economies	[1]
	Good Health and Well-being	Forests and other green spaces in and around cities provide a good environment for a variety of outdoor recreational and relaxation activities, contributing to the prevention and treatment of non-communicable diseases and the maintenance of mental health. Urban forests help reduce the incidence of non-communicable diseases by filtering and removing pollutants and particles	[1]
	Clean Water and Sanitation	Urban forests play an important role in controlling the urban water cycle. It filters drinking water by reducing biological and chemical contaminants, reduces the risk of flooding and erosion and reduces water loss by reducing interstitial spaces through the cooling process	[1]
	Affordable and Clean energy	Sustainable management of urban forests can generate renewable energy for urban communities. This is an important situation for the billions of people living in cities and urban areas around the world. This is especially true in low-income countries where wood is the cheapest and sometimes the only source of electricity	[1]
	Sustainable Cities and Communities	Urban forests enhance inclusion, safety, resilience and sustainability by providing green spaces, improving air quality and enhancing the urban environment	[1]
	Climate Action	Trees and forests in surrounding cities can help combat climate change by reducing carbon and greenhouse gas emissions, as well as saving energy, reducing the heat island effect and reducing flooding	[1]
	Life on Land	Urban forests create and improve habitats, become a source of biodiversity, significantly improve soil quality and contribute to soil restoration	[1]

(Borelli S., Forestry Officer, FAO, 2020) [1]

9.2 THE CONTRIBUTION OF URBAN FORESTS TO QUALITY OF LIFE

As evidenced in Chapter 5, the challenges posed by climate change in Milan are manifold and necessitate prompt intervention to address them effectively. The advantages of urban forests are multifaceted, as their integration into urban environments offers a range of direct benefits, including enhanced urban temperatures and air quality, as well as the mitigation of hydrogeological disruptions and the enhancement of citizen well-being. In the following sections, we will examine these benefits in greater detail.

In terms of environmental benefits, as previously stated, urban forests play a pivotal role in reducing temperatures by enhancing thermal comfort through the provision of shade and the enhanced transpiration of soil. Furthermore, urban forests facilitate the regeneration of habitats for numerous plant and animal species, thereby enhancing biodiversity and the sustainability of urban ecosystems. Additionally, the sequestration and storage of CO_2 in the atmosphere, which is of particular benefit to the city of Milan, improves air quality by reducing atmospheric pollution. Finally, the presence of urban forests and, consequently, permeable soil is advantageous in the context of natural disasters, such as extreme precipitation events that may result in flooding (Baronchelli, 2022).

The existence of urban forests also bestows numerous benefits at the social level. Indeed, these green spaces provide an opportunity for people to spend time in the midst of nature, which in turn leads to improvements in social cohesion. It is also important to consider the psychological benefits of greenery, which can help to reduce stress, anxiety and depression, as well as support cognitive development in children. Furthermore, the environmental benefits of forests can also contribute to an improved quality of life for citizens (La Redazione, 2017).

Furthermore, urban forestation offers economic benefits, including the support of food production and the creation of a green economy. However, it should be noted that there are also economic returns generated by ecosystem services (ES). Additionally, the cooling of urban areas results in reduced cooling costs for the environments in which citizens reside. (Ministero della transizione ecologica, 2021).

FIGURE 32 – BENEFITS OF URBAN REFORESTATION (SOURCE: BARONCHELLI, 2022)

9.3 ASSESSING THE REDUCING EFFECT OF URBAN FORESTS ON UHI

In order to gain a deeper understanding of the actual cooling effects that urban forests can bring, a number of articles dealing with this topic have been subjected to analysis. The methodologies that have been employed, the actual temperature reduction according to the type of intervention and the area reduction will then be analysed. This analysis is preparatory to understanding the extent to which, in our case study, the implementation of urban forests can reduce the temperature in and around the area itself.

TABLE 29 - LITERATURE REVIEW ON CASE STUDIES TO ESTIMATE TEMPERATURE REDUCTION THROUGH REFORESTATION (SOURCE: AUTHOR ELABORATION)

Authors	Title	Location	Method	Temperature reduction	Estimation method	Area size	Benefits measured
Upmanis et al., 1998	The influence of green areas on nocturnal temperatures in a high latitude city	Göteborg, Sweden	Comparison of park-urban area temperatures	5.9°C (night)	Measurements with thermometers and mobile weather stations	156 hectare park	Reduced nocturnal temperatures, improved thermal comfort
Ca et al., 1998	Reductions in air conditioning energy caused by a nearby park	Tokyo, Japan	Measurements in park and surrounding area	1.5°C	Measurements with thermometers and anemometers	0.6-hectare park	Reduced air conditioning energy consumption by 15%
Chang et al., 2007	A preliminary study on the local cool-island intensity of Taipei city parks	Taipei, Taiwan	Comparison between 61 parks and urban areas	0.81°C (average)	Regression analysis on data from fixed weather stations	61 parks from 0.5 to 26 hectares	Improved local microclimate, enhanced urban livability
Potchter et al., 2006	Climatic behavior of various urban parks during hot and humid summer in the mediterranean city of Tel Aviv, Israel	Tel Aviv, Israel	Comparison between 3 parks and urban areas	1.5-3°C (day), 2-4°C (night)	Measurements with portable weather stations	3 parks from 0.2 to 3.7 hectares	Improved thermal comfort, reduced heat stress
Spronken-Smith & Oke, 1998	The thermal regime of urban parks in two cities with different summer climates	Sacramento and Vancouver	Comparison between 10 parks and urban areas	1-2°C (day), 2-5°C (night)	Measurements with thermometers and mobile weather stations	10 parks from 1 to 78 hectares	Reduced urban heat island effect, enhanced public health
Bowler et al., 2010	Urban greening to cool towns and cities: A systematic review of the empirical evidence	Various	Meta-analysis of 16 studies	0.94°C (day), 1.15°C (night)	Statistical meta-analysis	Various sizes	General cooling benefits, improved urban sustainability
Chen et al., 2014	Effect of urban green patterns on surface urban cool islands and its seasonal variations	Beijing, China	Correlation and regression analysis	Seasonal variations, up to 3.3°C	Measurements with Landsat images and GIS analysis	6450 hectares total (various green types)	Seasonal cooling effects, enhanced urban resilience
Lee et al., 2018	The Quantitative Analysis of Cooling Effect by Urban Forests in Summer	Seoul, South Korea	Comparison between urban forests and urban areas	1.9°C (forest), 3.4°C (urban)	Measurements with automatic weather stations and statistical analysis	Urban forests and urban areas	Cooling effects
Beretta, 2012	The effects of greenery on urban heat island mitigation	Milan, Italy	Comparison between urban forest and grass area	Temperature difference between 12 pm and 12 am post intervention of about 8°C	Analysis with software Envi Met	Reforestation and park in Piazza Leonardo da Vinci, Milan	Cooling effect from 12.00 pm and 12.00 am. Trees have been shown to mitigate UHI better than grass

Following a review of the literature, which demonstrates the positive effects of reforestation actions in Milan, it was decided to consider Beretta's (2012) text and the case of the city of Gothenburg, Sweden, for the case study of the former CIMEP district. While the latter is considered a useful case for understanding how greenery influences temperature in built-up areas, providing a basis for theoretical investigation, Beretta's thesis is important to consider as the analysis was carried out in the city of Milan, the same city as our case study, and considers a very similar area to this one under study.

9.3.1 THE CASE OF GÖTEBORG, SWEDEN

This study examined three distinct types of urban parks in the Swedish region of Gothenburg, with the following objectives, as outlined by Upmanis et al. (1998):

1. Determine whether the size of the park affects the temperature difference between the park and the city centre. The park affects the city centre degree of cooling in parks
2. Determine how sky occlusion in parks and the city centre affects the temperature (sky view factor).

The study was conducted in the city of Gothenburg, situated on the west coast of Sweden. The Gothenburg region has a population of approximately 700,000 and is situated in a region with a maritime climate. The river Göta forms a natural boundary between the eastern and western parts of the city. The eastern section is characterised by forested areas situated between 50 and 150 metres above sea level, while the western region, which encompasses the selected park, is predominantly flat, with elevations reaching 60 metres. The city centre boasts a multitude of green spaces, with three parks selected for this study: Slottsskogen, Vasaparken and Guvòparken (Upmanis et al., 1998).

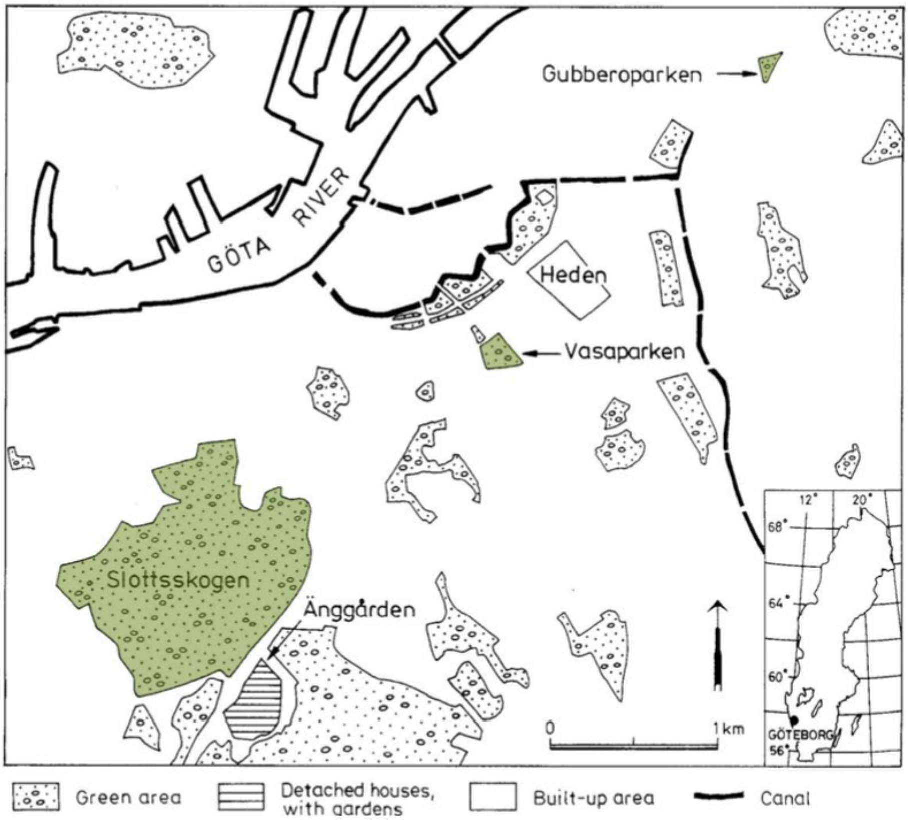


FIGURE 33 – CITY DIAGRAM OF GÖTEBORG IN SWEDEN AND THE THREE PARK AREAS UNDER STUDY (SOURCE: UPMANIS ET AL., 1998)

The initial analysis site, Gubbeparken, is a modest urban park occupying approximately 2.4 hectares and situated amidst a residential area characterised by six-storey buildings. The SVF (Sky View Factor) (which includes the spatial angle of the view of the sky measured from the urban space) is expressed as a numerical range from 0, which indicates a completely blocked view of the sky, to 1, which indicates a completely blocked view of the sky, as measured in the middle of the streets around the park. The SVF value for this particular site is 0.61. The eastern side is covered by three-storey buildings and green courtyards, with an SVF of 0.44. The western side is similarly developed, with an SVF of 0.44. The northern side is covered by three-storey buildings and green courtyards, with an SVF of 0.5. The southern side is a sand-covered playground, with some asphalted walkways and an SVF of 0.8 (Upmanis et al., 1998).

The second study was conducted at the Vasaparken site, which is situated in the city centre. The park covers an area of approximately 3.6 hectares and exhibits a distinctive topography, with an internal height differential of 13 metres. The buildings situated on the east and west sides of the park are approximately 20 metres in height, the road is 15 metres wide and the SVF (as measured at the centre of the road) is approximately 0.4-0.5. The park is characterised by open green grass, trees and bushes. It contains a university building with parking spaces in front of it and paved walkways (Upmanis et al., 1998).

Slottsskogen is the largest park in Gothenburg, covering an area of approximately 156 hectares. The park comprises a variety of vegetative elements, including wooded hills, meadows, sparse trees and shrubs. In addition, the park comprises various water bodies, paved roads and paths, buildings and areas covered with sand. The park exhibits a height differential of approximately 50 metres. The edifices situated on the northern periphery attain a height of approximately 20 metres, and the width of the thoroughfare is consistent, with an SVF of 0.4-0.7. The park's western and southern boundaries feature numerous small green areas and suburbs, with an SVF of approximately 0.75. The eastern side of the park is traversed by a transport road leading into the city, and it is also bordered by a small village called Anggarden, comprising independent houses, streets, and gardens. This village is encircled to the east by 584 hectares of forest (Upmanis et al., 1998).

In order to achieve the study's objectives, two distinct measurement techniques were employed across the three study areas. The first involved the use of mobile phones at motorway junctions to assess the horizontal temperatures within and outside the park. The second methodology entailed the utilisation of measurements at permanent monitoring stations. The study concentrated on the temperature differences between night and day in each park. Data were collected on clear, calm nights and clear days between January 1994 and September 1995. The rationale behind employing both mobile and fixed survey methods is to examine temperature patterns at varying spatial and temporal scales. Fixed stations provide continuous measurements, yielding an average temperature over a specified period, whereas mobile measurements yield an average temperature over a given distance. Through data analysis, it was determined that the largest ΔT u-p (temperature difference between urban areas and parks) occurs most frequently two to three hours after sunset. Consequently, the study focused on this specific time of night.

TABLE 30 - RESULTS OF MEASUREMENTS AT SLOTTSSKOGEN AND VASAPARKEN (SOURCE: UPMANIS ET AL., 1998)

Park (area)	Time after sunset (h)	Maximum ΔT_{u-p}	ΔT_{1-10}	Extension from park border (m)
Slottsskogen (156 ha)	0	5	2.2	175
	3.5	4	2.6	775
Vasaparken (3.6 ha)	0	0.8	—	20
	3.5	0.9	—	30

It is crucial to integrate this study into our investigation, as it demonstrates that the maximum temperature discrepancies are disparate across the three parks under examination. Specifically, the largest park, Slottsskogen, exhibits a maximum temperature differential of 5.9 °C, while the second largest, Vasaparken, displays a maximum temperature differential of 2 °C. In contrast, the smallest park, Gusseroparken, exhibits a maximum temperature differential of 1.7 °C. It can therefore be concluded that the size of the park is a significant factor in determining the magnitude of the temperature difference. In the largest park, Slottsskogen, and the smallest park, Guvòparken, the temperature difference from the city limits gradually increases as one reaches the centre of the park. However, in Vasaparken, a medium-sized park, the lowest temperatures due to changes in altitude occur in one of the lower corners of the park, rather than in the centre as before.

9.3.2 COOLING URBAN FORESTS: SIZE PROPAGATION

This study, conducted in Sweden, demonstrates the significant impact of vegetation implementation in urban areas on heat island mitigation. Building upon this research, Beretta (2012) employed Envi-met software to investigate the extent to which green areas facilitate cooling and whether the size of these areas influences the enhanced propagation of this effect. This paper presents two models, which are used to compare a green lawn solution and a forestation solution. Given that our project study views urban reforestation as the solution, only the effects of this will be assessed in the study conducted. (Beretta, 2012).

In this study, a graph was constructed for two time points (12:00 and 00:00) in which the size of the green area (in hectares) was used as the dependent variable, with temperature difference calculated from two measurements taken at the exact point: the first in the centre of an area, the second at the boundary of the area. The findings indicated that the cooling benefits of vegetation are distributed across the entire width of the 'park', although this phenomenon stabilises when the extent of green areas increases. Given that the area of the former CIMEP site is 4.7 hectares in size, the reforestation section of 5 hectares was considered in the study conducted by Beretta (Figure 34).

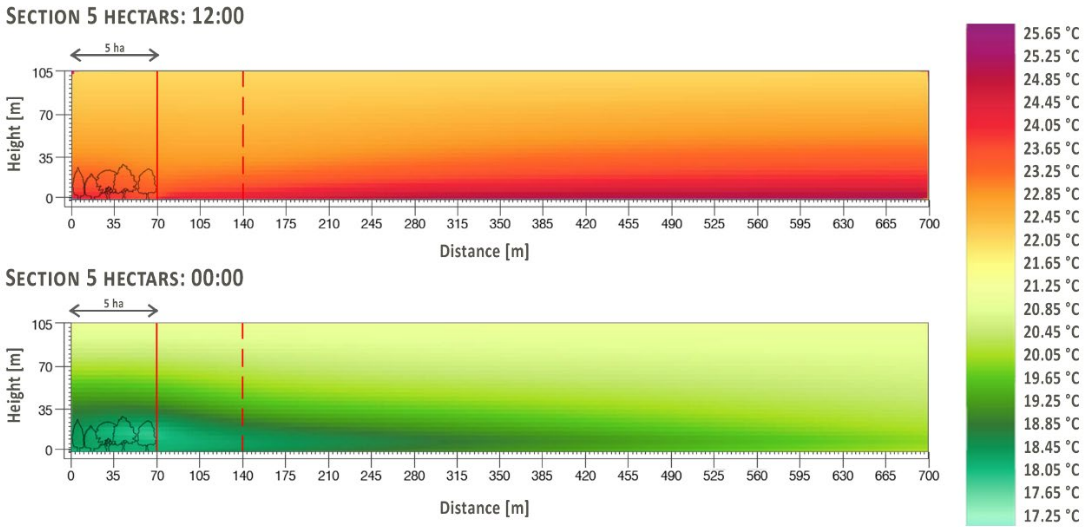


FIGURE 34 - TEMPERATURE POTENTIAL COMPARISON 12:00 AND 00:00 (SOURCE: AUTHOR RE-ELABORATION FROM BERETTA, 2012)

As illustrated in the above image, the inclusion of trees reaching approximately 20 metres in height has resulted in a notable reduction in temperature in the surrounding area, by several degrees. This is achieved as a result of the formation of shadows cast by the trees beneath their canopies, which partially block solar radiation, preventing it from reaching the ground in its entirety and thus preventing complete absorption by the soil, which remains cool. Additionally, the temperature is lower at night due to the ground's limited capacity to store heat during the day and subsequent release, creating a cooler zone. At night, the tree tops impede the upward spread of cool breezes, extending the effect beyond the green space. In both cases, the temperature will increase with distance from the wooded areas and decrease with proximity.

The simulations demonstrate that the extent of tree cover is a key factor in reducing heat islands. The depth of cold wind penetration correlates with the width of the vegetated area. Additionally, the ratio of forest area to temperature difference increases with increasing green areas, but this phenomenon tends to reach a point of stability. This indicates that reducing the urban heat island effect does not necessitate extensive green areas, but that positive outcomes can be achieved with smaller green areas at an appropriate distance.

10. SELECTION OF SUITABLE VEGETATION

The area of the former CIMEP site is currently in a state of neglect, with the vegetation remaining uncultivated and devoid of shrubs. The objective is to incorporate a wooded area within this space by selecting a variety of tree species to create a distinct group of trees. A number of fundamental criteria were considered when selecting the plants. Firstly, the plants must be able to provide ecosystem services to the surrounding environment and be able to withstand extreme climatic conditions, such as drought. Secondly, trees with limited disadvantages, such as high pollen production, fruit production or toxicity, were considered.

Following a comprehensive examination of Milan's shrub species and a subsequent selection based on the aforementioned criteria, the following percentages were identified. These percentages are determined by the inherent characteristics of the trees in question.

TABLE 31 - VEGETATION SELECTION AND PERCENTAGE OF PRESENCE IN PROJECT (SOURCE: AUTHOR RE-ELABORATION FROM FORESTAMI, 2020)

Scientific Name	Common name	% indicative
Quercus robur	English oak	30%
Carpinus betulus	European hornbeam	20%
Fraxinus excelsior	European ash	25%
Acer campestre	Field maple	15%
Populus Nigra	Black poplar	10%

The following pages will present the technical details of each tree species, with information sourced from the 'Trees for the City' catalogue produced by the Emilia Romagna region (Regione Emilia Romagna, 2021).

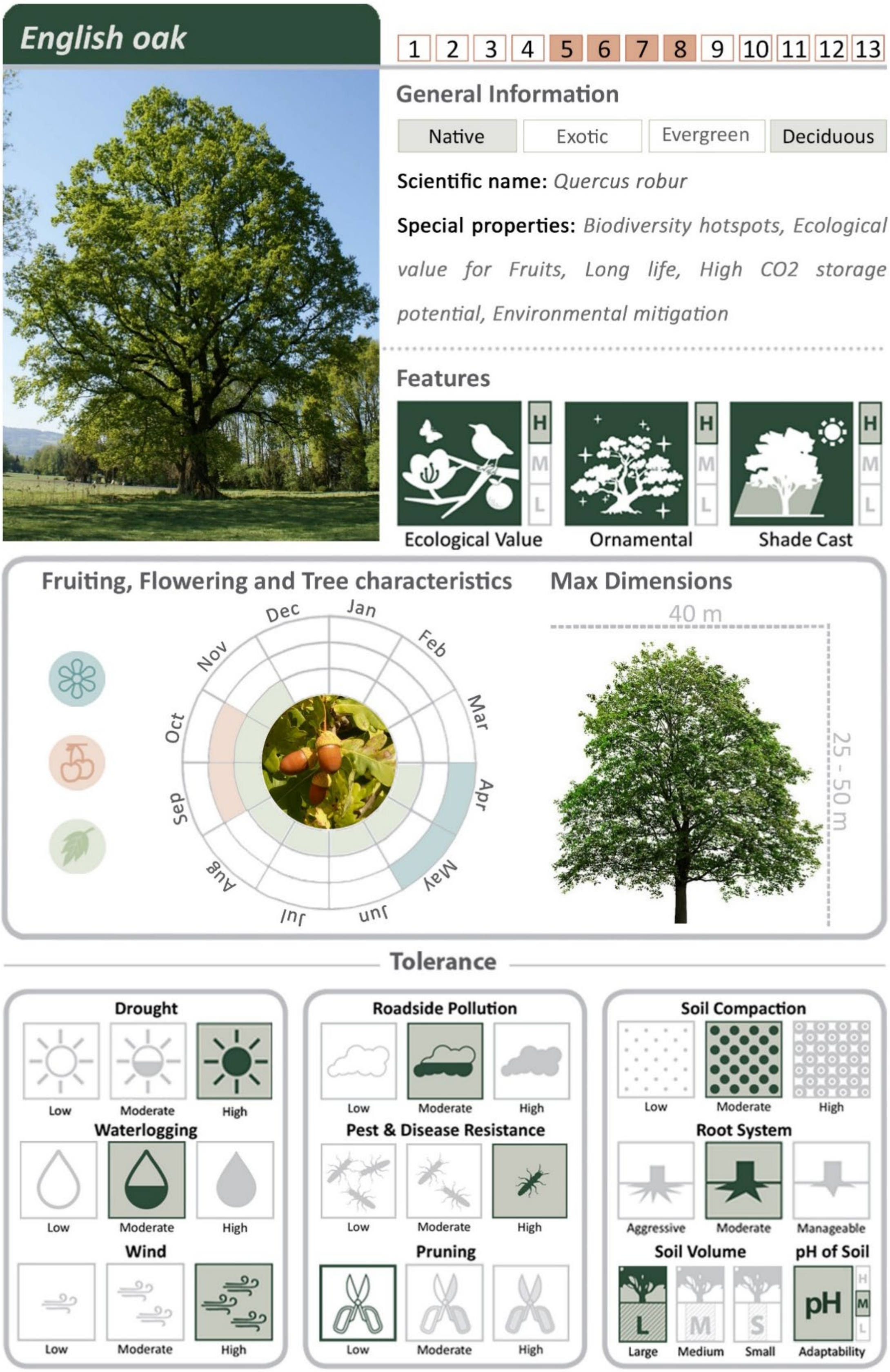


FIGURE 35 - QUERCUS ROBUR DATASHEET (SOURCE: AUTHOR ELABORATION)

European hornbeam

1 2 3 4 5 6 7 8 9 10 11 12 13

General Information

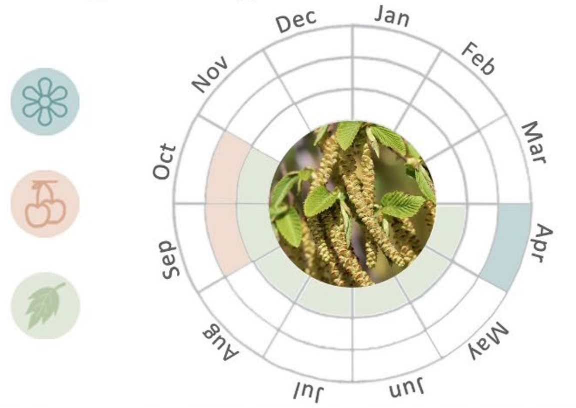
Native | Exotic | Evergreen | Deciduous

Scientific name: *Carpinus betulus*

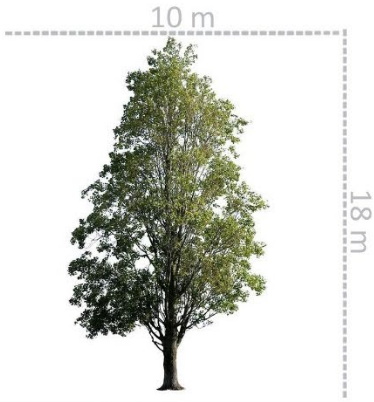
Special properties: *Soil improver, Remarkable suckering capacity, Wildlife attraction, Soil stabilisation*

Features

Fruiting, Flowering and Tree characteristics



Max Dimensions



Tolerance

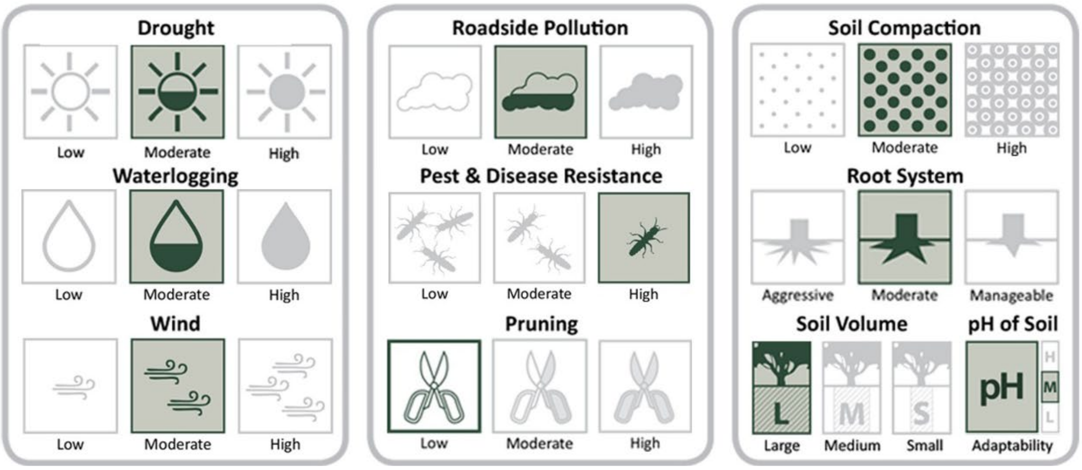


FIGURE 36 - CARPINUS BETULUS DATASHEET (SOURCE: AUTHOR ELABORATION)

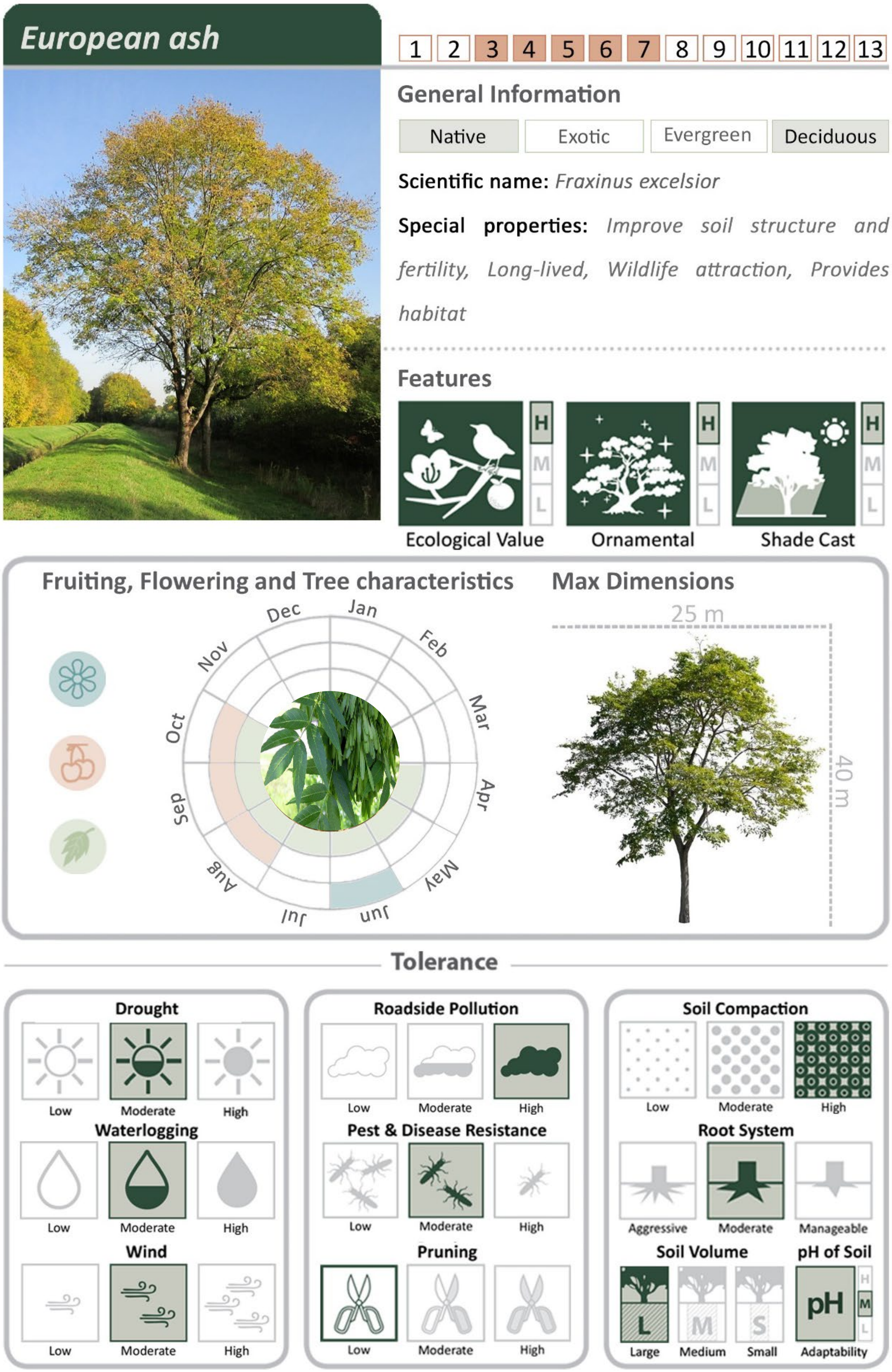


FIGURE 37 - FRAXINUS EXCELSIOR DATASHEET (SOURCE: AUTHOR ELABORATION)

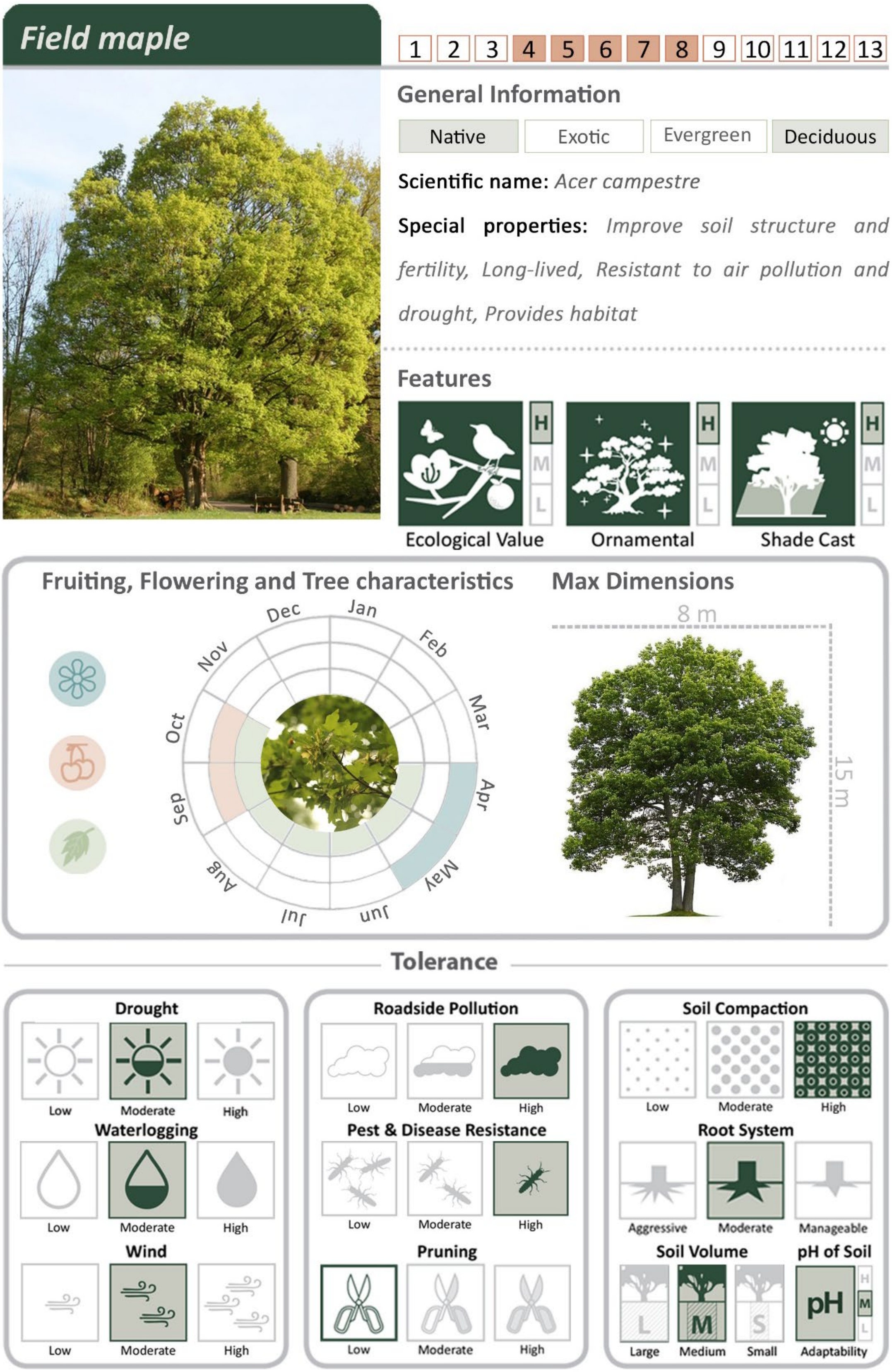


FIGURE 38 - ACER CAMPESTRE DATASHEET (SOURCE: AUTHOR ELABORATION)

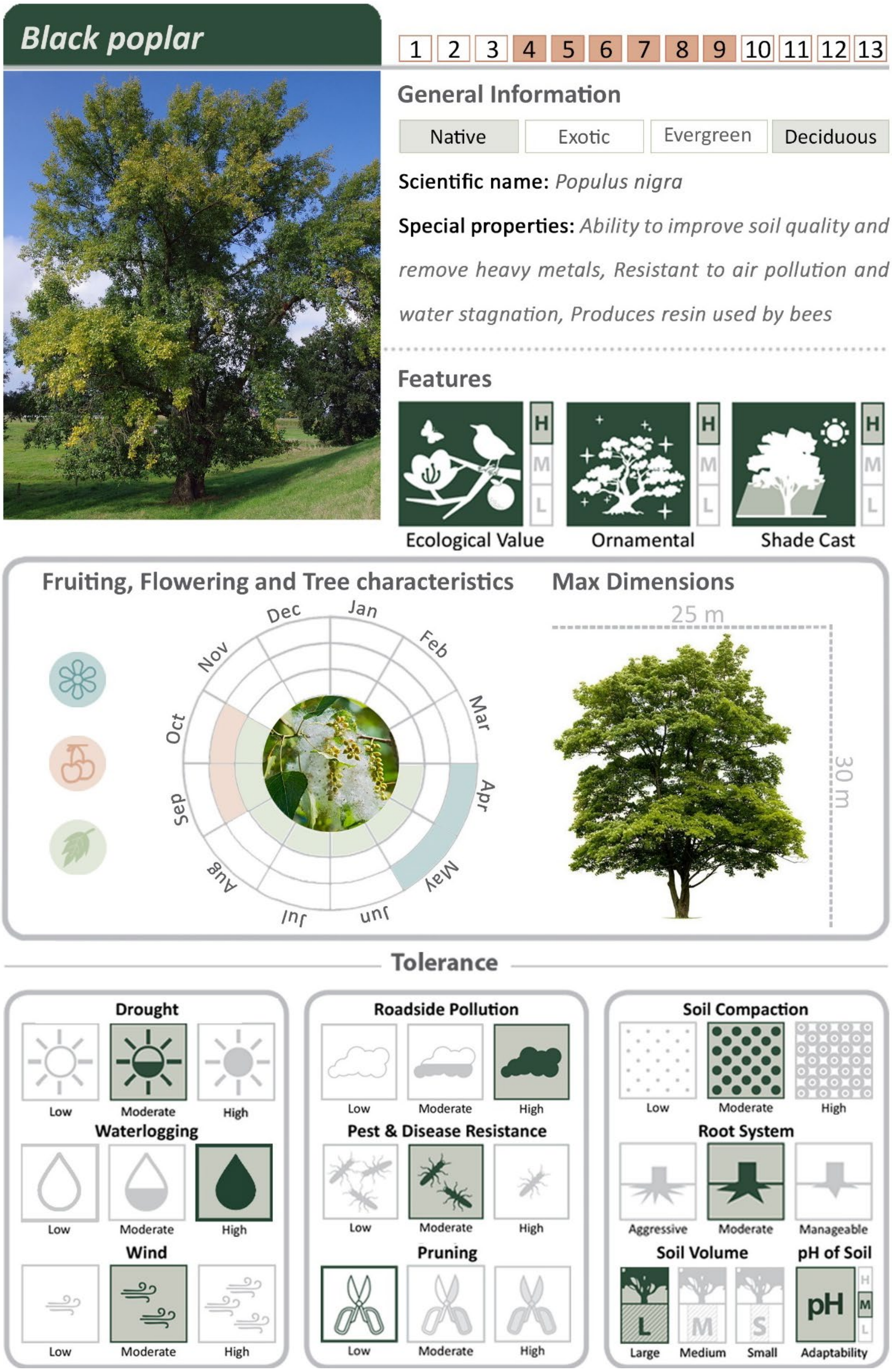


FIGURE 39 - POPULUS NIGRA DATASHEET (SOURCE: AUTHOR ELABORATION)

In order to optimise space in the area and ensure the good health and growth of the trees, planting was planned by creating a hexagonal planting scheme. The grid ensures a distance between the trees of 1.5 metres so that the trees can grow properly. An effective planting system must be easy to implement, have a balanced spatial distribution appropriate to the chosen species and also facilitate future maintenance (Frattegiani, 2003). In this case, the square was chosen because it is better suited to accommodate different tree species.

FIGURE 40 - TREE PLANTING SCHEME (SOURCE: AUTHOR ELABORATION)

11. ANALYSIS OF THE COST OF THE INTERVENTION

To estimate the amount of tree species to be included in the area, several case studies were taken as examples, including the ForestaMI project. From this project analysis, it was decided to include approximately 2,000 trees per hectare of area. The area of the former CIMEP site has a surface area of 46,794 square metres, or 4.68 hectares. Based on this surface area and the previously indicated percentages of trees (Table 32), the following sizing was carried out.

TABLE 32 - DIMENSIONING NUMBER OF TREES IN THE PROJECT (SOURCE: AUTHOR ELABORATION)

Overall area (ha)	N° trees per ha	Total number of trees
4,68	2000	9360

Scientific Tree Name	% indicative	Total trees
Quercus robur	30%	2808
Carpinus betulus	20%	1872
Fraxinus excelsior	25%	2340
Acer campestre	15%	1404
Populus Nigra	10%	936

In order to verify the economic implications of the realisation of the urban forest in the study area, a cost item analysis was carried out using the price list of the Lombardy Region (2024). The first phase of the implementation of the forest involves the demolition of a number of abandoned industrial buildings in the study area. This will be followed by the reclamation of the area, with a preliminary excavation of the ground to a depth of 0.15 m (Cormidi, 2023). During this phase, the existing vegetation, consisting of grass, shrubs and other plant species, will be removed and subsequently transported to a storage or recycling facility. The planting of trees will then begin. This phase involves preparing the holes in which the trees will be planted and planting the trees themselves. To facilitate irrigation, it is planned to insert a drainage pipe for each tree. Finally, to support the growth of the trees themselves, especially in the event of wind, it is planned to install two poles and tie wires for each tree.

The following table gives a detailed breakdown of each cost item, classified according to the unique identification code of each item provided by the Prezzario della Regione Lombardia (2024).

TABLE 33 - COST ANALYSIS FOR URBAN REFORESTATION (SOURCE: AUTHOR ELABORATION)

Code	Description	U.M.	Price [€]	Quantity	Area cost [€]	Note	Source
LOM241.OC.EEA.c01.C0000.Za000.0000	Building, industrial, of general material. WORK: Total/part demolition. INCLUDING: loading; transport to authorised landfill site. TECHNICAL SPECIFICATIONS: also unsafe, by mechanical means.	m³	12,62	6570,21	85.187,65	Total Area of abandoned buildings = 2250,07 m²	[1]
1C.02.050.0020	Excavation performed with mechanical means in soil of any kind, including uprooting grass, shrubs, small trees (easily eliminated with normal construction equipment), demolition and removal of fences and the like:					Generally, excavation involves a depth of about 15 cm (Cormidi, 2023). Volume calculation: 46794*0,15= 7019,1 m³	[1]
1C.02.050.0020.b	- with loading and transport of soil to storage, recovery	m³	19,01	7019,1	133.433,09		[1]
1U.06.200.0100	Planting of trees in rows or groups, with digging, planting, backfilling, formation of turnpikes, supply and distribution of fertilisers or soil conditioners 50 l/plant, watering with 150-200 l of water;						[1]
1U.06.200.0100.b	- circumference 15 to 20 cm - height 301 to 350 cm	cad.	30,87	9360	288943,2	See table 27	[1]
1U.06.210.0070	Broad-leaved plants with root ball of the species in variety: Acer, Betula, Prunus, Quercus, with guarantee of use, ready for use, disease-free, well formed, without stumps, trunk lesions and soil with well-developed root system. Planted in rows or groups, with digging, planting, backfilling, turning, supply and distribution of fertiliser or soil conditioner 50 l/plant, irrigation with 150-200 l water. Circumference:						[1]
1U.06.210.0070.e	- 17 ÷ 18 cm	cad.	184,20	9360	1724112	See table 27	[1]
1U.06.200.0110.a	- supply and installation of drainage pipe Ø 125 mm for watering, incl. T-piece, elbow, end cap	cad.	28,07	9360	262735,2	See table 27	[1]
1U.06.200.0110.c	- supply and installation of two autoclave-treated anti-cerspective poles to support the plants, including cutting, supplying the ties and tying them to the plant	cad.	20,38	9360	190756,8	See table 27	[1]
				TOTAL COST	**2.685.168 €**		

[1] Regional Price List of Public Works, Lombardy Region, 2024

In addition to construction costs, it is also necessary to consider maintenance costs for at least the next 20 years. 20 years have been estimated as the life cycle of the NBS, as this is considered to be the maturity period of the NBS in order to assess its long-term impact. The 2024 price list of the Lombardy Region was used as a reference for the cost items. Ordinary annual plant maintenance consists mainly of pruning, fertilisation, hoeing and weeding, pesticide treatments, irrigation, etc. The following table shows the cost items.

TABLE 34 - MAINTENANCE COST ANALYSIS FOR URBAN REFORESTATION (SOURCE: AUTHOR ELABORATION)

Code	Description	U.M.	Cost [€]	Quantity	Area cost [€]	Note	Source
1U.06.570.0010	Annual maintenance of trees with support poles, up to five years after installation. Including: opening of turnstiles and subsequent closure, hoeing and weeding of the turnstile, fertilisation, suckering of the collar and trunk, cutting to correct crown development and possible replacement or re-binding of the supporting poles.	cad.	24,04	9360	225.014,40	See table 27	[1]
1U.06.570.0020	Fertilisation and/or disinfection of the soil around plants, with soil perforation for the formation of injection channels with fertiliser and/or plant protection product infiltration; including all necessary materials.	m²	3,44	46794	160.971,36	\	[1]
1U.06.570.0030	Pest control treatment and/or fertilisation, carried out by injection of liquid insecticide, fungicide or fertiliser into the trunk of the trees; per injection; including all necessary materials.	cad.	9,43	9360	88.264,80	See table 27	[1]
1U.06.570.0150	Watering of trees, in groups or in rows; carried out with a tanker truck equipped for dispensing, with water injected into the draining pipe placed in a ring around the root system or in the plant turner at a rate of 150 ÷ 200 litres per plant with watering ring	cad.	10,27	9360	96.127,20	See table 27	[1]
1U.06.580.0030	1U.06.580.0030 Dry-removal pruning on trees in unobstructed locations; dry-removal pruning aims to 'clean' the tree of all its parts that are no longer viable. The intervention must be carried out strictly and completely, avoiding accidental damage to green parts. Under no circumstances must stumps be left behind. In the specific case of conifers, the intervention must be conducted with extra care so as not to cause irreparable damage to the tree's vegetation. In addition, cuts larger than Ø 5 cm must be treated with fungicides.						[1]
1U.06.580.0030.a	- for plants from 11 ÷ 20 m	cad.	102,48	9360	959.212,80	See table 27	[1]
				TOTAL COST PER YEAR	1.529.590,56 €		

[1] Regional Price List of Public Works, Lombardy Region, 2024

12. COST-BENEFIT ANALYSIS (CBA)

The aim of this work is not only to estimate how much urban heat islands can actually be reduced locally, but also to estimate the cost of reforestation per se and the economic return from its implementation through the ecosystem services provided. For the economic quantification of the ecosystem services provided by the reforested area, reference is made to the article "Green Ecosystem Services: TEV as a decision-making tool for urban planning" (Neonato F. et al., 2019). The aim of this article was to assign an economic value to ecosystem services in order to help decision-makers evaluate projects. Different types of green spaces were valued:

1. Agricultural parks and peri-urban agricultural areas
2. Large peri-urban parks
3. Historic parks/gardens
4. Memorial greens (cemeteries, memory gardens, etc.)
5. Neighbourhood green spaces (urban gardens, school gardens, playgrounds, green sports facilities, community gardens, etc.)
6. Therapeutic gardens (for well-being in hospitals, retirement homes, assisted living)
7. Green roofs, green walls, green balconies
8. Green and blue eco-structures (tree-lined avenues, hedges, roundabouts, green traffic islands, railway embankments, river banks, etc.)
9. Technological greenery (bioswales, rain gardens, tree boxes, wetlands, etc.).

Next, four types of ecosystem services were considered (Neonato F. et al., 2019):

1. Supporting ES, i.e. all those services that are necessary for the proper functioning of ecosystems. These can be environmental services, such as the reduction of heat islands or air pollution, or ecological services, i.e. those aimed at preserving and protecting biodiversity.
2. Provisioning ES, i.e. those services that provide energy, food or raw materials.
3. Regulatory ES, i.e. those aimed at regulating physical, ecological or biological processes, such as reducing the consequences of catastrophic events.
4. Socio-cultural ES, i.e. all those intangible benefits that enrich man/citizen at the level of culture, psycho-physical well-being, such as improving landscape quality, attracting tourism, etc.

The value of ES was estimated through the inclusion of 100 trees per hectare, with an economic return of a maximum of 8.2 €/sqm/year (Neonato F. et al., 2019). Given that 2000 trees per hectare are planned in our area, the economic figure provided required further elaboration to ensure its suitability for our context.

The initial calculation entailed determining the number of trees per square metre in the event of both 100 trees/ha and 2000 trees/ha scenarios:

$$Trees\ per\ square\ metre = \frac{100\ trees}{10.000\ m^2} = 0{,}01\ trees/m^2 \qquad [9]$$

$$Trees\ per\ square\ metre = \frac{2000\ trees}{10.000\ m^2} = 0,2\ trees/m^2 \qquad [9]$$

The second step was to proportion the values provided by the ES; in fact, in the case of 100 trees/ha, 8.2€/sqm/year was estimated, in the case of 2000 trees/ha, the value would vary as follows:

$$New\ revenue = \frac{8,2\frac{€}{m^2}\ per\ year}{0,01\ tree/m^2} * 0,2\frac{tree}{m^2} = \frac{164\ €}{m^2} per\ year \qquad [10]$$

Therefore, if 0.01 trees per square metre yields 8.2 €/sqm/year, 0.2 trees per square metre will yield 164 €/sqm/year. However, as a precautionary measure, the price derived has been reduced by approximately half, i.e. by 80 €/sqm/year (Neonato F. et al., 2019), also because the highest value considered in the literature is approximately this figure.

Once these fundamental values were established, CBA was initiated with the objective of assessing the feasibility of the project in light of the projected construction costs, maintenance costs and revenues from SEs over a 20-year period.

Cost Benefit Analysis (CBA), explained in more detail in section 4.3.1.1, is currently used to estimate the market value of an asset by simulating its transformation over its life cycle. In fact, this analysis represents monetary flows as the difference in each time period between sales revenues and realisation costs. This difference in values is called NPV (Net Present Value). If this value is positive, it indicates that the project is feasible. Conversely, if it is negative, it means that the investment is not economically viable (Roscelli, 2014).

It is evident that our case study does not concern the sale of tangible goods; therefore, the SE calculated above will be employed as revenue. The estimated life cycle for reforestation was determined to be 20 years (Hilbert et al., 2019). The CBA table is provided below for reference (Table 35).

TABLE 35 - COST-BENEFIT ANALYSIS (CBA) OF URBAN REFORESTATION (SOURCE: AUTHOR ELABORATION)

YEAR	COSTS	REVENUES	NET CASH FLOWS
1	2.685.167,94 €	0 €	- 2.685.167,94 €
2	1.529.590,56 €	959.277,00 €	-570.313,56 €
3	1.529.590,56 €	1.918.554,00 €	388.963,44 €
4	1.529.590,56 €	2.877.831,00 €	1.348.240,44 €
5	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
6	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
7	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
8	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
9	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
10	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
11	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
12	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
13	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
14	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
15	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
16	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
17	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
18	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
19	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
20	1.529.590,56 €	3.837.108,00 €	2.307.517,44 €
NPV	21.956.022 €		
DISCOUNT RATE	4%	*(Reference and Discount Rates, 2024)*	
IRR	37%		

When considering the economic return in the years following the implementation of the urban forest, 25% of the total return was considered in the first year, 50% in the second year and 75% in the third year. This approach is justified by the fact that newly planted trees need a few years to adapt and produce sufficient ES.

The above table shows a positive Net Present Value (NPV) (+4%) and an IRR of 37%, confirming that despite the construction and maintenance costs of the site, the economic return generated by the ecosystem services is fully compensated. In terms of proportionality, this type of project provides the majority of socio-cultural ecosystem services, followed by regulation, support and supply (Figure 41). Consequently, this type of intervention will not only improve urban heat islands and thus the quality of life of citizens, but it will also provide a valuable service to the city of Milan and its residents.

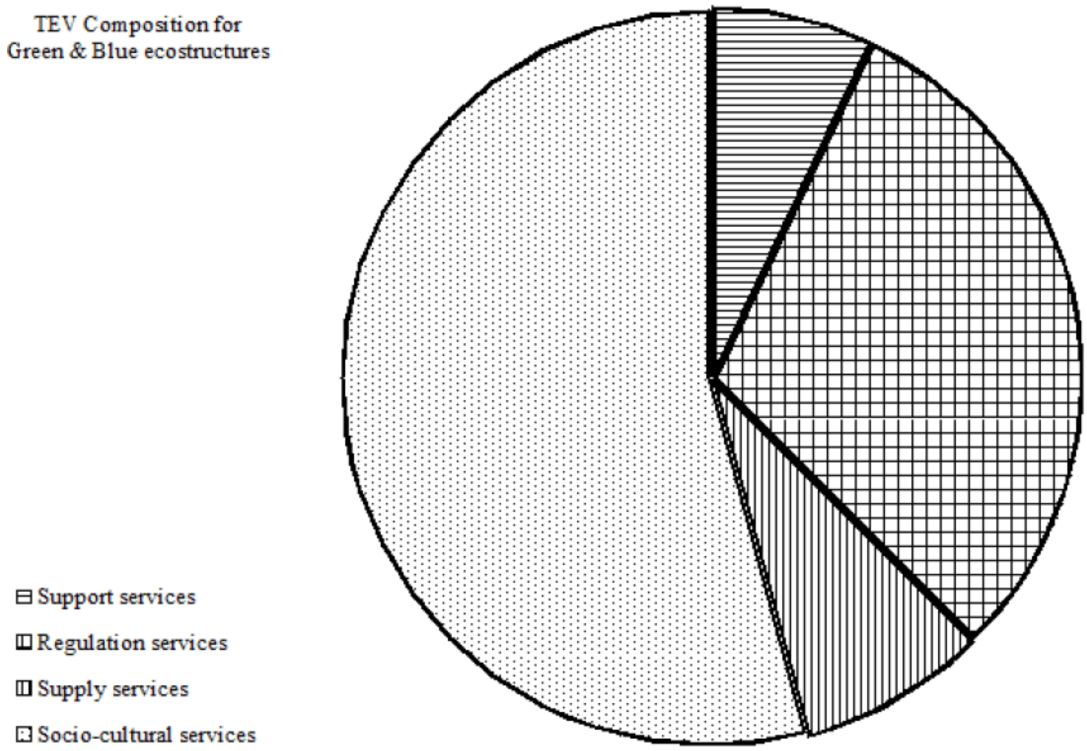


FIGURE 41 - TEV COMPOSITION FOR REFORESTATION IMPLEMENTATION (SOURCE: NEONATO ET AL., 2019)

It can thus be posited that the implementation of urban greenery in the form of forests is an action that bestows a plethora of benefits, both in environmental, social, and economic terms, through the provision of SE.

The following page shows an indicative masterplan of how the area of the former ex-CIMEP compound will look after urban reforestation. As can be seen from the masterplan, in addition to the actual reduction in temperatures resulting from the UHI phenomenon, it will also benefit the surrounding areas in terms of viewpoints but also green spaces in which to spend time for socialising and pastimes.

Figure 42 - Masterplan reforestation ex area CIMEP (Source: Author elaboration)

CONCLUSION

The objective of this thesis was to evaluate the effectiveness of nature-based solutions (NBS) in mitigating the vulnerability of urban areas to urban heat island (UHI) effects in the city of Milan. More specifically, the methodology focused on the redevelopment of abandoned green areas on site, also proposing a model to quantify the environmental and social benefits of the applied intervention. To this end, a vulnerability map was constructed, through the application of Spatial Multicriteria Analysis (SMCA), with the aim of identifying the most critical areas with respect to environmental, social and infrastructural factors. This elaboration, therefore, makes it possible to create a scale of priorities for intervention in the city of Milan, showing which areas are more urgent as opposed to less urgent on which to intervene. It is important to emphasise that this assessment model is not only applicable in the Milanese context but can be replicated in other urban contexts through research and analysis of indicators specific to the place of application.

During the creation of the vulnerability map in the city of Milan, some challenges emerged related to the availability of adequate indicators, crucial for the determination of vulnerable areas. In fact, in order to construct the vulnerability index, it was necessary to select an accurate cluster of indicators; however, it was not possible to incorporate all the predetermined variables resulting from the literature analysis carried out. This difficulty was due to the lack of available or updated data for some of the selected criteria. These initial data gaps made it necessary to revise the selection of indicators and adopt a more pragmatic approach. This resulted in the exclusion of some information that would have been interesting to introduce into the cluster of indicators for future analysis; consequently, the final result, while interesting given the situation, may not fully reflect all the dimensions of vulnerability that were predetermined in the theoretical research phase. On the other hand, the use of a smaller number of basic and easily available data for the creation of the criteria makes it possible to replicate this type of analysis in other Italian urban contexts. Certainly, this situation highlights the importance of investing in the improvement of data collection and management in cities in order to allow for more in-depth and comprehensive analyses in the future.

Consequently, due to the lack of data especially in the environmental domain, the environmental domain was represented by a single indicator, namely land surface temperature (LST). In spite of this challenge, the environmental, social and infrastructural criteria with related sub-criteria were then determined, which underwent preliminary reworking to make them suitable for the elaborations for the realisation of the vulnerability analysis. At the end of the spatial elaborations through the QGis software, two types of vulnerability scenarios were produced with different weightings, carried out through an analysis with the SuperDecision software: one with equal weighting of the criteria and the other with differentiated weighting of the criteria, in which more weight was given to the environmental criterion, as it was the focus of our research objective. A limitation encountered in this phase of the grading was certainly the lack of a comparison with technical experts in the Milan area capable of supporting and advising on the assignment of the different weights in the various cirteria analysed. The analysis of the two results led to the conclusion that the differentially weighted map would be the most suitable for the purpose of the work as the vulnerability values obtained show greater continuity in the spatial variation of the data than the uniformly weighted map. The result of the overlapping between the disused green areas of the city of Milan and the vulnerability map identified C.I.M.E.P. - lot 67 (Consorzio Intercomunale Milanese Edilizia Popolare), a former car depot, as the most vulnerable site and therefore the object of the project.

In order to make the area in question less vulnerable, a crucial role in mitigating the effects of UHI is played by NBS as they offer a multifunctional approach that integrates environmental, social and economic benefits while contributing to urban resilience and improving the quality of life and well-being of the population. After an analysis conducted on the selected area through the Land Use Plan (TMP), a holistic analysis was carried out to assess the most suitable NBS for the purpose of the work, i.e. UHI mitigation. It was then determined that urban reforestation would be a valuable addition to the area, representing one of the most effective solutions for UHI mitigation. After evaluating the positive impacts this action would have on the community and the city as a whole, an assessment was conducted to determine the degree to which the UHI would be reduced. As shown by several studies analysed in this thesis, the analysis showed that by planting trees approximately 20 metres high, the temperature, both at midday and at midnight, also decreased significantly in the surrounding areas. This is due to the shading generated by the tree crowns, which partially obstruct solar radiation, preventing it from reaching the ground and being absorbed in turn. The canopies also prevent the dispersion of cold breezes upwards, thus also generating cooling to the surrounding areas. It is therefore demonstrated that the extension of green roofs is a key factor in the reduction of UHI. This first result demonstrates not only how this solution is valid and effective but also its ability to adapt to different contexts where the same problem persists as in the area under study. In fact, it is not necessary to have large green areas, even small areas positioned at the right distance are sufficient to generate the cooling effect.

A further key point of this thesis work is to estimate the economic cost generated by the implementation of the urban forest. In order to assess the economic implications of the creation of the urban forest in the study area, a cost analysis was conducted based on the Lombardy Region price list (2024). First, however, several dimensional calculations were made to determine the sufficient number of trees to be planted in an area of approximately 5 hectares. In order to make this estimate, several case studies were taken into consideration, which resulted in the decision to plant approximately 2,000 trees per hectare in order to also have a significant impact in lowering temperatures. This equates to a total of 9360 trees that can be planted in the specified area. Subsequently, five native trees were selected that reflect environmental criteria, including encouraging the creation of new habitats, drought resistance and resistance to pollutants. The above-mentioned criteria were used to select these trees and their respective percentages of occurrence are as follows: Quercus robur (30%), Carpinus betulus (20%), Fraxinus excelsior (25%), Acer campestre (15%) and Populus Nigra (10%). Subsequently, a planting scheme was created as a schematic indication of the arrangement that the aforementioned plants will have on site.

Once the size data had been defined, the actual calculation of the cost of reforestation and its annual maintenance was carried out. The costs turned out to be considerable, due to the large number of trees planted. In fact, taking into account the cost of felling some of the abandoned buildings on the site and the tree-planting work, the cost was €2,685,168. As far as maintenance is concerned, on the other hand, the costs per year are also high, amounting to €1,529,590 per year. To verify the feasibility of the project, a cost-benefit analysis (CBA) was conducted, where the revenues generated from ecosystem services (ES) were compared with the costs incurred during construction and maintenance over a period of 20 years, the average life cycle of trees in urban areas. The analysis showed that the project is indeed feasible, with a positive Net Present Value (NPV) of 21,956,022€ and an IRR of 37%. The analysis of the ecosystem services provided by the implementation of urban reforestation showed very positive effects on socio-cultural services, but also in regulatory services.

The project developed in this thesis provides a clear illustration of the beneficial results that can be achieved for both the city and its inhabitants when abandoned or degraded urban green areas are redeveloped using green alternatives. In fact, the aim of this work is also to provide a simple and replicable procedure to enable public and/or private operators to assess at the planning stage which areas are most in need of intervention and how to estimate the costs of intervention and the economic return from the provision of SE. A step that would have been interesting to take is to do a vulnerability index check by adding the green area that is the subject of this project to the system of green areas already present, which are part of the indices used, in order to assess whether the index would actually improve and by how much. Unfortunately, this step would have entailed a possible but not complete verification due to the lack of post-intervention Land Surface Temperature (LST) data.

The creation of green areas in areas that have long been neglected provides new opportunities for local residents to engage in recreational activities, while fostering social relationships and facilitating connections with the natural environment. These experiences contribute significantly to the physical and mental health of residents. In addition, the expansion of vegetation and permeable surfaces contributes to slowing the accumulation of heat in urban areas, resulting in lower local temperatures and promoting favourable microclimatic conditions. The creation of favourable climatic conditions results in a reduction in the demand for space cooling, which in turn leads to a decrease in electricity consumption and costs for residents and public institutions. Furthermore, the reduction of excessive temperatures mitigates the risk to human health. In fact, excessive heat can have fatal implications for some vulnerable groups, such as the elderly and children. Transforming previously abandoned land into accessible green areas has a twofold advantage. Firstly, it improves the aesthetic appearance of the area, enhancing its quality of life. Secondly, it has a knock-on impact on the value of surrounding properties, increasing their marketability. In addition, green areas facilitate the natural absorption of rainfall, helping to reduce the likelihood of flooding. The formation of natural habitats within urban areas enables the rapid spread and maintenance of native flora and fauna, thus contributing to the ecological harmony and resilience of urban ecosystems. In addition, urban vegetation acts as a natural filter that helps absorb pollutants and particulate matter, benefiting the respiratory system of people living in these areas. Redevelopment of abandoned areas can facilitate the creation of new commercial and recreational activities, which can lead to job creation and stimulate the local economy. Conversely, well-kept public spaces can promote social interaction and a sense of belonging to these places, thus strengthening cohesion within communities. In conclusion, the implementation of NBS in urban areas can be considered an effective method to counteract the problem of heat islands and climate change, while generating additional benefits for the city and its residents.

In light of the aforementioned reasons and benefits, it is imperative that urban centres allocate resources towards the implementation of these solutions, with the aim of enhancing the liveability of their respective urban environments. The model developed for the city of Milan offers such flexibility that it can be applied to other urban contexts, such as Turin. The city of Turin presents a multitude of derelict green spaces, currently unmanaged and often situated in areas with a history of industrial activity. This has resulted in the creation of significant urban voids and the release of considerable quantities of heat. Implementing this model in Turin would facilitate the identification of areas requiring priority intervention, thereby representing an initial step towards the mitigation of climate change in the city, a problem that cannot be postponed any longer.

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