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Special Issue 2.2023

Burn or sink
Planning and managing the land

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Cover photo by Giuseppe Mazzeo. Rising wheat fields on the hills of Conza della Campania, Irpinia. January 31, 2023.

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BURN OR SINK
PLANNING AND MANAGING THE LAND

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TeMA Journal of Land Use, Mobility and Environment

EDITORIAL PREFACE
Special Issue 2.2023

Burn or sink

Planning and managing the land

Giuseppe Mazzeo*

In the last few years, we have witnessed an increasing frequency of extreme events such as heavy rains, floods, landslides, fires, and long periods characterized by high temperatures and scarce precipitation. The vast majority of scientists attribute these events to climate change resulting from anthropogenic activities, which leads to a rise in the global average temperature and a consequent disruption of meteorological and climatic balance.

These changes affect both the normal progression of seasons and the frequency of extreme weather events. For the former, the most evident phenomena are the rise in average temperature and the significant variation in average and total precipitation. For the latter, changes are highlighted not so much by the occurrence of such events, as by the reduction in the return period of these phenomena and their displacement from areas of the globe normally affected by extreme events to other areas.

The primary cause of these processes is the use of fossil fuels for energy production.

The extreme events that have impacted many regions in recent years have emphasized the vulnerability of the environment and heightened concerns about potential future consequences on the social and economic organization of these areas. The aspects involved are diverse, ranging from demographic to social, from economic to political.

Urban and territorial planning is also implicated, and in recent decades there has been an increased focus on sustainability-related aspects. In urban areas, for example, policies related to adaptation and regeneration have multiplied. Meanwhile, in larger territorial areas, efforts to protect and develop natural resources have been intensified.

Natural resources are a heritage of territories, an identity value, and one of the factors of their economic and social resilience. They give rise to high-value-added products that are recognized at both the national and international levels. Moreover, within a territory, they represent a specific indicator of balance between the environment and humans.

On natural resources the attention is global, as evidenced, for example, by the Sustainable Development Goals of the United Nations and by the environmental action programs of the European Community. For this reason, these resources must be analyzed in their constituent processes and defended both from overproduction and from climate change. They must be considered as strategic resources and fully integrated into territorial and urban planning processes.

The Special Issue *Burn or sink- Planning and managing the land* focuses on the relationship between natural resources, territorial planning and management, and the observation that resources are in a fragile situation due to climate change.

The scientific community pays close attention to this topic and deepens it through various interrelated lines of study. One line of research of particular interest to planning focuses on ecosystem services, i.e., the free goods and services provided to communities by certain types of natural capital. Two of these (water and soil) form the basis of economic and social systems and enable the establishment of communities.

A second line of research focuses on natural capital factors – the stock of resources including soil, air, water, and living organisms – which are capable of producing a flow of goods and services to keep for the future.

A third line of research is related to the FEW (Food-Energy-Water) Nexus approach, which explores the connections between the subsystems of food production, energy, and water. It uses methodological and analytical tools to quantify the intensity of relationships between them, both locally and globally.

In addition to these, there are lines of research not specifically focused on natural resources but delved into the impact of climate change on the urban environment. For example, studies on urban heat islands or the role of urban greenery fall under these lines.

The focus on natural resources necessitates their proper planning and management, with new rules able to address the protection of natural and agricultural territories, the reduction of soil consumption, and the enhancement of territorial quality in response to climate change processes. The goal is to increase the territorial capacity to respond to critical events, in other words, to enhance its resilience to extreme events caused by climate change.

Planning involves the use of land to make existing settlements livable for the population. When we create a plan, we hypothesize the livability conditions of a future that we can only predict, as it is uncertain whether the transformation over time guided by the plan will achieve the set objectives. Too often, the impact of this second phase is not considered or, more accurately, is delegated to the implementation of rules that gradually become more and more obsolete.

Therefore, it is necessary to structure plans that are more consistent with reality. If humans are the central element around which planning is built, they are also the main contributors to global warming processes. Consequently, it is obvious that planning must contribute to halting and, if possible, reversing the trend affecting certain processes.

The ability of institutions to develop governance mechanisms that are more suitable for addressing these problems and reducing risks for citizens will be crucial. Studies on this topic seem to affirm that there is no one-size-fits-all system of governance, and the presence of a wide range of good practices testifies that the best solution varies on a case-by-case basis.

TeMA Journal has already shown extensive interest in these aspects. Over its 16-year lifespan, the journal has explored broad themes that characterize today's environmental crisis, with the aim of outlining new planning paths. For the first time, the journal's editorial staff is proposing a Special Issue aimed at deepening the topic by soliciting articles focused on scientific aspects, the development of innovative practices, and the role of social behaviors.

TeMA Journal's Special Issue *Burn or sink - Planning and managing the land* features a collection of eight original papers. These were written specifically for this issue following the call for papers launched in October 2022. The papers present ideas, theories, empirical insights, methodologies, experiences, and techniques about policy issues, best practices, and research findings on the Special Issue themes.

Lai and Zoppi, with the paper *Factors affecting the supply of urban regulating ecosystem services. Empirical estimates from Cagliari, Italy,* present a study to analyze the relationships between supply of ecosystem services, features of green areas and characteristics of settlements in the urban contexts of Cagliari (Italy). The urban ecosystems offer services as heat mitigation, carbon capture and storage, and runoff control, but they are differentiated in relation to the characteristics of the territory (if they are green areas or urban settlements). The outcomes of the paper are in terms of urban planning and of policy implications.

The paper by Fratini, *The Eco-Pedagogical Microforest a shared Oasis of proximity. A cutting-edge project at the intersection of ecology, urbanism and pedagogy*, deepens the topic of the urban forests. A series of evidence suggest that planting trees represent one of the most effective solutions to mitigate climate change. The paper illustrates an experimentation of a tiny forestation action at the neighborhood scale in Rome, with the aim to integrate both regulative and social-cultural ecosystem services. The project demonstrates that even a small patch of nature can increase young people's biospheric values, influencing pro-environmental behaviors and actions, and enhancing wellbeing.

Mobaraki, whit the paper *Spatial analysis of green space use in Tabriz metropolis, Iran,* presents a descriptive and analytical research aimed to evaluate the use of green spaces in the city of Tabriz (Iran) and the way they are distributed in the urban area. The results of the study indicate that per capita use of green space in Tabriz is much lower than the national and international standard. Furthermore, the spatial distribution of green space use is not the same in the different districts.

The paper by Isola, Leone and Pittau, *Evaluating the urban heat island phenomenon from a spatial planning viewpoint. A systematic review*, deals with the issue of urban heat islands. One of the main causes of higher temperatures in urban areas are the impervious surfaces. The urban heat islands present negative impacts on the health of the population and lead to increased energy consumption for cooling. Ecosystem services are a valuable tool to mitigate the effects of UHI. Starting from the existing literature of the last fifteen years, the paper deepens the phenomenon through an interpretation key based on the issues addressed, the methods used and the spatial scales to which these methods have been applied.

Dinç, with the paper *Unveiling shoreline dynamics and remarkable accretion rates in Lake Eğirdir (Turkey) using DSAS. The implications of climate change on lakes,* deepens the issue of the inland lakes. Lakes and their shorelines are important ecosystem areas with the diversity of living species they host. In addition, lakes are an almost indispensable resource for humans as a source of fresh water. To understand the vulnerability of lakes to global climate change, it is of interest to study the temporal rates of change that occur on lake shorelines. In this study, Landsat multi-temporal images of the east part of Isparta Eğirdir Lake in Turkey were obtained and the change in the shoreline over a 10-year period (2013-2022) was examined using DSAS (Digital Shoreline Analysis System) tool.

The paper by Quagliarotti, *The Water-Energy-Food Nexus in the Mediterranean Region in a scenario of polycrisis*, faces with the notion of multiple global crises and their impact on the availability and access to fundamental resources to human survival and well-being: water, energy and food. The Mediterranean region could be considered both a water, energy and food (WEF) Nexus case-study and a climate change hotspot. Climate change, war and other crises modify the global commodity markets on energy and food markets, with ripple effects likely to extend into the next future. The new global systemic risks call for a paradigm shift by adopting measures to reduce exposure and strengthen resilience turning the conventional WEF Nexus into a virtuous circle.

Mazzeo, with the paper *Analysis of strategic natural resources: the FEW Nexus model applied to Irpinia (Italy) and implications for regional planning,* analyses specific types of natural resources (soil, water and energy) and identifies their potential contribution to local development in a perspective of reduced environmental loads in an inland area of the Campania Region. The attention to the three systems of resources is evidenced by the development of research based on FEW Nexus and on other models. This does not translate into attention from planning tools. The paper shows that the regional planning tool for the province of Avellino only partially considers such resources, failing to assign any strategic importance to them. This may be considered a weakness both in regional planning and in land management. For this reason, the last section of the paper proposes changes in regional planning policy.

The paper by Federico, Di Giustino, Ferraioli and Lucertini, *Circular and metabolic perspectives in urban contexts. Integrated flows analysis for an ecological transition*, deepens the issue of circular economy, security and sustainability of food production and reduction of emissions. The intention is to emphasise the commitment of territorial and urban planning to consider the current systemic components related to the flows that cross urban, peri-urban and rural territories, fostering the development of sustainable and circular supply chains capable of supporting an ecological, energetic and climatic transition. The case study of the Territorial Plan of the Metropolitan Area (PTAV) of the Province of Rimini identifies some methodological aspects useful for a trend shift towards effective actions aimed at the sustainable and circular management of local resources.

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Factors affecting the supply of urban regulating ecosystem services. Empirical estimates from Cagliari, Italy

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Abstract

This study aims at analyzing the relationships between supply of ecosystem services, features of green areas and characteristics of settlements in urban contexts, by taking the Italian city of Cagliari as study area. The services offered by the urban ecosystems that are identified as the most relevant in association with the spatial framework of green areas in urban environments are heat mitigation, carbon capture and storage, and runoff control, with particular reference to flood-related events. The features of green areas are identified with reference to the height of vegetation, by distinguishing between grasslands, shrubby cover, and trees and woodland cover. Finally, we characterize the urban settlement through the building and population densities, and through the education level, as a proxy for the residents' social statuses. The assessment of performances of the urban ecosystem services shows negative correlations with the intensity of urbanization, whereas the size of the enhancement in the supply of ecosystem services can be associated with different types of green areas. In terms of policy implications, the outcomes of the study show that there is plenty of room for improvement in the ecosystem services performance based on fine-tuning measures which involve building and population densities and vegetation cover.

Keywords

Ecosystem services; Urban vegetation; Carbon capture and storage; Urban runoff control; Urban heat mitigation.

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1. Introduction

According to figures available from the World Bank, around 56% of the world's population is presently concentrated in urban areas, whereas the population living in cities is forecast to grow up to nearly 70% by 2050[1]. The increasing urban expansion trend generates radical transformations in city landscapes, which entail, for example, decrease in urban biodiversity that causes destruction of habitats and widespread development of alien invasive species, loss of habitats and addition of new habitats, increase in vegetated land cover fragmentation (Tratalos et al., 2007; Warren et al., 2021; Davis, 1978), decrease in agriculture production, increase in air temperature (Donovan et al., 2005; Bonan, 2000), loss of carbon storage and capture potential (Floris & Zoppi, 2020), and increase in flood risk due to the growing trend of soil sealing (Isola et al., 2023).
A well-grounded approach to mitigation of negative impacts of intensive urbanization on natural ecosystems is represented by the paradigm of the "compact city" (Bibri et al., 2020), which aims at minimizing land-taking processes by concentrating city services in the central locations of urban fabrics (UN-Habitat, 2015; UN-Habitat, 2014a; UN-Habitat, 2014b; UN-Habitat, 2014c; UN-Habitat, 2011). By doing so, decrease in urban sprawl and important ecological and social positive impacts are implemented in the long run, so as to boost living quality in urban, periurban and rural environments (Guida, 2022; Hofstad, 2012; Jenks & Jones, 2010).
A less investigated profile is represented by the effects of intensive urbanization processes on the areas where such processes take place, with reference to ecosystem services endowment and provision (Gaglione & Ayiine-Etigo, 2021; Geneletti et al., 2019; Zucaro & Morosini, 2018; Tratalos et al., 2007).
For this purpose, three ecosystem services are identified in this study, which are particularly important as regards city environments, such as carbon capture and storage (CCS), runoff control (ROC) and heat mitigation (HEM).
CCS through biotic processes can be identified with photosynthesis, which takes place in ecosystems such as forests, woodlands, shrubs, garrigues, natural grasslands, and heathlands. Photosynthesis eliminates carbon dioxide from the air, and stores carbon in soil and biomass (Lal, 2008) while releasing oxygen in the atmosphere. Soil and air composition, and their interactions, significantly contribute to global climate regulation, and are heavily related to land covers and their transitions (Jobbagy & Jackson, 2000). Thus, green areas and soil play key roles in carbon cycle processes at the global level by supplying the CCS ecosystem service (European Commission, 2012; Millennium Ecosystem Assessment, 2003). Soil is the largest carbon terrestrial pool (Lal, 2004), since the carbon quantity stored in the soil is quite larger than in the biomass located overground (EEA, 2012). That is why even low changes in carbon concentration in the soil may generate relevant effects on the aerial concentration of carbon dioxide and on the temperature at the global level (Muñoz-Rojas et al., 2013; Arrhenius, 1897). Climate and soil show a mutual connection. On the one hand, climate changes influence geophysical and geomorphological conditions and environmental processes related to soil; on the other hand, soil transitions generate important effects on the terrestrial climate (Molinaro, 2020; EEA, 2012). The identification of the relation between climate change and the quantity of organic carbon stored in the soil is a fundamental point of reference to mitigate the negative impacts of climate changes (Yigini & Panagos, 2016). Since the global mean surface temperature (GMST) in the period 2011-2020 already shows an increase of 1.09 °C with respect to the preindustrial reference point (1850-1900)[2] and a growing trend thereof, the Protocol of Kyoto and the Paris Agreement state that the signatory parties will work to reach a world peak in greenhouse gas emissions (GHGEs) in the very short run and a virtuous balance between decrease in GHGEs and increase in CCS, so as to limit the increase in GMST to 1.5 °C by 2100 (World Meteorological Organization, 2018; United Nations, 2016). In this perspective, urban planning policies should play a relevant role as regards conservation and enhancement of the CCS ecosystem service provided by soils,

1 https://www.worldbank.org/en/topic/urbandevelopment/overview#:~:text=Today%2C%20some%2056%25%20of%20the,people%20will%20live%20in%20cities.

2 https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-2/.

which entails the implementation of specific and effective measures aimed at improving its capacity of storing carbon (European Commission, 2012).

ROC is related to regulation of flood events, which can be operationalized through shaping and maintenance of river courses and floodplains so as to implement effective drainage and adequate runoff, underground aquifers recharge and generation of groundwater tanks to be used in case of drought as well. Soil permeability is fundamental as regards regulation of flood flow rates and related runoff speed, and, that being so, it represents a key factor in the provision of the ROC ecosystem service, which entails a reduction in sediment downstream flows as well. Permeability makes agricultural areas perform quite well as ROC ecosystem service providers (Bridgewater, 2018; Patekar et al., 2021). Effective management of forests, as well as of other wooded and tree areas, provides an adequate ROC in case of flood events, especially through the implementation of appropriate drainage and runoff into floodplains (Pede et al., 2022; EEA, 2021). Forest management coupled with effective ROC is also very important with reference to reduction of the share of polluted wastewater from industrial and agricultural productive activities which flows downstream through waterways (Mysiak et al., 2019). Nature-based solutions aimed at conveying surface waters into underground aquifers are very effective in maximizing the positive impacts of the ROC ecosystem service (EEA, 2021). ROC can be appropriately implemented in urban contexts through rainwater collection and storage, like for instance raingardens, swales and bioswales, green roofs and walls, and collection tanks (UNaLab, 2019; Berland et al., 2017). Another relevant paragon is represented by the realization of roads, parking lots, pedestrian paths and playgrounds, covered with porous, water-permeable materials, aimed at regulating runoff (Wild, 2020; Bridgewater, 2018), and, in so doing, at conveying a relevant rainwater share into the groundwater aquifers, which would constitute important reserves in case of drought, and, at the same time, would reduce flood flow rates, which often generate dramatic events in urban environments (Du et al., 2019). Moreover, rainwater flows through porous pavements are associated with a filtering action which entails an important enhancement in the quality of the underground aquifers (Depietri & McPhearson, 2017).

In this study, land surface temperature (LST) is targeted as a key point of reference to address the issue of HEM. In other words, decrease in LST is taken as a proxy for the provision of the HEM ecosystem service. As per Hulley et al. (2019), LST is a fundamental climate-related and biological factor which influences the ecosystems viability at different geographical scales. In particular, LST can be assumed as a measure of the thermal radiance generated by the interaction between the land surface, or the canopy in case of tree areas, and the sun power (Echevarria Icaza et al., 2016; Salata et al., 2016). Furthermore, as per the NASA Earth Observatory[3], LST can be considered as the temperature felt to the contact and can be identified by the temperature of what you can see from a satellite by looking through the atmosphere, be it the soil surface or the canopy of an urban woodland; thus LST is different from air temperature. Under this perspective, it is evident that the spatial taxonomies of land cover and LST are interrelated, and that land cover transitions influence climate change trends (Alfraihat et al., 2016; Li et al., 2016). Several studies are available in the current literature related to these issues. Landsat TM/OLI images concerning 1999, 2009 and 2019 are used by Al Kafy et al. (2020) to detect land cover transitions in Rajshahi (Bangladesh). The association between LST changes and land cover transitions in Pune City (India) is analyzed by Gohain et al. (2021), with reference to the 1990-2019 period, by means of a mixed GIS-remote sensing approach. A three-phased methodology is used by Tran et al. (2017) to identify relations between LST and land covers in the Hanoi metropolitan area (Vietnam), which develops from the use of the normalized built-up and vegetation indices to characterize each land cover and detect the relations which connect LST, vegetated areas, anthropic characteristics and agricultural zones, through the identification of the relation between heat islands and land cover transitions by means of hot spot and urban landscape analyses, to assess future scenarios related to urban climate based

[3] This definition is available on the NASA Earth Observatory's website: https://earthobservatory.nasa.gov/global-maps/MOD_LSTAD_M.

on a non-parametric regression. The relations between vegetated areas and LST transitions are investigated by Akinyemi et al. (2019) with reference to the Caborone (Botswana) urban semi-arid environment, through LST detected during the day and the night provided by MODIS and the Normalized difference vegetation index (NDVI), in the 2000-2018 time period. The relations between LST and land cover transitions were assessed in a number of studies concerning Italian urban contexts. Among many, Zullo et al. (2019) assess the effects of urbanized zones on LST as regards the Po River Valley during the 2001-2011 time period. The relations concerning NDVI, normalized difference built-up index (NDBI) and LST are analyzed by Guha et al. (2018) with reference to Naples and Florence, whereas urban and landscape morphology effects on LST are investigated by Scarano & Sobrino (2015). Four Italian urban environments, located in Basilicata, Campania, Molise and Apulia, are analyzed by Stroppiana et al. (2014), as regards the association of LST, topography, land cover transitions and radiation from the sun.

The three ecosystem services described so far are generated through peculiar characteristics of highly urbanized contexts and work as relevant factors related to the quality of life in cities. The provision of CCS, ROC and HEM is associated with urban land cover, and it basically depends on two intertwined aspects. First, as discussed above, the three ecosystem services are supplied by unsealed soils, therefore the building density structure, which identifies the urban taxonomy of sealed and unsealed soils, is a focal point to detect if, and to what extent, urban environments can be providers of such ecosystem services. Second, the intrinsic characteristics of urban unsealed soils play a fundamental role in the effectiveness of the provided ecosystem services. In other words, to detect the correlations between provision of ecosystem services and urban land cover characteristics is highly important. Such correlations can lead to relevant implications in terms of planning policies aimed at increasing the provision of urban ecosystem services and at improving the living quality of urban communities.

The research question that this study aims at addressing is, therefore, identified as follows: how and to what extent is the endowment of sealed and unsealed areas related to the supply of ecosystem services in intensively urbanized urban areas?

The study develops as follows. In the second section, the spatial data used to identify urban land cover characteristics and building structure are presented, and the approach to derive them is explained, with reference to the city of Cagliari, the regional capital city of Sardinia, Italy, which is taken as the urban context for the implementation of this study. Moreover, the methodology used to identify the correlations between ecosystem services supply and urban characteristics is described. The third section assesses the outcomes of the correlation analysis and of the estimates of the regression models. In the fourth section, such outcomes are discussed in the context of the current literature, and as regards their implications for future research. The concluding section remarks the value added of the study, with particular reference to planning policy implications.

2. Materials and methods

2.1 Study area

The area chosen for this study is Cagliari (Fig.1), the regional capital of Sardinia, an Italian region and a Mediterranean island. Hosting notable remains of the Phoenician and of the Roman settlements, the inner and pluri-stratified part of the town much owes to the medieval urban morphology. As many medieval towns, it was (and partly still is) surrounded by defensive walls and fortified bastions, which constrained the urban growth and spurred soil sealing and densification within the walled settlement; it is therefore not surprising that the historic districts host only a few tiny green areas. The parts of the city that surround the old districts are also characterized by a dense urban fabric; however, some large green areas and parks can be found therein, and larger roads are often lined with rows of trees. The outer, and most recent, districts are characterized by a larger share of green areas, and host, for instance, scattered houses or multi-story residential buildings with private gardens and courtyards, as well as public green areas. This reflects on the uneven spatial pattern of the residential density: as of December 2022, Cagliari's resident population was around 150,000 people and the population density was 1,751, with peaks of nearly 19,000 residents/km^2 in the most central districts (Comune di Cagliari, 2023). Therefore, the complex and variegated urban morphology and uneven endowment of green areas make the city of Cagliari a good case study to investigate the relationship between sealed/unsealed areas and the supply of ecosystem services in an urban context.

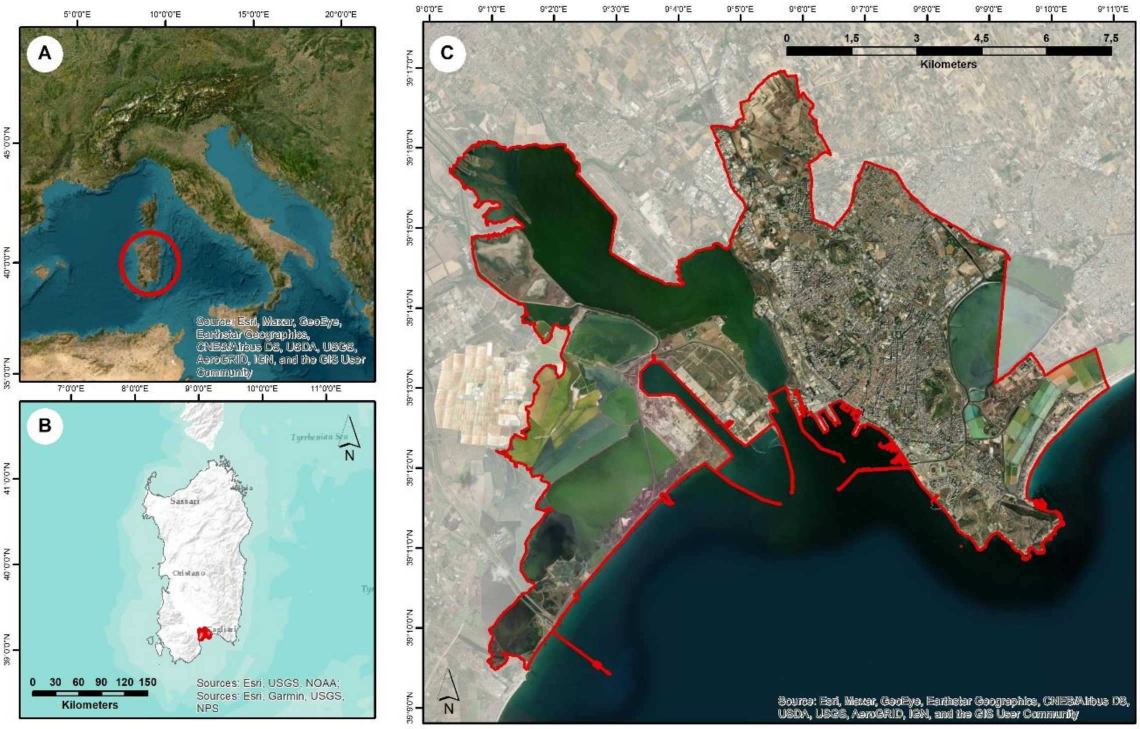

Fig.1 Study area: Location of Sardinia (A), location of Cagliari within Sardinia (B), administrative boundaries of Cagliari (C)

2.2 Spatial data

As per the introduction, factors concerning the urban settlement that might influence the provision of the selected urban ecosystem services can be grouped into three main classes: land cover types; aspects related to the built environment; socio-economic characteristics of the resident population.

Spatial references for each factor are the 1,285 census tracts in which the municipality of Cagliari is divided for statistical purposes, shown in Figure 2[4]. Census tracts are highly homogeneous in terms of urban fabric characteristics, and represent subdivisions of the 31 districts that make up the city. While all the factors were mapped across the whole municipality of Cagliari, the correlation analysis and the regression model next described in section 2.3 were implemented by looking only at the 1,114 census tracts inhabited at least by ten residents (blue hashed in Fig.2).

The indicators for the three selected urban ecosystem services are listed in Tab.1, together with their definition and data sources. The following paragraphs provide a synthetic account of how each indicator was mapped across the study area.

[4] Boundaries of census tracts can be retrieved from: https://www.istat.it/storage/cartografia/basi_territoriali/Sezioni-Censimento-kmz.zip.

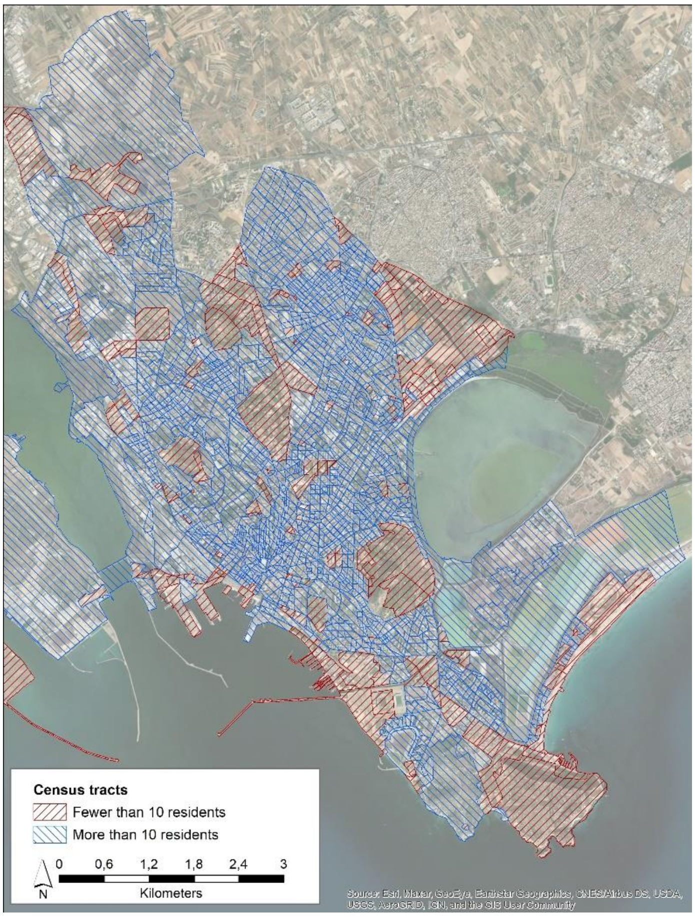

Fig.2 Census tracts in the study area

Variable	Definition and unit of measurement	Data sources
C_Stor	Average density of carbon capture and storage in a census tract [Mg/hectare]	Regional land cover map (https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=14480&es=6603&na=1&n=100&esp=1&tb=14401) 2005 National Inventory of Italian Forests (https://www.sian.it/inventarioforestale/) Regional pilot project on land units and soil capacity in Sardinia (https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=14481&es=6603&na=1&n=100&esp=1&tb=14401)
LST_Cmax	Maximum land surface temperature in a census tract [°C]	Landsat Collection 2 Surface Temperature (available from https://earthexplorer.usgs.gov/)
Dens_Ret	Density of runoff retention in a census tract [m^3/m^2]	City of Cagliari's 2021 land cover dataset (not published) Sardinian Hydrological Annals as for rainfall depth (https://www.sardegnaambiente.it/index.php?xsl=611&s=21&v=9&c=93749&na=1&n=10) Permeability map of Sardinian substrates (https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=94083&es=6603&na=1&n=100&esp=1&tb=14401) Curve number table, tailored to Sardinia (https://www.sardegnageoportale.it/documenti/40_615_20190329081206.pdf)

Tab.1 Selected urban ecosystem services: list, definition, and data sources

Concerning CCS, the InVEST "Carbon Storage and Sequestration" model, which is a part of the InVEST suite, was used. This model focuses on carbon stored in four terrestrial pools: above-ground biomass, below-ground biomass, dead organic matter, and soil, i.e., the top 30-cm layer. INVEST estimates the amount of carbon stored in the area of interest through a land cover map and a lookup table that provides carbon density values for each land cover type and for each carbon pool for which data are available from on-site surveys, inventories or literature. The result is a carbon density map, measured in megagrams (Mg) of carbon per pixel, where the carbon stored in each pool is aggregated as per equation (1):

$$TC_{LCk,i,j} = TSC_{LCk,i,j} + DMC_{LCk,i,j} + BGC_{LCk,i,j} + AGC_{LCk,i,j} \quad (1)$$

where, for each cell denoted as the cell i, j and whose land cover type is LCk,

- TC is the total carbon density;
- TSC, DMC, BGC, AGC are the carbon densities stored, respectively, in: top-soil layer, dead organic matter, below-ground biomass, above-ground biomass.

No information is available regarding below-ground biomass in the study area; therefore, the InVEST model was applied solely focusing on the three remaining carbon pools: above-ground biomass, soil organic content, and dead organic matter. The total carbon density values for each pool were determined using data from the 2005 National Inventory of Italian Forests and a regional pilot project that examined land units and soil capacity in Sardinia. Through zonal statistics, the total carbon density stored in each census tract (C_Stor) was calculated.

As for LST, raster maps are currently available off-the-shelf from the United States Geological Survey (USGS) through its Earth Explorer service, which makes it possible to retrieve Landsat Collection 2 Level-2 products, including 30-m land surface temperature raster maps, by selecting the area of interest, a time range and, optionally, other parameters such as maximum cloud cover. A four-month interval, from June to September 2022, was selected. Among the twenty LST maps retrieved from Earth Explorer, the one having the highest LST mean value across the study area (once the wetlands were removed) was selected, having unique identifier LC09_L2SP_192033_20220719_20220723. Through zonal statistics, the variable LST_Cmax was calculated as the maximum LST in each census tract.

Finally, ROC was mapped using the tool the InVEST "Urban Flood Risk Mitigation" model, which enables to estimate both runoff levels and the water volume retained by permeable soils and green areas, hence providing an assessment of the flood regulation ecosystem service. The model requires the following input data: the area of interest (vector map); the rainfall depth; a raster map of the soil hydrologic group; a land use/land cover raster map; a biophysical table.

For each pixel *i*, the runoff retention volume (RRV) is expressed by equation (2):

$$RRV_i = (1-\frac{Q_{RFD,i}}{RFD}) \cdot RFD \cdot A_i \cdot 10^{-3} \quad (2)$$

where:

- RRV is the runoff retention volume [m^3];
- RFD is the rainfall depth [mm];
- *i* is a pixel, whose area is A_i [m^2];
- Q is the runoff (in mm), which is null if RFD is not enough to initiate runoff ($RFD \leq \lambda \cdot PR_i$); otherwise, it takes the form in equation (3).

$$Q_{RFD,i} = \frac{(RFD - \lambda \cdot PR_i)^2}{RFD + (1-\lambda) \cdot PR_i} \quad (3)$$

where:

- PR_i is the potential retention [mm] in pixel *i*, and it is related to soil characteristics and land cover types through the curve number CN as per equation (4):

$$PR_i = \frac{25400}{CN_i} - 254 \quad (4)$$

- CN is an empirical and dimensionless parameter introduced by the Unites States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS, 2004). CN depends on soil characteristics and land cover types, and it represents the runoff potential of an area of land, ranging from 30 to 100 (where CN=100 signals no retention capacity), after a rainfall event;
- $\lambda \cdot PR_i$ is the "initial abstraction", i.e., the amount of rainfall required to initiate runoff (in mm), where λ can be taken as 0.2 (USDA-NRCS, 2004, p. 4).

RFD represents a measure of the amount of rain associated with a rainstorm, without considering the temporal dynamics of the event (Quagliolo et al., 2021). In this study, the 2012-2021 Sardinian hydrological annals were scrutinized to identify the day in which the largest rainfall depth was recorded in the study area. In Cagliari, in the ten-year timeframe examined, the largest amount of rain fallen in 24 hours was recorded on November 13, 2021, and it amounted to 101.8 mm[5].

As for soil hydrological groups (SHG), the model requires a map where the groups are classed using the four-category classification (A, B, C, D) of the United States soil, ranging from soil type A, having low runoff potential and high infiltration rates, to type D, having high runoff potential and low infiltration rates, whereas B and C represent intermediate situations (USDA-NRCS, 2007). A 1:25,000 vector permeability map of Sardinian substrates was used, which classes infiltration levels into five groups (low-mid-low, medium, mid-high, high) that were reclassed into the four SHG groups; the map was next rasterized to feed into the model.

The land cover municipal map, already mentioned in reference to vegetation, was used coupled with a biophysical table that associates each land cover in the map to four curve numbers, each corresponding to one soil group type (A-D). To fill in this table, a report produced by the Regional Agency for the environment (ARPAS, 2019) was used, which details the four curve numbers needed for each Corine four-level land cover type present in Sardinia.

By using the delineation of the census tracts as area of interest, the retention volume associated with a 101.8 rainfall depth in each tract (Dens_Ret) was obtained.

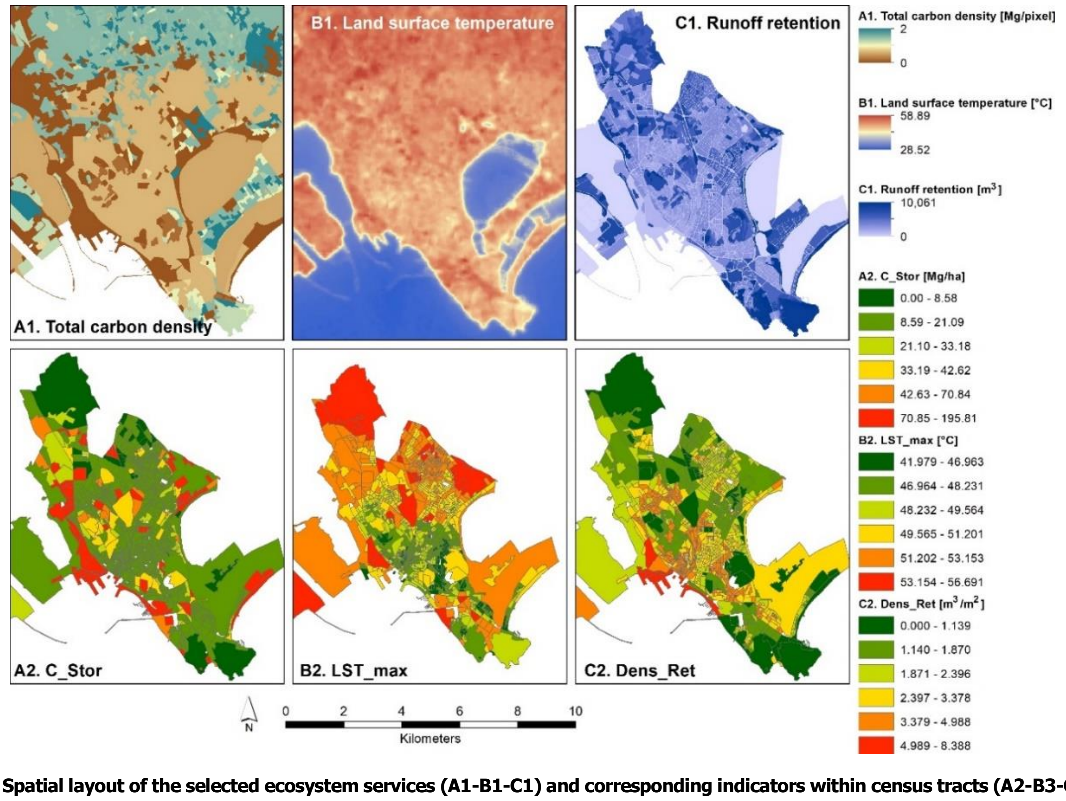

Fig.3 Spatial layout of the selected ecosystem services (A1-B1-C1) and corresponding indicators within census tracts (A2-B3-C2)

[5] The reader can refer to the 2021 regional hydrological annal (https://www.sardegnaambiente.it/documenti/21_393_20220729125359.pdf), label "Cagliari RF", pages 119 and 123.

Finally, for each of the three variables representing as many ecosystem services (C_Stor, LST_Cmax, and Dens_Ret) their spatially lagged variables (C_Stor_lag, LST_Cmax_lag, and Dens_Ret_lag) were assessed to control for their spatial autocorrelation. Anselin's approach (Anselin, 1988; 2003) was followed, as implemented in the freeware GeoDA[6] (Anselin et al., 2006), by taking census tracts as the minimum spatial units and by considering the first-order queen contiguity to determine weights.
The spatial distribution of the three selected proxies for CCS, HEM, and ROC, together with their indicators within each census tract, is shown in Fig.3.
Factors that can affect the provision of the three selected urban ecosystem services are listed in Tab.2, together with their definition and data sources. The following paragraphs provide a synthetic account of how such factors was mapped across the study area.

Variable	**Definition and unit of measurement**	**Data sources**
Perc_Tree	Share of a census tract occupied by tall trees [%]	Public green areas and tree lined roads from the City of Cagliari's geoportal (https://geoportale.comune.cagliari.it/) City of Cagliari's 2021 land cover dataset (not published) Sentinel-2 Copernicus satellite imagery (https://dataspace.copernicus.eu/)
Perc_Bush	Share of a census tract occupied by medium-height shrubs [%]	
Perc_Lowveg	Share of a census tract occupied by low-height vegetation [%]	
Vol_Dens	Built volume density (i.e., built volume per unit of land) within a census tract [m^3/m^2]	Geotopographic dataset of Sardinian urban centers and inhabited areas (https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=95648&es=6603&na=1&n=100&esp=1&tb=14401)
Sup_Nvp	Share of sealed area within a census tract [%]	Public green areas and tree lined roads from the City of Cagliari's geoportal (https://geoportale.comune.cagliari.it/) City of Cagliari's 2021 land cover dataset (not published) Sentinel-2 Copernicus satellite imagery (https://dataspace.copernicus.eu/) Geotopographic dataset of Sardinian urban centers and inhabited areas (https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=95648&es=6603&na=1&n=100&esp=1&tb=14401)
Dwel_Dens	Density of housing units (i.e., number of dwellings per unit of land) within a census tract [no./m^2]	2011 National Census dataset (https://www.istat.it/storage/cartografia/variabili-censuarie/dati-cpa_2011.zip)
Res_Dens	Population density within a census tract [residents/hectare]	
Perc_Degr	Share of residents holding a college degree within a census tract [%]	

Tab.2 Factors that can affect the supply of the selected urban ecosystem services: list, definition, and data sources

As well as the boundaries of census tracts, spreadsheets are available from the National Census website providing several data related to the built environment and to resident population at the tract level; this made it possible to retrieve the variables Dwel_Dens, Res_Dens and Perc_Degr within each census tract.
As for the built volume, a dataset available from the regional geoportal and termed "Geotopographic dataset of Sardinian urban centers and inhabited areas" was used. The dataset, having nominal scale 1:2000, was released in 2021; it derives from aerial photogrammetric restitution of data acquired in 2006-2008 flights and contains also more recent elements integrated by the regional office in charge of cartography and geographic information systems. From this dataset, the layer "ST02TE01CL01PLG" that describes elementary building units was used as it provides information on the elevation at the building's eaves (attribute A02010101) and base (attribute A02010102), hence making it possible to calculate the volume for each building unit and, through simple geoprocessing operations, the total built volume per census tract.
Concerning the three types of vegetation (tall trees, medium-height shrubs, low vegetation), no spatial dataset having appropriate temporal resolution and minimum mapping unit (MMU) provides such information for the

6 Version 1.20 was used, retrievable from: http://geodacenter.github.io/index.html.

Cagliari area. The 2018 Corine Land Cover map produced within the framework of the Copernicus Land Monitoring Service coordinated by the European Environment Agency, for instance, has an MMU of 25 hectares[7], while the 2008 regional land cover map produced by the Regional Government of Sardinia, having an MMU of 0.5 hectares within urban settlements[8], is now more than 15 years old. Useful information is provided by the municipal geoportal, which maps road tree lines, public greenery, urban parks, and agricultural periurban areas. Moreover, a municipal land cover map has recently been produced within the ongoing revision of the municipal masterplan; this map basically takes urban blocks as minimum polygons and classes land covers by detailing the traditional three-level Corine nomenclature up to the fourth level. Both data available from the city geoportal and the municipal land cover map, therefore, neglect private green areas that are included within single blocks (for instance, secluded courtyards) or interspersed between blocks (for instance, front or back gardens or lawns). For this reason, the available data sources were complemented with an NDVI raster map to detect small green areas included within polygon classed as "artificial land covers" within the municipal land cover map. To produce the NDVI map, 10-meter resolution Sentinel-2 satellite images were retrieved from the Copernicus Data Space Ecosystem; a six-month timeframe (January to June 2022) was chosen so as to include the spring period, when vegetation is in its full potential in Sardinia. For each satellite image, its corresponding NDVI map, having cell size ten meters, was produced, using the well-known equation (5) (among the first studies that used this index: Rouse et al., 1973; Tucker, 1979; Dave, 1980):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{5}$$

where NIR and RED represent the spectral reflectance measurements captured within the near-infrared and the red (visible) spectrums. For Sentinel-2 data, equation (5) takes the form provided in equation (6):

$$NDVI = \frac{B8 - B4}{B8 + B4} \tag{6}$$

where B8 and B4 are, respectively, the NIR and the RED bands.

Among the January-June 2022 images retrieved, the NDVI map obtained from the March 9, 2022 Sentinel-2 image[9] was selected, as this was the one with the highest mean value of the NDVI across the study area, hence potentially allowing for the best detection of vegetation within built-up areas. The latter was identified as the parts of the blocks classed as "artificialized" in the municipal land cover map that were not occupied by the building footprints and for which the NDVI was larger than 0.18. Such threshold was selected after checking approximately 1,500 control points (classed into seven groups: barren land, buildings, lawns, roads, shrubs, trees, water) across the study area and it is consistent with findings from previous literature (e.g., Akbar et al., 2019; Bondarenko et al., 2021; Aryal et al., 2022). While the threshold differentiating green areas from buildings, roads and barren land was quite straightforward, the analysis of control points showed some overlap between low-vegetation areas (such as lawns or gardens), bushes, and threes. Therefore, cautiously, all the green spots within built-up areas were classed as "low-height vegetation".

To sum up, the vegetation map for the study area was developed by using the city's land cover map and the city's map of green areas as primary sources of information, by reclassing the vegetation types into three types: trees, shrubs, and low-height vegetation, of which the latter was complemented with green spots within built-up areas, identified through the NDVI raster map.

Once the vegetation map was built, the variables Perc_Tree, Perc_Bush, and Perc_Lowveg could be calculated, as well as the variable Sup_Nvp, which represents the share of the census tract that is sealed, i.e., non-vegetated.

7 https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=metadata.
8 https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=14480&es=6603&na=1&n=100&esp=1&tb=14401.
9 Unique identifier: S2A_MSIL2A_20220309T100841_N0400_R022_T32SNJ_20220309T134626.SAFE.

2.3 Methods

In this study, unsealed areas in highly urbanized contexts are identified through three types of land covers, as follows: tall vegetated cover, such as in wooded and tree areas; medium-height shrubby cover; and, ground cover, such as garrigues, natural grasslands, heathlands and sparsely vegetated or bare soils. Sealed zones are featured by built-up blocks, roads, sidewalks, and the like. In order to represent such zones, the following characteristics are used: built-up volume; number of households; number of houses; and, the size of the area not covered by vegetation.

The relationships between the supply of ecosystem services in intensively urbanized environments, and the presence and quantity of sealed and unsealed areas, are analyzed and assessed through correlation analysis and regression models, as described in the following sections.

Correlation analysis

The associations of the distributions of the supply of the three selected ecosystem services (CCS, ROC, and HEM) with the distributions of the variables which represent land covers concerning sealed and unsealed areas can be identified through correlation analysis, which makes it possible to associate the distributions of two variables with each other so as to detect if, and to what extent, the two phenomena show similar trends.

The Spearman's rank correlation coefficients (SRCCs) are estimated to detect correlations between the distributions of the variables, related to census tracts, associated with CCS, ROC and HEM, that is, density of CCS (C_Stor), density of runoff retention (Dens_Ret) and maximum land surface temperature (LST_Cmax), and the distributions of those representing sealed and unsealed areas. Unsealed areas are associated with the following: percentage share of a census tract covered with: i. tall plants (Perc_Tree); ii. medium-height shrubs (Perc_Bush); or, low-height vegetation (Perc_Lowveg). Sealed zones area associated with the following: population density (Res_Dens), built volume density (Vol_Dens), density of housing units (Dwel_Dens), and percentage share of sealed area (Sup_Nvp). Since the forms of the distributions are unknown, SRCC can be identified as the most reliable measure to detect the presence and size of correlations between the variables at stake (Schober *et al.*, 2018). The assessment of the results of the SRCCs estimates as regards the expectations on such estimates is based on three items, that is, the sign, the size, and the related *p*-values. The detail of such results is presented and discussed in section 3.1.

Regression model

Three linear regression models are implemented to identify the correlations between the variables associated with the provisions of CCS (C_Stor), ROC (Dens_Ret) and HEM (LST_Cmax) ecosystem services, and the covariates associated with vegetated (Perc_Tree, Perc_Bush) and sealed (Sup_Nvp) land covers. Among the variables related to land covers, indicated in the previous section, Perc_Lowv in not included in the sets of the explanatory variables of the regression models since it is the complement to 1 of the sum of Perc_Tree, Perc_Bush and Sup_Nvp, and, that being so, it has to be omitted to avoid multicollinearity. As it is shown by the SRCCs results reported in the next section, the variables representing sealed land cover (Res_Dens, Vol_Dens, Dwel_Dens, Sup_Nvp) are strictly correlated with each other and, therefore, just one of them can be included in the set of the explanatory variables. Sup_Nvp is selected among the variables associated with sealed land cover since it is the one most correlated with the three dependent variables (C_Stor, Dens_Ret and LST_Cmax), as it is shown in the next section, which reports the results concerning the estimates of the SRCCs. Moreover, Sup_Nvp identifies sealed soils in the most complete way, since it takes account not only of buildings, dwellings and inhabitants, but also of paved areas such as roads, squares, sidewalks, parking lots, pedestrian paths, playgrounds, and the like.

The three regression models operationalize as follows:

$$\{C\_Stor \mid Dens\_Ret \mid LST\_Cmax\} = \beta_0 + \beta_1\, Perc\_Tree + \beta_2\, Perc\_Bush + \beta_3\, Sup\_Nvp + \beta_4\, Perc\_Degr + \beta_5\, \{C\_Stor\_lag \mid Dens\_Ret\_lag \mid LST\_Cmax\_lag\} \tag{7}$$

where labels are associated with dependent and explanatory variables, described and identified in detail in section 2.1., as follows:

- C_Stor is for density of CCS in a census tract;
- Dens_Ret is for density of runoff retention in a census tract;
- LST_Cmax is for maximum land surface temperature in a census tract;
- Perc_Tree is for percentage share of area covered with tall plants in a census tract;
- Perc_Bush is for percentage share of area covered with medium-height shrubs in a census tract;
- Sup_Nvp is for percentage share of sealed area in a census tract;
- Perc_Degr is for percentage share of residents holding a college degree in a census tract;
- C_Stor_lag, Dens_Ret_lag and LST_Cmax_lag are the spatially lagged dependent variables that control for spatial autocorrelation of C_Stor, Dens_Ret and LST_Cmax.

The estimates of the coefficients of the regression models reveal the correlations between the supply of the CCS, ROC and HEM ecosystem services and the presence of vegetated and sealed parcels in census tracts.
Multiple regression models are used since there are not any prior hypotheses associated with the relation between dependent and explanatory variables, which is in line with the current literature concerning this issue (Zoppi et al., 2015 Sklenicka et al., 2013; Stewart & Libby, 1998; Cheshire & Sheppard, 1995). In this perspective, a spatial variable related to *n* factors can be associated with a surface, which develops in a space with *n* dimensions, whose equation is not identified. The functional form of such surface can be approximated, in a very small neighborhood of each of its points, by the hyperplane which is tangent at that point (Couper & Wolman, 2003; Byron & Bera, 1983). That is why the linear equations estimated through the multiple regression models (7) are assumed as adequate approximations, in six-dimensional spaces, of the relationships between C_Stor, Dens_Ret and LST_Cmax, and the covariates which identify models (7).
Variable Perc_Degr, which represents the share of graduates within a census tract, is used as a proxy for the residents' economic welfare, since no data on household or personal income are available at the census tract level, which is likely to provide information on such item. This covariate controls for a possible income effect related to the provision of the three ecosystem services at stake. An increase in the income level is expected to be correlated with an increase in the supply of ecosystem services since public goods such as CCS, ROC and HEM ecosystem services should be seen as luxury goods in urban contexts and, in so doing, as drivers of gentrification phenomena (Leccis, 2019; Ferreira & Moro, 2013).
The covariates C_Stor_lag, Dens_Ret_lag and LST_Cmax_lag are associated with the spatially lagged values of C_Stor, Dens_Ret and LST in models (7), and control for their spatial autocorrelation on the basis of the methodological approach by Zoppi & Lai (2014), which develops from Anselin's articles (Anselin et al., 2006; Anselin, 2003).
Finally, the statistical significance of the estimated coefficients of the regression models are tested through their *p*-values.

3. Results

This section reports and discusses the outcomes of the estimates of the SRCCs and the results of the regression models, implemented on the basis of the definitions presented in the previous section. Estimates are related to the urban area of Cagliari. The section develops through two subsections, concerning the SRCCs and the regression findings respectively.

3.1 Spearman's rank correlation coefficients

The SRCCs estimated with reference to the correlations between the variables associated with the supply of the three targeted ecosystem services (C_Stor, Dens_Ret and LST_Cmax), and the covariates representing the characteristics of sealed and unsealed soils, generally show the expected sign and significant *p*-values, as reported in Tab.3.

Variable	Coefficient	t-Statistic	*p*-Value
Carbon capture and storage (C_Stor)			
Perc_Tree	-0.00603	-0.20110	0.84066
Perc_Bush	0.20989	7.15852	0.00000
Perc_Lowv	0.25416	8.76325	0.00000
Vol_Dens	-0.25830	-8.91600	0.00000
Res_Dens	-0.19024	-6.46204	0.00000
Dwel_Dens	-0.21294	-7.26748	0.00000
Sup_Nvp	-0.27868	-9.67642	0.00000
Water retention (Dens_Ret)			
Perc_Tree	0.04398	1.46801	0.14238
Perc_Bush	0.22418	7.67089	0.00000
Perc_Lowv	0.48682	18.58474	0.00000
Vol_Dens	-0.52649	-20.65031	0.00000
Res_Dens	-0.41839	-15.36086	0.00000
Dwel_Dens	-0.46388	-17.46138	0.00000
Sup_Nvp	-0.45443	-17.01156	0.00000
Mitigation of land surface temperature (ref.: Land surface temperature, LST_Cmax)			
Perc_Tree	-0.19263	-6.54632	0.00000
Perc_Bush	-0.02725	-0.90892	0.36359
Perc_Lowv	0.17642	5.97667	0.00000
Vol_Dens	-0.07881	-2.63617	0.00850
Res_Dens	0.02683	0.89487	0.00000
Dwel_Dens	-0.05421	-1.81036	0.00000
Sup_Nvp	0.22581	7.72974	0.00000

Tab.3 Spearman's correlation coefficients of targeted ecosystem services

As for C_Stor, variable Perc_Tree shows a very low SRCC associated with a high *p*-value, which indicates no correlation between wooded and tree covers and CCS. This is consistent with the features of wooded and tree covers in the highly urbanized urban area of Cagliari, where wooded and tree areas are characterized by tree rows planted in small garden beds with limited soil size. The other SRCCs are in a range between 19% and 28%, with very low and significant *p*-values; moreover, they show the expected correlation signs. Perc_Bush and Perc_Lowv are positively correlated to the supply of CCS, which is consistent with expectations, since unsealed shrubby soils covered with medium-height plants or low-height ground covers generally perform as important sinks for CCS (Yigini & Panagos, 2016; European Commission, 2012). On the other hand, Vol_Dens, Res_Dens, Dwel_Dens and Sup_Nvp are negatively correlated with C_Stor, which is also consistent with expectations, since all of them are measures of the size of the soil-sealing phenomenon. Moreover, such four variables are highly correlated with each other, as reported in Tab.4. These findings are consistent with the

SRCCs estimates associated with the ROC and HEM ecosystem services, as shown below. Therefore, this indicates that the densities of population, built-up volume and housing units, and the size of the unsealed area, can be considered four measures, consistent with each other, of the size of land subtracted from the potential provision of important ecosystem services in the densely urbanized urban context of Cagliari.

Variable	Coefficient	t-Statistic	p-Value
Built volume density (Vol_Dens)			
Res_Dens	0.74078	36.77303	0.00000
Dwel_Dens	0.81686	47.22204	0.00000
Sup_Nvp	0.68789	31.60424	0.00000
Population density (Res_Dens)			
Dwel_Dens	0.94272	94.23846	0.00000
Sup_Nvp	0.58721	24.19157	0.00000
Mitigation of land surface temperature (ref.: Land surface temperature, LST_Cmax)			
Sup_Nvp	0.66033	29.32140	0.00000

Tab.4 Spearman's correlation coefficients of variables associated to sealed soil

With reference to Dens_Ret, the three variables associated with unsealed soil are positively correlated with the supply of the ROC ecosystem service, and the estimated SRCCs are highly significant in terms of *p*-values, which indicates that the larger the size of the unsealed soil, the higher the potential runoff retention, as expected. On the other hand, the SRCCs of the four variables related to sealed soil are all negatively correlated with Dens_Ret and highly significant in terms of *p*-values, as expected as well.
Finally, the variable LST_Cmax, associated with the supply of the HEM ecosystem service, shows a negative and significant correlation with Perc_Tree and a positive and significant correlation with Perc_Lowv, whereas the estimate of the SRCC with respect to Perc_Bush is very low and not significantly different from zero in terms of *p*-value. Such findings entail the following: i., lower LSTs are associated with larger woods and tree canopies, whose shading is generally recognized as an outstanding factor as regards heat waves mitigation; ii., low-height vegetated and sparsely vegetated or bare soils characterize areas with LST comparatively higher than zones featured by shading canopies, which explains a positive LST gradient from such zones towards low-height vegetated or bare soils; iii., since the SRCC concerning LST_Cmax and Perc_Bush is very close to zero, there is no evidence of correlation between the supply of the HEM ecosystem service and land cover characterized by medium-height plants, which implies that such areas show neither a shading effect due to more-or-less extended canopy, nor a positive LST gradient associated with the vegetation height.

3.2 Regressions

The estimates of the coefficients of the Perc_Degr control variable are not significant in terms of *p*-values in two out of three cases. As indicated above, the share of the graduates is identified as a proxy for the income level, and public goods such as the CCS, ROC and HEM ecosystem services are likely to work as luxury goods in urban contexts and eventually as drivers of gentrification phenomena, as stated in section 2.3.2. (Leccis, 2019; Ferreira & Moro, 2013). According to the estimates of the regression models, this only happens in the case of the HEM ecosystem service, represented by the LST_Cmax dependent variable, since the estimated coefficient of Perc_Degr shows a very low and significant *p*-value and a negative sign. This implies that an increase in land surface temperature, which identifies a decrease in the supply of the HEM ecosystem service, is negatively correlated with the share of graduates (a proxy for the income level), consistently with the expectations. On the other hand, changes in Perc_Degr do not show any influence on the supply of the CCS and ROC ecosystem services, which entails that there is no evidence of an income effect as regards the supply of these ecosystem services.

Moreover, the spatially lagged covariates C_Stor_Lag, Dens_Ret_Lag and LST_Cmax_Lag reveal positive and significant estimated coefficients as regards *p*-values, which indicates an adequate control for the spatial autocorrelation associated with the dependent variables.

Since the estimated coefficients of the spatially lagged variables provide evidence of an effective control for the autocorrelation phenomena related to the dependent variables, and the existence of income effects is adequately investigated, the impacts of the explanatory variables associated with permeable and sealed soils can be considered reliable and well-grounded on the basis of the estimates reported in Tab.5.

Variable	Coefficient	t-Statistic	p-Value
Dependent variable: Carbon capture and storage (C_Stor)			
Perc_Tree	-0.04090	-0.86124	0.38929
Perc_Bush	0.21349	2.86994	0.00418
Sup_Nvp	-0.04283	-2.84009	0.00459
Perc_Degr	0.01913	0.87229	0.38324
C_stor_Lag	10.52142	16.87334	0.00000
Mean and Standard deviation of dependent variable: 45.11756, 10.90465			
Adjusted R-squared: 0.21705			
Dependent variable: Runoff retention (Dens_Ret)			
Perc_Tree	-0.02728	-9.93164	0.00000
Perc_Bush	0.04036	9.52346	0.00000
Sup_Nvp	-0.01721	-17.07541	0.00000
Perc_Degr	-0.00049	-0.39350	0.69403
Dens_Ret__Lag	0.77435	26.87518	0.00000
Mean and Standard deviation of dependent variable: 2.36299, 0.99759			
Adjusted R-squared: 0.69620			
Dependent variable: Mitigation of land surface temperature (reference: land surface temperature, LST_Cmax)			
Perc_Tree	-0.03426	-6.87215	0.00000
Perc_Bush	0.04804	43.68462	0.00000
Sup_Nvp	0.00001	7.80715	0.00000
Perc_Degr	-0.03800	-15.12484	0.00000
LST_Cmax_Lag	1.07469	206.51714	0.00000
Mean and Standard deviation of dependent variable: 48.27731, 31.47218			
Adjusted R-squared: 0.93872			

Tab.5 Estimates of regression models

As for Perc_Tree, the results show there is no evidence of a significant impact of the covariate associated with the share of wooded and tree areas on the supply of the CCS ecosystem service, which is consistent with the estimate of the SRCC concerning C_Stor and Perc_Tree. As noted above (section 3.1.), this is consistent with the fact that throughout the city of Cagliari wooded and tree areas are featured by the limited size of the small garden beds and planting pits where trees are usually planted, hence allowing for a limited capacity of CCS. Moreover, the limited size of the small garden beds associated with wooded and tree land covers can explain why the ROC ecosystem service, represented by the Dens_Ret dependent variable, is negatively and significantly correlated with the covariate Perc_Tree, since such limited size allows a large part of the runoff waters to flow over the ground and minimizes underground runoff retention. Finally, Perc_Tree shows a negative and significant influence on LST_Cmax, which implies that the impact of the size of the shading tree canopies play a decisive role in mitigating heating waves, which is particularly important in the hottest days of the year (Pace et al., 2021).

With reference to Perc_Bush, the estimated coefficients are positive and significant in terms of *p*-values, which implies that an increase in medium-height shrubby land cover areas is associated with an increase in the supply of the CCS and ROC ecosystem services, which is consistent with expectations, since such land cover entails large room for soil and subsoil carbon storage (He et al., 2020; Maiti et al., 2015), and for drainage capacity, especially in case of relevant meteorological events (Casermeiro et al., 2004). Moreover, the results of the regression concerning the HEM ecosystem service show evidence of a positive impact of Perc_Bush on land surface temperature, which entails that an increase in the share of shrubby medium-height land cover is associated with an increase in LST_Cmax. This indicates that shrubby land cover areas, which do not grant an adequate canopy such as tree and wooded areas, have a negative impact in terms of mitigation of urban heating waves (Shen et al., 2022).

Finally, the impacts of Sup_Nvp on the supply of the CCS, ROC and HEM ecosystem services are always negative, meaning that the higher the share of sealed soil, the lower the provision of CCS, ROC and HEM. This is consistent with the results related to the SRCCs, which show significant negative values as for C_Stor and Dens_Ret, and a positive value with reference to LST_Cmax.

4. Discussion

This section focuses on the discussion of main findings stemming from sections 3.1 and 3.2, therefore looking at the relationships between, on the one hand, CCS, HEM, and ROC, and, on the other hand, trees, bushes, and low-height vegetation and their significance in affecting the provision of the three selected ecosystem services.

Firstly, as for the relationship between the share of a census tract covered by trees and carbon storage, both coefficients in Tab.3 and Tab.5 are negative and, as far as the regression is concerned, not significant. The importance of urban trees in removing carbon from the atmosphere and storing it in their biomass is acknowledged by many authors (e.g., Nowak & Crane, 2002; Johnson & Gerhold, 2003; Roy et al., 2012; Strohbach & Haase, 2012). Urban tree's effectiveness in providing CCS is affected by several factors, first and foremost the size of land covered by trees (Nowak et al., 2013), but also other factors such as tree density, limitation to tree growth due to management such as pruning (Ningal et al., 2010), species type (Soares et al., 2011; Tan et al., 2021; Shen et al., 2023), age, structure, and overall condition (Russo et al., 2014). Most studies focus on urban forests and urban parks, while the role of street trees is under-researched; such role is highly important in our study area because most records concerning trees in the city dataset used in this study refer to street trees. In Cagliari, they usually grow in small planting pits in sidewalks, which can hamper carbon sequestration by affecting the soil substrate and its quality (Schütt et al., 2022), as well as water dynamics and water retention, hence impacting on trees' growth and overall condition (Nielsen et al., 2007). Tang et al. (2016) maintain that the magnitude of carbon density and sequestration by street trees in Beijing is comparable to that of non-urban forests in China, although lower than in European cities; however, Soares *et al.* (2011) report carbon sequestration by street trees to be fairly low in Lisbon, compared to either North-American cities or to urban forests. This might explain the low value of the coefficient linking Perc_Tree to C_stor in both Tab.3 and Tab.5. Moreover, a possibly relevant observation for Cagliari is that by Havu et al. (2022), according to whom street trees in Helsinki can act both as carbon emitters or sinkers depending on their age and on seasonal variations, which might also help explain the lack of significance of the regression coefficient in Tab.5, since no information concerning age is available in the study area.

Contrary to Perc_Tree, both Perc_Bush and Perc_Lowv show positive and significant correlation with C_Stor (Tab.3) and the impact of Perc_Bush on C_Stor is positive and significant as far as the regression model is concerned (Tab.5). As with trees, factors such as species type, size, and structure are important in CCS provided by urban shrubs (Khan et al., 2020). Although it is well known that shrubs store less carbon than trees (see for instance, Curry et al., 2016 for an assessment in Michigan, United States), a study by Edmondson et al. (2014) on gardens in Leicester (UK) shows that carbon storage in the topsoil is higher under trees, followed by topsoil beneath urban shrubs and herbaceous vegetation, which both perform better than non-urban agricultural fields, hence highlighting the importance of mid- and low-height vegetation in fostering carbon storage in soils. Furthermore, a relevant study on CCS by shrubs is that by Baraldi et al. (2019), who, despite estimating their CCS capacity lower than that by trees because of their smaller structure and leaf coverage, report that evergreen shrubs can perform better than deciduous trees because their removal activity through photosynthesis spans across the year. This is most likely of importance in Cagliari, where large areas are covered by evergreen shrubby vegetation, such as Mediterranean maquis with Euphorbia in south-eastern hills along the coastline, halophyte mid-height plants closer to the two larger wetlands, woody bushes and low, immature coniferous trees in the most important urban parks.

Secondly, as far as ROC is concerned, Tab.3 highlights the positive significant correlation between Dens_Ret and Perc_Bush and Perc_Lowv, as well as the positive, but far less significant, correlation between Dens_Ret and Perc_Tree. This signals that, in general, ROC is positively correlated with whichever type of vegetated land cover, not only because of the soil's higher porosity, but also because vegetation, even when herbaceous, channels water fluxes through the roots (Técher & Berthier, 2023), although trees have been found to deliver the higher levels of runoff mitigation in urban forests in a study by Rahman et al. (2023), possibly because of their deeper roots which slow down water saturation in superficial soil layers. Moreover, Tab.5 singles out Perc_Bush as the most important factor in positively driving Dens_Ret, while, and counterintuitively, the coefficient of Perc_Tree is negative, although quantitatively modest.

Trees recorded in the city dataset are mostly street trees in planting pits surrounded by paved surfaces; therefore, this highlights the significance of permeable, vegetated areas in retaining rainwater, therefore also shedding light on the quantitatively relevant, negative, and significant Pearson coefficient reported in Tab.3 as for the relationship between Dens_Ret and Sup_Nvp. This is in line with Armson et al. (2013), who found grassy areas to contrast stormwater runoff much better than trees in planting pits in Manchester because of the reduced infiltration within tree pits, while also showing that even small tree pits help reducing surface runoff if compared with fully paved sidewalks and roads.

The negative impact of impervious areas is fully acknowledged in several other studies, some of which propose mitigating solutions that result in increased vegetated areas, such as planting bushes and trees in paved areas to improve infiltration in Turin (Salata et al., 2021) or unsealing paved areas and planting native shrubs to improve water retention in Izmir (Turkey) (Salata et al., 2022).

Finally, in regard to HEM, Tab.3 and Tab.5 highlight the positive impact of Perc_Tree on HEM, since both coefficients are significant and negative, hence an increase in the size of treed areas within a census tract is associated with lower maximum values of the surface temperature, although the magnitude of the impact is small, as signaled by the low regression coefficient. Zardo et al. (2017) assess the effects of tree canopy coverage, soil cover, and unsealed land size on the cooling capacity of three climatic regions; one of the most important, and straightforward, finding, is that size matters: in the Mediterranean area, unsealed soils smaller than two hectares have limited cooling capacity even when having a good canopy coverage. This helps explain the counterintuitive positive coefficient that relates LST_max and Perc_Lowv in Table 3, which, in the built-up and dense part of the city, include all of the small green areas within building blocks retrieved through the NDVI map, as explained in section 2.2.

In agreement with the above finding by Zardo et al., Marando et al. (2019) confirm that the HEM capacity of urban trees in the Mediterranean context is affected by the size of the area they stand on: by taking Rome as a case study, they show that the mitigating capacity of tree canopies in road tree lines is approximately half that of urban and periurban forests; according to the authors, and in line with evidence from Cagliari, this happens because street trees' roots are mostly constrained within planting pits surrounded by sealed soils which hamper evapotranspiration, and ultimately the cooling effect. The limited cooling capacity of tree lines can be improved through appropriate design, which includes not only choosing the most appropriate species (Ballinas & Barradas, 2016) to increase both evapotranspiration and the size of the shadow, but also selecting the appropriate interval between individual trees depending on their height and width (Park et al., 2019). What is more important, notwithstanding their lower cooling capacity compared to urban forests, tree lines or even isolated trees within built-up areas are significant in reducing heat-related illnesses in the elderly, thus improving human well-being, as discussed by Venter et al. (2020), who simulate tree removals and apply a counterfactual model to the city of Oslo.

Similar positive effects of scattered trees in densely urbanized areas on the health of vulnerable populations have also been reported in the case of Boston (Tiesken et al., 2022), to the extent that the authors assert that the HEM capacity of urban trees is underestimated.

In this vein, the city of Los Angeles has launched its "Million Trees LA initiative", whose benefits in terms of reducing mortality rates have been assessed by McPherson et al. (2011) through scenario simulation. Finally, with reference to the low-height vegetation land-cover type, which includes grassland, lawns and gardens, contrary to the findings from this study its HEM service has been found to be observable, although much lower than that of trees, in previous literature (for instance Park et al., 2021 as regards Yongin-si, in South Korea, or Zhang et al., 2017 as for Nanchang City, China).

5. Conclusions

This study focuses on the impacts of intensive urbanization on the supply of ecosystem services. The city of Cagliari, a medium-sized Italian regional capital city, is targeted as the urban environment to analyze such impacts, on the basis of the assessment of the relationships between the provision of ecosystem services and the spatial framework of the urban fabric, characterized by land covers identified by unsealed and sealed soils. Unsealed soils are classed as wooded and tree areas, medium-height shrubby land cover, and ground cover featured by low-height vegetation and sparsely vegetated or bare soils. Moreover, four characteristics of sealed soils are targeted, which are highly correlated with each other, such as population density, built volume density, density of housing units, and unsealed area. The supply of three ecosystem services is assessed, identified with CCS, ROC, and HEM, with reference to spatial distributions which target census tracts as reference areal units.

Two complementary methodological approaches are implemented in order to assess the relationships between the supply of urban ecosystem services and the size of unsealed and sealed soils. First, the SRCCs concerning the variables associated with the supply of the three ecosystem services and with the characteristics of sealed and unsealed soils, are computed and assessed in terms of *p*-values. Second, regression models are estimated to control for the impacts on the provision of the three ecosystem services generated by a set of covariates associated with urban land cover features. The results related to the SRCCs are significant and in line with expectations in terms of the signs of the coefficients, and consistent with the estimates of the regression models.

Policy implications can be straightforwardly identified, which entail that increases in the supply of the CCS, ROC, and HEM ecosystem services target the expansion of shrubby and low-height ground covers, and of wooded and tree areas grounded on large garden beds, or, even better, on continuous vegetated areas. The increased size of vegetated areas, be they characterized by forests or woodlands, or medium- or low-height vegetation, would be associated with increases in CCS and in the effectiveness of ROC, whereas the presence of trees and wooded areas would be correlated with heating mitigation. That being so, the integrated increases in the size of vegetated areas and of tree-covered areas would generate a comprehensive significant improvement in the city quality of life (Lai et al., 2020; Gómez-Baggethun & Barton, 2013), in terms of the three targeted ecosystem services. Policies aimed at pursuing such integrated increases should be associated with virtuous behaviors on behalf of the local communities, organized citizen groups, building companies, and public administrations (Mazzeo et al., 2019; Zoppi & Lai, 2013).

An important issue concerns the narrow relationship between the value of land and the maximum permitted volume, in terms of either residential or service buildings. In this perspective, the plantation of new vegetated areas, be they covered by trees, shrubs, or low vegetation, or the expansion of areas characterized by such land covers, would imply the implementation of appropriate planning measures. Said measures should carefully integrate the landowners' demands and the public interest which would entail a plea for a robust increase in the size of urban green areas, in face of a significant decrease in the value of a share of the urban land.

In view of this, rigorous rules should be operationalized to control over building permits related to new and existing urban settlements, which should be associated with an adequate provision of wooded and tree areas or vegetated areas, such as green roofs, walls and facades, rain gardens, swales, and related collection tanks (Berland et al., 2017; UNaLab, 2019), as much as green and blue urban grids, as it occurred in East London (Jenning et al., 2016; Mathey et al., 2011).

Moreover, a structured system of public financial incentives should be planned to make the implementation of urban greening policies attractive for landowners and investors (De Noia et al., 2022; Bramley & Watkins, 2014; Webster, 2005). Such operational framework can be based on the integration of several instruments, such as grants made available to building firms on condition that new developments are endowed with an agreed-upon amount of wooded, tree or green areas, impact fee reductions, and VAT and property tax allowances (Slätmo et al., 2019; Buijs et al., 2019). Lastly, the commitment of local governments towards increasing the supply of the CCS, ROC, and HEM ecosystem services should be made visible and recognizable to the local societies through flagship financial operations such as public purchasing of areas where to implement urban greening policies (Pérez-Urrestarazu et al., 2015; Fors et al., 2015).

The methodological approach defined in this study, and the outcomes provided by its implementation with reference to the city of Cagliari, effectively address the research question highlighted in the Introduction, namely, how and to what extent is the endowment of sealed and unsealed areas related to ecosystem supply in intensively urbanized urban areas? As discussed across the article, the findings indicate that an adequate endowment of vegetated areas and of tree-covered areas would be associated with a comprehensive and relevant urban living quality, which builds on suitable levels of the CCS, ROC, and HEM ecosystem services.

The value added of the methodology here implemented is identified by the fact that it is readily exportable to other urban contexts of different demographic sizes, and physical and social conditions, since it develops through databases whose structure is easy to build and whose data are straightforward to retrieve and collect, across cities located in different regions and countries. Moreover, not only is the methodological approach easy to export, but also the results of its implementation as regards cities located in different national and international urban contexts can be readily and effectively compared.

Finally, this study leaves plenty of room for future research concerning other ecosystem services supplied in and by urban environments, such as food production, recreational services, natural and cultural heritage, and so on, whose analysis can build on the identification and assessment of their relations with urban land covers and uses, whose specification can be different and possibly more detailed than the characteristics considered in this article.

Authors' contributions

Sabrina Lai (S.L) and Corrado Zoppi (C.Z.) collaboratively designed this study. Individual contributions are as follows: C.Z. wrote Sections 1; 2.3, 3, and 5. S.L. wrote Sections 2.1, 2.2, and 4.

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Image Sources

Fig.1 to 3: Author’s elaboration.

Table Sources

Tab.1, 2: Different sources mentioned in the tables;

Tab.3 to 5: Author’s elaboration.

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The Eco-Pedagogical Microforest a shared oasis of proximity. A cutting-edge project at the intersection of ecology, urbanism and pedagogy

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Abstract

Cities and urban areas are one of the critical global systems that can accelerate and upscale climate action and more than ever need to achieve the 11 goals of Agenda 2030 becoming inclusive, safe, resilient and sustainable. In 2019, Science published a paper suggesting that planting trees, on a massive scale and sustained period of time, represented one of the most effective solutions at our disposal to mitigate climate change. Cities across the world have started implementing urban forests to address multiple environmental issues. Urban forests are capable to provide more complete solutions than other urban NBS. In this context, the challenge for cities is to disseminate UF-NBS throughout the city in order to release environmental and social benefits even in the most dense areas, spreading wellbeing for all citizens. The paper illustrates a cutting-edge experimentation of a tiny forestation action at the neighborhood scale, aimed at integrating both regulative and social-cultural ecosystem services. In line with the principles of the UN Agenda 2030, the Eco-Pedagogical Microforest project, that took place in Rome, demonstrates that even a small patch of nature can increase young people's biospheric values, influencing pro-environmental behaviors and actions, enhancing wellbeing.

Keywords

Climate change; Green infrastructure; Urban forestation; Environmental learning; Citizen science.

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1. Climate change, green urge

1.2 Cities as key actors

New environmental, ecological and social emergencies call into question the Global Economic Model and the anthropocentric approach to development. Today, the planet's inhabitants exceed 8 billion (Worldometer, 2023) and will reach the threshold of 9.8 billion in 2050, according to UN estimates (United Nations, 2022). By the same date, the world economy could have more than doubled, according to the World Economy Report (PWC, 2017). But already by 2020, the weight of man-made materials exceeded the weight of biomass: not an easy achievement, marking a watershed moment for our species (Elhacham et al., 2020).
How can the course of events be redirected? In 1972, Aurelio Peccei, in the foreword to the Italian publication of the Meadows Report, expressed his fear of a dead-end crisis and the need to start a process that must go to the very roots of our economic model. As the founder of the Club of Rome noted at the time, "the political class in every country will continue to lag behind the times, prisoner of the short term, of sectorial and local interests" (Peccei, 1972). And 50 years later the framework is still the same. During the Sharm El Sheikh COP, in 2022, the nation-state engagements of the Paris summit (COP 21) have failed and a goal that seemed essential to keep global warming below the +1.5 °C threshold has vanished.

Fig.1 Global warming. Low cost NBS to temporary mitigate heat island in cities. Paris, Parc Rives de Seine

Producing less energy, reducing fossil resources consumption, a sector that for Our World in Data Lab accounts for 84% of global primary energy, seems unachievable (Our World in Data, 2023). But it has been possible for a handful of weeks. In 2020 the planet came to a standstill to fight the Covid-19 pandemic, which caused over six million deaths (WHO Covid 19, 2023). Instead for the seven million people who lose their lives every year due to air pollution, the world's great economies are unwilling to slow down the GDP locomotive (WHO, 2021).
Pending structural macro-economic revisions and the consideration of models that move in the direction of prosperity without growth (Jackson, 2009), the UN urges cities to become agents of change with Agenda 2030, Objective 11: Make cities and human settlements inclusive, safe, resilient and sustainable (United Nations, 2016).
This perspective turns out to be not only achievable, because mayors are more collaborative than national rulers, but also strategic: 70% of greenhouse gas emissions and more than 50% of the world's population are concentrated in cities (World Bank, 2023). Cities and urban areas are one of the critical global systems that

can accelerate and upscale climate action (Papa et al., 2015; AA.VV., 2018). As well as gaining prominence in its own right, this focus on cities is also to be found in the increasingly converging international agendas for urgent action on climate change and biodiversity.

The New Urban Agenda SDGs have pointed to both the interconnected nature of sustainable development and the importance of cities and communities. If states stand back, cities are at the forefront of mitigation and adaptation actions. As the Covenant of Mayors initiative demonstrates, cities have become key actors of a worldwide green, soft transformation towards resilience. Since 2008 over 10,000 cities and mayors are increasingly the protagonists of change adopting the Sustainable Energy and Climate Action Plan (SECAP) and taking action to implement it (European Commission, 2023).

1.2 The green colour of urban resilience: from NBS to UF-NBS

In order to create more resilient and sustainable cities and societies, Europe set its agenda to implement research and innovation projects. Since 2014, the European Commission has been funding multiple green projects for cities through the Horizon 2020 programme (H2020) by identifying Green Infrastructures (European Commission, 2013) and Nature-Based Solutions (European Commission, 2015) as key elements to mitigate the impacts related to Climate Change in urban contexts (Galderisi & Ferrara, 2012).

Among NBS that produce services, which in turn provide social and ecological benefits for communities, the role played by Urban Forests is growing in importance. Therefore cities across the world have started implementing Urban Forests to address multiple environmental issues (Uforest, 2022).

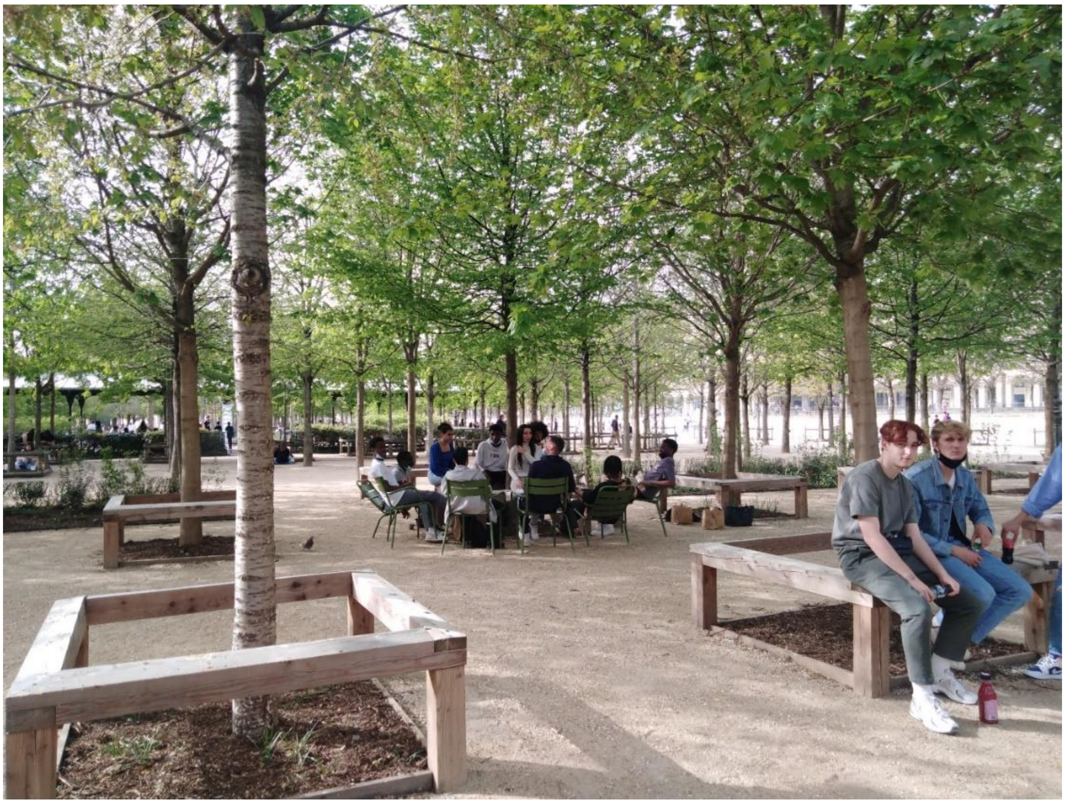


Fig.2 Urban Forest an effective solution to increase people's resilience

In 2007, the New York 'Milliontreesnyc Programme' opened the race for urban forestation. Since then, other capital cities follow the path of trees to counteract the effects of climate change and increase biodiversity (Dickinson, 2022). These bring nature and the city closer together, develop cost-effective actions and long-term measures able at enhancing urban resilience (FAO, 2021). In this regard, Science published a paper suggesting

that planting trees, on a massive scale and sustained period of time, represents one of the most effective solutions at our disposal to mitigate climate change and improve the quality of life (Bastin et al., 2019).
The same year, the United Nations Economic Commission for Europe launched the 'Trees in Cities Challenge'. Worldwide mayors and local governments are invited to make a tree-planting call and set objectives for making cities greener, resilient and more sustainable (UNECE, 2019a). By 2022, over 11.2 million trees have been planted thanks to the commitment of 70 world cities. Europe in 2018 launched the Green Deal (European Commission, 2018) and in 2020 started to invest in forestation mainly in urban and peri-urban areas through the 'New EU forest strategy for 2030' that envisages the planting of 3 billion trees by 2030 (European Commission, 2021).
And if urban forests can contribute significantly to generating ecosystem services (Roeland et al. 2019) providing recreation and amenity values (Konijnendijk, 2005), what new studies tend to argue is the importance of the cultural and social services produced by UF-NBSs, such as social cohesion and the engagement of local communities in favor of the environment, highlighting their ability to provide more comprehensive solutions than other NBSs (van den Bosch et al., 2017).
Thus UF-NBS need to be experimented in order to demonstrate if this can constitute a better solution to build stronger link between communities and nature that can develop long term care practices able to increase resilience, environment quality and wellbeing as well (Clearing House, 2021).
From this acknowledgement, the illustrated project investigates and experiments 'for real' a new form of UF-NBS that can enhance at one time regulating, social, cultural and pedagogical ecosystem services in order to strengthen the link between people and nature and therefore guarantee a long term stewardship that helps UF-NBS blossom and thrive. This new form is the Microforest or Tiny Forest, a cutting-edge kind of forestation that can be spread in the dense city, conquering underused and empty urban spaces.
'Forests can cover vast areas as in the Amazon and Borneo. A Tiny Forest can cover vacant islands of land, a highway roundabout, a small portion of a playground in a nursery school' (Hawken, 2022). From field experiences, the press and the web, more than from scientific literature, this new pocket-sized forestation is emerging and conquering cities and neighbourhoods of the world: 'Tiny Forests are popping up in big cities' (Hewitt, 2021).

2. Forests for the dense city: the Tiny Forest revolution

2.1 Tiny Forests' short profile

Tiny Forests are germinating, blossoming and colonizing worldwide city spaces. Thanks to Japanese botanist Akira Miyawaki (Miyawaki, 1996) and Shubendu Sharma (Afforestt, 2011), the mini forestation has become a Method that encourages public involvement, can be implemented by everyone and everywhere. 'By communities, classrooms, cities, clubs, families. We do not have to wait for nations, banks and corporation to act' (Hawken, 2022). Generally, Tiny Forests are no larger than a tennis courts, 250 m2 is the average size, but they can even be smaller and easily fit in any kind of public space. These features make the Miyawaki Method revolutionary (Lewis, 2022).
This urban patch of nature, inspired by the Miyawaki's Method, has been developed from 2011 first in India, by former Toyota engineer Shubendu Sharma who registered the Tiny Forest trademark (Sharma, 2014). In 2015 the format was imported into Europe by the Netherlands' IVN Natuureducatie association (IVN Natuureducatie 2023a) and since it has spread in Belgium, from England to Germany, arrived in France and more recently landed in Italy. A Tiny Forest can be planted in one day, grows fast and becomes more biodiverse than a 'classical' one. It took only 5 years to the trees of the first European Tiny Forest of Zaandam (Netherlands) to rise and gain 12 meters height (IVN Natuureducatie, 2023b).

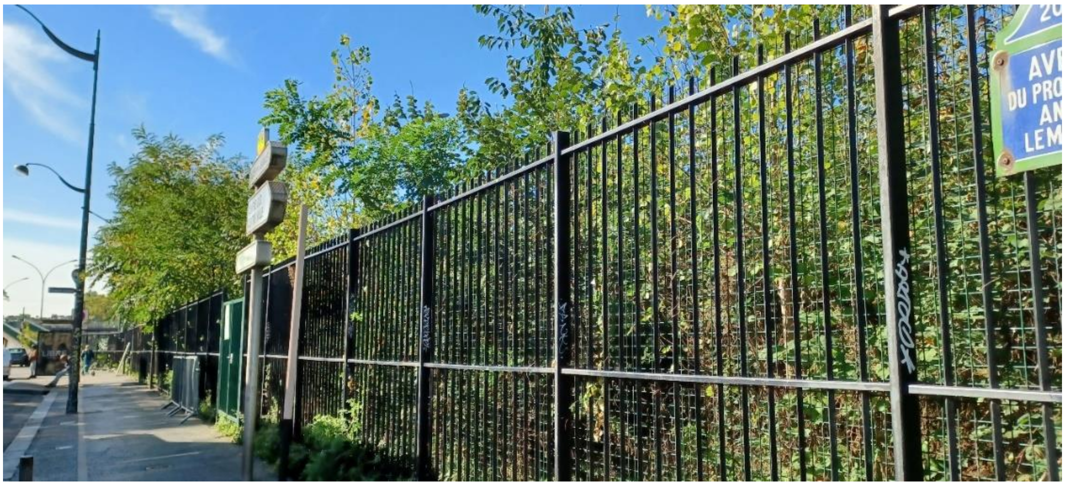


Fig.3 The first Tiny Forest in Paris, 400 m2 along the périférique. Paris, XX° Arrondissement

Since the Tiny Forest movement began, 3,000 tiny forests have been planted, 96.7% of which developed into resilient ecosystems within 10 years (Earthwatch Europe, 2023).

Tiny Forests foster a new approach of urban forestation as place-making and reinforce the links between citizens and nature, supporting citizen's environmental engagement. EarthWatch Europe based in UK, the most European active association on the field along with the Dutch IVN, states that each Tiny Forest is expected to engage up to 100 volunteers on planting and monitoring days; 4-6 volunteers as a Keeper Team to take care of the forest; wider community, visitors and school children as an inspiring place to enjoy nature (EarthWatch Europe, 2023).

2.2 What a Tiny Forest can do

The Tiny Forest's recent history has not made it possible to develop a conspicuous scientific literature on the matter, but the beneficial invasion underway in the landscape of the planet's urban contexts unquestionably demonstrates its value.

There are only two sources that publish reports on the subject and in both the findings are the results of volunteering citizen scientists who undertake scientific research projects: IVN Natuureducatie and Earthwatch Europe that has partnered with IVN.

IVN cooperated along with Wageningen University in order to develop scientific surveys focused on the topic of biodiversity, with the support of 12 volunteers involved in a Citizen Science performance. The first place investigated is Zaandam where the first Dutch Tiny Forest has been implemented in 2015.

The report released in 2017 by the University demonstrates that the Tiny Forest is a biodiversity attractor to a greater extent than neighbouring forests giving home to 595 plants and animals (Ottburg et al., 2018; Müller, 2021).

The following report, published on the IVN website, includes a wider range of case studies (11 Tiny Forests) and encompasses multiple issues: biodiversity, microclimatic comfort, CO_2 sequestration, water retention. The surveys show an average number of 270 species per Tiny Forest, including both plants and fauna; a cooling capacity of 7 °C; 127.5 kg/year of CO_2 sequestration for the first 5 years, then 250 kg/year as the mini-forest grows older (IVN Natuureducatie, 2022). Finally, the average value of water / year absorbed by each Tiny Forest is around 10,000 litres.

The second source is the Earthwatch Europe association, which published on its website two reports on its monitoring activities in 2021 and 2022 (149 Tiny Forests). Here too, the data are collected by citizen scientists who have increased in number significantly from 776 volunteers in 2021 to 3,465 in 2022 (Earthwatch Europe, 2023).

As the most recent data demonstrate biodiversity thrives in Tiny Forests (36 species) and this is the main documented research field investigated. The sequestered CO_2 has been calculated considering the green weight of the different species planted and the result is that each Tiny Forest absorbs on average 160 kg/year.

Tiny Forests' infiltration rates are determined by measuring the length of time taken for 450 ml of water to fully infiltrate in the soil. And the experiments demonstrate that water infiltration is 32% faster inside the Tiny Forest than outside. Concerning the thermal comfort, no consistent trends could be discerned from data. Thus, as the thermal comfort is related to individual feelings, physical and psychological factors, a survey through questionnaires has been realized with the results that 93% of people attending the Tiny Forest feel cooler.

Finally, even though the data released by the two sources cannot be compared, at the end the reports achieve similar outcomes. The capacities to demonstrate are biodiversity attraction and water absorption. But Tiny Forests can do much more. They can release environmental quality, wellbeing, social cohesion and connectedness to nature.

To assess this, social surveys are being gathered across the Tiny Forest network from volunteers and partners of Earthwatch Europe association (73 participants surveyed at 11 Tiny Forests in 2021 and 2022). "90% of participants surveyed said the Tiny Forest made them feel calm and relaxed (88% in national Monitor of Engagement with the Natural Environment survey); 93% of participants said the Tiny Forest made them feel refreshed and revitalised (90% in national MENE survey); 97% of participants said they felt close to nature; 98% of participants using the Nature relatedness scores (80) had a score greater than 3 showing they already had a strong connection to nature which is related to how much people care for and act to protect the environment" (Earthwatch Europe, 2023).

So in short, this unusual form of nature easily finds space in urban contexts, grows and generates ecological benefits in a short time. When the development of Tiny Forests is accompanied by an active multigenerational community and the project is enhanced by paths of scientific knowledge, including Citizen Science actions, the social and cultural benefits complement the ecological ones, increasing not only the community's wellbeing, but also environmental awareness. In the end, a Tiny Forest helps reconnect people with nature.

2.3 The urge of neighbourhood Microforest

The Tiny Forest is definitely a neighbourhood forest, a Micro ecosystem and a cutting-edge urban green component where regulating ecosystem services, biodiversity, wellbeing, participation, place-making topics converge.

From this point of view, it presents analogies with the concept of the Oasis, which recalls the need to develop multisensory and participatory approaches to propose new figures of urban composition capable of integrating environment, sociality and physical space (Fratini, 2020a; Leroy-Thomas et al., 2021). Like the Oasis, a Microforest increases, at the size of a neighbourhood, the multisensitivity of local landscape (Peyrouzère, 2018; Pelorosso et al., 2013; Miles et al., 2001).

The social activities that can take place around a Microforest, the multiplicity of observations that can be carried out from nature's life, the sensitive phenomena released by the vegetation and fauna induce a sense of curiosity, contentment, calm and well-being (Balaÿ et al., 2018). In this regard a Microforest, as an UF-NBS, reveals all its potential as a complex ecosystem, providing more comprehensive solutions than other NBS (van Den Bosch, 2017).

Furthermore the Microforest is not an island, it is an urban ecosystem surrounded by roads, buildings, activities, people. A dimension that requires multidisciplinary expertise, the interaction between place and users, a metric of uses attuned with the specificities and rhythms of nature (De Biase et al., 2018).

An approach is thus configured that outlines a new urban vision, at the intersection of ecology and urbanism (Clergeau, 2020), which reinforces the importance of a planning approach focused on the environment potentialities of empty spaces, capable of reactivating links between city spaces, nature and citizen's community (Marry, 2018).

From this point of view, the Microforest can support the reconstitution of a system of possible meanings, values and roles to be defined through the contribution of local society, giving 'sense to place' (Di Giovanni, 2018).

Fig.4 The Microforest aims at increasing curiosity and exploration, fostering interaction between very young people and nature. Rome, Parco dei Caduti

The multifaceted dimension of the ecosystem services delivered also intersects the drive for an innovative interpretation of the theme of urban welfare, proposing Microforest as a 'neighbourhood equipment' in tune with the principles of the 2030 Agenda.

In this regard the NBS Institute suggests the 3-30-300 rule for greener, healthier, and more resilient cities which means at least 3 trees in sight from every home, school or workplace; no less than 30% tree canopy in every neighborhood; and never more than 300 meters to the nearest public green space (NBSI, 2023). As Konijnendijk states, the rule focuses on the crucial contribution of urban forests to our health and wellbeing, as well as climate change adaptation, and it also addresses the need for urban forests to percolate into our living, working, and living environments. We need to bring trees and nature into neighborhoods, streets, and on people's doorsteps in order to capitalize on their many benefits (Bell, 2005; Dwyer, 1992; Livesley, 2016). By creating more leafy neighborhoods we also encourage people to spend more time outdoors and to interact with their neighborhood, which in turns promotes conviviality and wellbeing (Konijnendijk, 2021).

Finally planting neighbourhood forests means pursuing an integrated approach to mitigate climate change impacts, enhance people's nature connectedness and encourage multipurpose experiences for healthier and happier cities for all, within 15 minutes walking distance (World Urban Forest Forum, 2018; Semeraro et al., 2022).

3. From Tiny Forests to the Eco-Pedagogical Microforest

3.1 Seven objectives for an Eco-Pedagogical Microforest project in Rome

All that being said, the paper illustrates an empirical project that intends to explore an easy to handle and fast growing Microforest to be planted within the size of a neighborhood. Given that the Eco-Pedagogical first goal is to attract and educate very young people, schoolchildren, to the cause of the environment and increase connectedness with nature. the project envisages the involvement of very young people, the schoolchildren community, from the early steps of the process through an Eco-Pedagogical Pathway. Therefore, from the beginning, the Microforest has become Eco-pedagogical.

The theme is indeed a subject of significance considering that cities need more than ever to be sustainable, time for changes is short and Urban Forestation is the easiest and fastest way for cities to try and mitigate climate change impacts and increase resilience, especially in the dense city.

The underlying challenges of the project can be summarized as following:

- Diffuse Urban Forestation in the dense city, considering the principles delivered by Agenda 2030;
- Promote Urban Forestation at the neighborhood scale;
- Implement multistakeholder partnerships to support the neighborhood forestation project;
- Design and realize a cutting-edge Urban Forestation project local-based, low cost and fast growing;
- Build a successful involvement process to empower children and teenagers in the design, realize and monitoring stages;
- Design an Eco-Pedagogical Pathway to awake in young generations empathy towards nature, turning education into an experience to learn about the environment;
- Disseminate the project and build synapses with existing planning programmes.

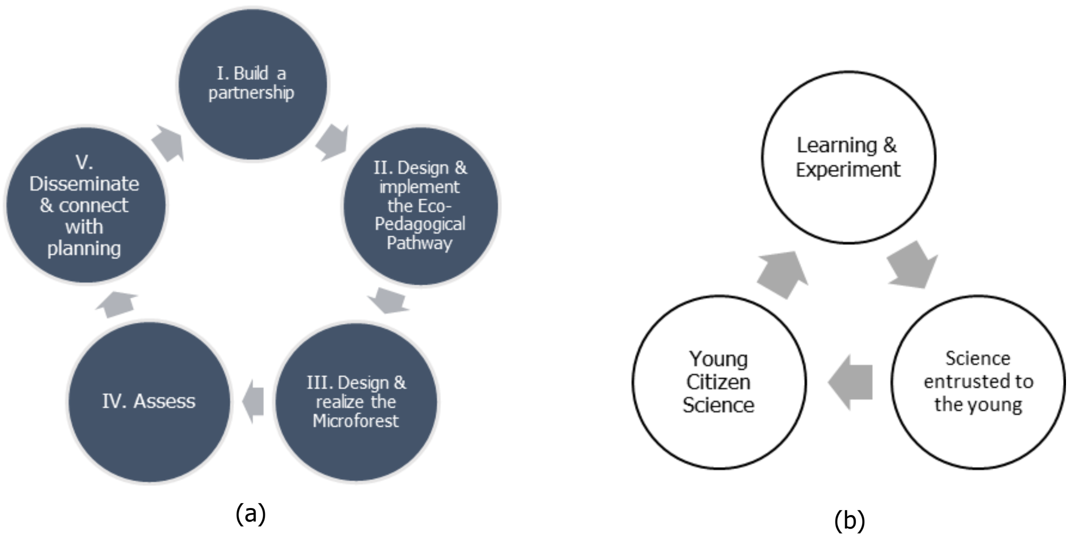


Fig.5 The 5 stages of the methodology (a) and the 3 stages of the Eco-Pedagogical Pathway (b)

The Eco-Pedagogical Microforest project, funded by a Third Mission Sapienza research, intends to decline urban forestation on a local scale, framing the experimentation within a multilevel strategy, empowering young citizens through the proactive involvement of the schoolchildren community. The multistakeholder and multilevel partnership which made it possible is composed by Regione Lazio – Progetto Ossigeno, Comune di Roma, Municipio II, Municipio VIII, ICS Tiburtina Antica 25, local associations and University Sapienza Engineering, Biology and Psychology Faculties with 7 professors of different disciplines, 3 PhD students and 100 students.

The methodology is articulated in five main stages. The first is dedicated to building a multistakeholder and multilevel partnership. While the second consists in the design and realization of Microforests, the third is focused on the Eco-Pedagogical Pathway. The assessment stage is related to the third stage because the surveys are mainly released through young citizen science actions. The last stage concerns dissemination and the research of possible connections with the urban regeneration programmes of Rome.

While the Eco-Pedagogical stage has been developed following a timetable, the timing of the realization, related to the decision-making trajectories, has been impossible to foresee. But at last, after only one year the project has been concluded in all its parts.

3.2 Stage I - Kind of partnerships, different results

Within this framework, two Microforests have been created within 12 months from the start of the Third Mission Sapienza research. The first was planted the 17th of December 2022 in the Parco Malaspina (Municipio

VIII), the second the 24th of February 2023 in the Parco dei Caduti, in the San Lorenzo neighbourhood (Municipio II).
The mosaic of the partnership, and the mix of stakeholders involved, the sources of funding determine the difference between the two case studies.
With a Public – Private – People Partnership (UNECE, 2019b; Boniotti, 2023), the Municipio VIII, along with Sapienza, the AzzeroCO_2 private firm, Fasteweb and Ostiense – Garbatella neighborhood committee has planted, the 17th December 2022, 1,000 small trees and bushes in an area of 800 m^2 located close to the Ostiense railway station. In this case the process, that was put in place in short time due to Fastweb's priorities, was led by Municipio VIII, the local association participated as the entity responsible for the area, and Sapienza was consulted for the Microforest project. The second stage of the process, the one focused on the involvement of the local school, was not considered a priority and so it is still in progress. The result: the Microforest is now suffering from a lack of stewardship and waiting to be "discovered". The multiple benefits that it can produce remain, for now, in incubation.

Fig.6 Parco Malaspina, the Microforest planting day. 1,000 plants distributed in 800m2 by the Fastweb team

In the case of the Parco dei Caduti, a Public – People Partnership led by the University was put in place with the Municipio II and the Lazio Region – Progetto Ossigeno and the Microforest was planted the 24th February 2023. From the early stage of the process the school community has been actively involved and the Microforest has blossomed thanks to the primary and secondary schools of ICS Tiburtina Antica 25.
Teachers and schoolchildren have been guided through the 'eco-pedagogy of the Microforest' process by the University team (Nogué, 2010). The one-year learning and experiment pathway that took place in San Lorenzo nurtures the growth of a relation between very young people and nature. During this time children and teenagers increase their awareness on environmental topics and thus improve their behaviors in a way that will allow them to safeguard nature (Chistolini, 2016). At the end of the process, the Microforest has become a scientific laboratory, a symbol of rebirth, a perceptive reference for the neighborhood's community.
Thus the paper illustrates the Microforest of Parco dei Caduti's successful process that starts with the school community of San Lorenzo gathered in the Parco dei Caduti to design the border of the Microforest to be built and is still continuing with the young citizen science activities that have been implemented to monitor and assess the 'healing power of the forest', quoting Miyawaki (Miyawaki, 2007).
'We need to tell the stories of success from communities across the globe, these achievements are grassroots, wholesome, and empowering, and ensure that trees will not be neglected, as a passing by fashion' (Clearing House, 2021).

4. Stage II - Design and realize the Microforest: the pilot case of Parco dei Caduti

4.1 Why San Lorenzo

San Lorenzo is the place where the first Eco-Pedagogical Microforest of Rome has been planted. The neighborhood is, since 2016, the field of green-oriented empirically based experiments carried out through Sapienza funding in collaboration with the Municipio II, associations, and the local school. 'Oasi San Lorenzo Green Network' is the research that frames the temporary and nature based micro-realizations inspired by an approach of urban acupuncture (Lerner, 2014; Fratini, 2020b).

The first cutting-edge experimentation is the 'San Lorenzo Temporary Forest' built in 2018 with 100 potted trees, 18 donated by the Presidential Reserve of Castel Porziano, and located in the Ex-Dogana area (Fratini, 2020). From the success of this case comes the Eco-Pedagogical Microforest in the Parco dei Caduti.

The choice of location is inspired by a place-based approach (Castellar, 2021), and is aimed at regenerating a central and disputed public space, with the purpose of developing multifunctionality and favor tolerance, new uses and behaviors, environment awareness and the respect of nature, stewardship to help the Microforest to grow and thrive.

Fig.7 The Bosco Temporaneo San Lorenzo, 100 potted trees under the tangenziale to bring nature in a former railways deposit area, today under construction

The Parco dei Caduti is a space included in the urban fabric surrounded by buildings, what Gordon Cullen would call an enclosure (Cullen, 1964). The area is lived in and crossed daily by the inhabitants and the children of the school, which is located just 20 meters from the entrance. Proximity with the school, multifunctionality, mixed users are the successful ingredients of a UF-NBS project that intends to increase conviviality, include nature in the urban landscape, develop links between citizens (young but not only) and forms of vegetation closer to a "nature reserve" than to a garden.

Within a Green Infrastructure approach, the Eco-Pedagogical Microforest of the Parco dei Caduti is a component of a neighborhood green layout, to be put in practice, designed to connect public space, existing green areas and those to be regenerated through green streets and slow mobility, with reference to the Barcelona Superblock Programme (Ajuntament de Barcelona, 2022). These interlinkages can have multiple benefits, providing ecosystem services (Hansen & Pauleit, 2014; Carrus et al., 2015; Zardo, 2017) integrating the social and environmental concerns of landscape with urban planning (Arcidiacono & Ronchi, 2021; Tulisi, 2017).
Finally the Microforest is not an isolated dot but a node of the neighborhood's green network (Local Green Infrastructure), a green-multifunctional recreational opportunity located at walking distance from the center of the neighborhood and close to the school. Thanks to its features the Eco-Pedagogical Microforest has the capacity to decline ecology, proximity, participation and solidarity within the neighborhood unit and thus become a green equipment for the 15 minute-city model (Moreno, 2021).

4.2 What? The shape of the Microforest

What does the Microforest look like? The more diffused kinds of Microforest, as the city experimentations on the field demonstrate, are edible Tiny Forest (Zandaam, 2015); adaptive Microforest (Reggio Emilia, 2023); natural Microforest (Paris, 2018). The type selected for the Eco-Pedagogical Microforest is the latter with the purposes of creating a tiny natural reserve of Mediterranean scrub enclose in the Parco dei Caduti area providing a landscape of a shared natural and cultural heritage (UNESCO, 1994; Lowenthal, 2005).

Fig.8 Microforesta Parco dei Caduti, 24 February 2023. The inauguration day with over 300 schoolchildren

As the European Landscape Convention (2000) and the Faro Convention (2005) outlined, landscape and cultural landscape link people and places, tangible and intangible elements and provide fundamental resource for human well-being and sustainable development (Bianconi et al., 2018; Sodano, 2018).
On the other hand the purpose is to fulfill the Method designed by Akira Miyawaki in order to increase the survival chances of the trees and bushes. The Method is based on vegetation ecology, is able to encourage public involvement and nurture a small ecosystem that restores life (Miyawaki, 1996).

The 4 principal rules of the Miyawaki Method concern the selection of native species, high density, a multi-layered architecture, soil preparation (Miyawaki, 1999). Miyawaki calls for planting young native species close together, with a standard density of 3 plants/m^2, to mimic a mature natural forest and to make plants to quickly thrive. Therefore the 123 plants chosen for the Parco dei Caduti Microforest are all native and adapted to the Mediterranean climatic zone, able to resist to climate stress, especially heat and dryness phenomenon, facilitate higher biodiversity and cope better with disease. The plants are supplied by the forest nursery of the Monti Aurunci Regional Natural Park. The Miyawaki Method also suggests a planting density between 2 and 7 trees per m^2 and a distribution of plants according to functional layers, based on the ecophysiological characteristics of the vegetation (Miyawaki, 1996). Dense planting stimulates mutualistic and competitive interactions and facilitates connections with soil microorganisms (Lewis, 2022).
With regard to density, account was taken of the first experimentation of the Miyawaki Method in Mediterranean contexts carried out in Sardinia in 1996, which envisaged a density between 2.1 and 0.86 plants/m^2 (Schirone et al., 2010) while, in Northern European countries, the density averages 3 – 5 plants/m^2. Thus the planting density adopted in the Parco dei Caduti Microforest is 2 plants/m^2 closer to the Sardinia experiment than to Northern European experiences rooted in a colder and more rainy climate zone, in order to enhance the survival rates of the plants.
The Japanese botanist identifies the most appropriate species mix that would naturally occur in a specific area in order to create a biodiverse, multi-layered forest identifying the potential natural vegetation (PNV) (Miyawaki, 1999). Accordingly, a mix of 13 species of Mediterranean plants are distributed in an area of 120 m^2 on the basis of 3 layers. The first consists of trees, Quercus ilex and Quercus pubescens. All around are scattered tall shrubs, such as Phillyrea latifolia and Arbutus unedo (85 specimens), punctuated by low shrubs (123 specimens) with flowering plants (such as Coronilla emerus, Spartium junceum) and berries (such as Viburnum tinus, Myrtus communis), so as to attract birdlife and pollinating insects, favoring biodiversity.
Finally the Method requests a preparation of soil aimed at decompacting and amending the site with organic materials and covering the ground with a layer of mulch made of natural ingredient (straw, fallen leaves, wooden barks). In this regard a 60 cm deep hole has been excavated, the ground amended and 20 cm of fertilized soil added on top.
To discourage invasive species from taking root, the planting ground is covered with a biodegradable fabric and a thick layer of pine bark.
This, from the very first day of planting, gives off a forest scent that radically changes the perception of this part of the Park considered, before the arrival of the Microforest, a marginal area.
For a period of at least 3 years the Method suggests to water the plant, but afterwards the forest plants will be able to grow and shade the soil, mitigating the water evaporation. Consequentially, the watering system has been developed in two phases. For the first few months after planting, a citizen's pact was set up under the direction of the Environment Department of Municipio II, between associations (neighborhood committee, Oltre cooperative, senior citizens' association) and the school to guarantee the water necessary for the plants. The second phase involves the construction of an underground tank fed with surplus water from the park fountain, a water pump, and a drip irrigation system.
Based on these parameters, a Miyawaki forest grows ten times faster than a classical forest, is 30 times denser and 20 times more biodiverse (Urban Forests, 2022).
Observing the evolution of the landscape of the Parco dei Caduti, what emerges today is the importance of enhancing the multifunctional nature of the forest (Hale et al., 2015), pursuing a project at once "of place and of community", the purpose of an open coexistence towards exploration, knowledge and respect between worlds and species (Endreny, 2018).
A little over three months after its planting, the Microforest does not record any acts of vandalism or theft of plants, despite being located in a complex neighborhood and a contested space (Mattijssen et al., 2017).

5. Who? University, students & schoolchildren

5.1 Stage III. The Eco-Pedagogical Pathway

The Eco-Pedagogical Pathway (EPP) takes shape from the concept of nature as an educating factor and involves from the beginning the community of the Borsi secondary school of San Lorenzo neighborhood (ICS Tiburtina Antica 25), 68 pupils and 4 teachers.

The outdoor activities are scheduled to promote an experiential environmental - oriented learning and aimed at increasing young people's awareness, support their commitment to nature as a solution to climate change challenges (Jucker & von Au, 2022). The 7 objectives that inspire the EEP process are:

- focus on experiences that promote environmental and climate change awareness through scientific applications;
- provide time for direct engagement with nature and immersion in green areas;
- share examples of people's enthusiasm and care for nature;
- make young people partners of scientific communication concerning their learning and outdoor experiences;
- transform the care activity in the young citizen science;
- support cultural and scientific vertical and horizontal exchanges between different kinds of students / pupils (schoolchildren and university students) through shared experiences;
- take seriously the young people's efforts and realize pupils' and students' ideas.

In order to set-up a wide range and cutting-edge environmental training activities, topics and contents are shaped on the basis of IVN Naatureducatie, Earthwatch Europe experiences, Outdoor environmental learning websites, H2020 Clearing House project and shared with school community. All the activities designed are meant to increasing curiosity, interest, exploration; develop empathy and caring for natural habitats (Clearing House, 2021).

Therefore the Microforest is designed to become both a place and an educational pathway, starting from the youngest, aimed at changing attitude and behavior in favor of the environment; it constitutes a step toward empowerment, nature connectedness, environmental stewardship and nurturing (Kudryavtsev et al., 2012; Tidball, 2011). Starting from these premises the methodology is developed in 3 steps 'Learning & Experiment'; 'Science entrusted to the young'; 'Young Citizen Science'.

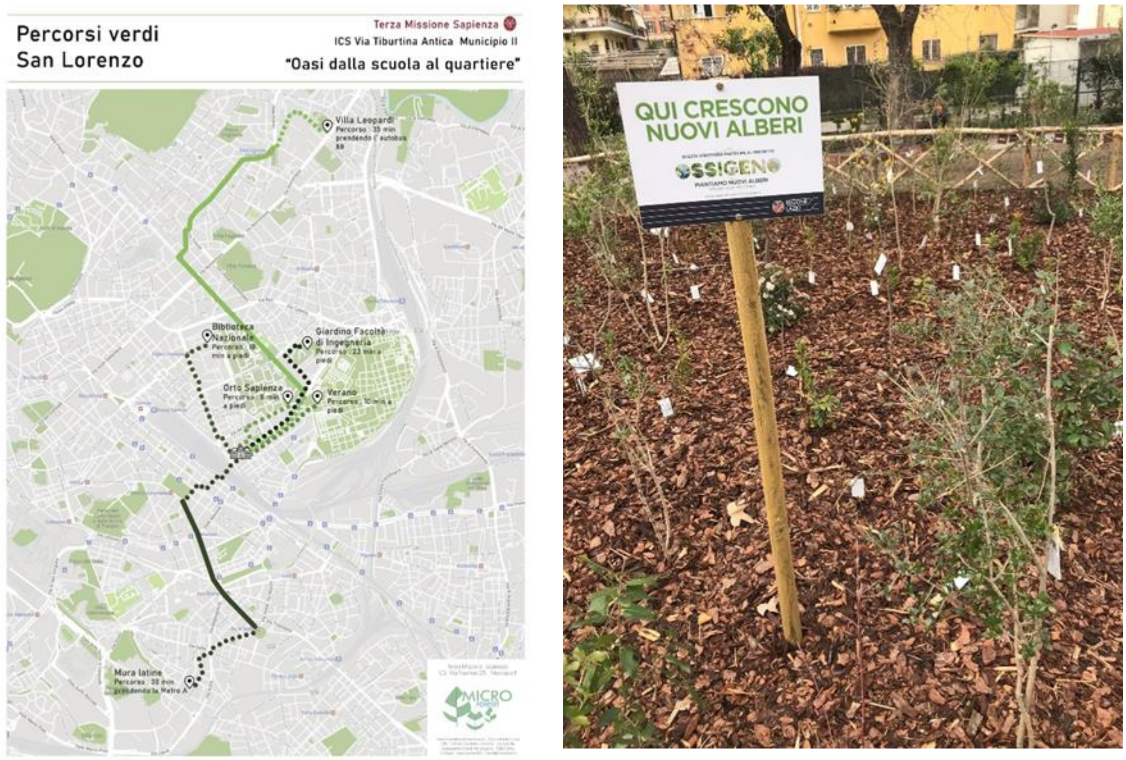
5.2 Learning & Experiment

The first stage of the EEP is implemented taking into account four components: topics, places, key actors and tools.

The multidisciplinary palette of the topics selected for this first stage concerns climate, air quality, water, vegetation, pollinators, wellbeing, waste cycle. The lectures – experimentations are designed and held by the Sapienza Third Mission transdisciplinary team.

The places chosen for the outdoor green spaces are accurately selected taking into account their accessibility through slow mobility, therefore maximum 20 minutes' walk from the school or reachable with public transport, and the opportunity to meet people, experts and associations, from outside the school community.

Key actors. Places and key actors are the dot of the outdoor activities' map. Among them Sapienza Scientific Garden and Professor Laura Varone, who develops experimentations on vegetation biomonitoring and plant phenology; Roda Onlus engaged in the care of the spice garden at National Library of Rome with disabled young people; Villa Leopardi and its association involved in the regeneration of the area and supporting biological fight against tree pest.



(a) (b)

Fig.9 (a) The Eco-Pedagogical paths: green places, slow mobility, experts and association to talk about climate change, NBS and wellbeing and (b) Trees and bushes of the Microforest, Progetto Ossigeno Regione Lazio

Fig.10 Mobile sensors to measure temperature, humidity, CO2, PM10, PM 2,5. A scientific tool able to catch at best children attention

The tools used for experiments and measurements are both do-it-yourself and digital. Sensors are used as a medium to increase the children's and students' awareness of climate phenomena, he benefits of nature's solutions and catch at best their attention.

The experimentation of mobile sensors guides the understanding of concepts such as the heat island and NBS that can mitigate its effects. The fundamental role of trees is revealed by measuring the temperature values collected by a portable sensor, and the intensity of harmful rays, monitored by means of a UVA & UVB light meter, in the district's most mineral square, Piazza dei Sanniti, and in the Verano cemetery under the protective canopy of cypresses and holm oaks.

The fluorescent light that illuminates an alga and urges it to produce oxygen turns the spotlight on the fundamental role played by the sun and vegetation, even in the city: trees allow us to breathe.

And more: every plant is a value in itself. Not only because our lives depend on them, but also because much of our possibility of happiness depends on them (Mancuso, 2019).

5.3 Science entrusted to the young

How to make young people partners of scientific communication concerning their learning and outdoor experiences? How to help them become young citizen scientists?

The second stage explores how to help children and teenagers to become young citizen scientists by transferring the knowledge acquired during the workshops.

In this stage from listeners and novice experimenters, schoolchildren of different ages are called to become science communicators during the 'Science entrusted to the young' cycle of activities, which is implemented through 4 events. The European researchers' night at the children's Explora Museum of Rome (30th September 2022); the Science Festival of Rome (21st November 2022); the Saffi school Open Day (20th December 2022); and the Inauguration of the Microforest (24th February 2023) are the events that seal the change of the role of the schoolchildren, challenging them in scientific communication, and allow them to act in favor of nature, actively support the realization of their future Microforest.

5.4 Become a young citizen scientist

The third stage is dedicated to put into practice a monitoring programme based on Citizen Science activities, taking into account the IVN and Earthwatch Europe's experiences. And though it is a step forward to the stage IV: the assessment part of the project.

The designed activities are developed on the basis of the knowledge and tools tested during the Learning & Experiment phase through a timetable focused on five issues: air quality; soil quality; water cycle; plant health; biodiversity; wellbeing and nature connectedness.

The first workshop of this third stage was held at the Microforest with 100 university students, over 100 schoolchildren from the primary and secondary schools and a trained équipe of Sapienza thesis students (4th May 2023). Children and students were arranged in small mixed groups and worked together.

The workshop was dedicated to the knowledge of the Mediterranean plants and the programming of questionnaires focused on the topic of nature connectedness to be answered by the children assessing their own experience.

In order to fulfill the first assignment, children were invited to delicately pick the leaves of trees and bushes of the Microforest, name the species, draw and write down their features, including the capacity to stock CO_2 and filtrate PM2,5 and PM10. A register of the trees and bushes will be put in place and updated with the height, and the healthy state of the vegetation observation along the year.

For this purpose during the workshop a first check of the chlorophyll activity of the different species was implemented with a mobile sensor by Sapienza thesis students supported by the schoolchildren. These data will be checked again every 3 months.

The second assignment consists in the programming of a questionnaire. Two groups of children of the secondary school and university students were assigned to this activity. In this regard the task begins with an explanation of the five pathways to nature connectedness listed in the 'City of Tree inspirational package' delivered by Clearing House (Clearing House, 2021). From this starts the elaboration of the questions aimed at measuring the growth of their own sensitiveness towards nature thanks to the Microforest project. The questionnaire will be posted online.

Fig.11 The first Young Citizen Science workshop. Children and students work in small groups to check the Microforest species, their features and their capacity to produce chlorophyll

Ultimately, young citizen science aims to weave bonds between the youngest and nature, represented by the Microforest, which will accompany their growth into adulthood and beyond. Eco-pedagogy plays a fundamental role in this respect and in the whole process.

School is the ideal place to initiate a process of growth and empowerment through long-term learning, and the creativity of the Citizen Science process encourages stewardship. Thus, it is important to integrate ecological pedagogy into community development programs because a heightened awareness of environmental issues and their implications can initiate new patterns of behavior towards the environment (Mochizuki & Bryan, 2015).

6. The final stages, assess and disseminate

6.1 Has young people's awareness increased?

Looking back, what becomes clear is that the time spent experimenting with and measuring natural phenomena, involving schoolchildren, teachers, lecturers and young university students, transforms the Microforest into a call for nature that pupils address to local decision makers.

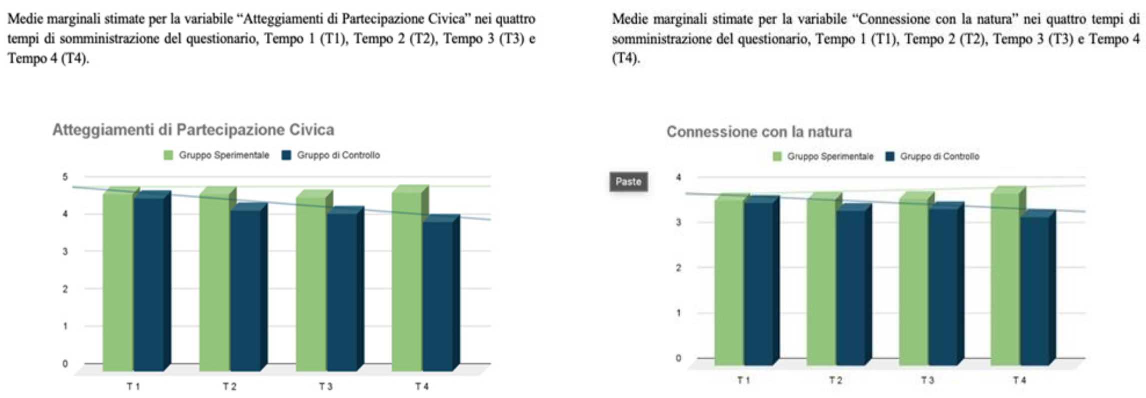
The mission that the young and very young people have accomplished is to convince the institutions of the inescapability of the realization of the Microforest.

During the one year of the project implementation the Parco dei Caduti and the micro - local community have been changed. The change observed in the school community is a perception shared by the pupils themselves, teachers and lecturers of the Sapienza. This is how Maja explains, at the end of the project, her personal connection to the Microforest. New awareness and sensitiveness have grown: ‘when I take my children to see the San Lorenzo micro-forest, I will tell them that I planted these trees with my classmates, thinking of their future’ (Maja Sechi, III b, Borsi school). Helping children learn to be responsible, becoming leader of virtuous change in favor of their environment can increase the likelihood that they will be more environmentally aware throughout their lives (Thor & Karlsudd, 2020; Gough & Scott, 2003; Littledyke, 1996).

However, in order to measure and categorize the effects of this training course on the pupils of the Borsi school, the Terza Missione Sapienza project developed, with colleagues from the Faculty of Psychology, a survey to assess its impacts by means of a questionnaire consisting of a battery of measurement scales adapted from the literature.

At the current stage of the project, it is important to emphasize that the increase found in the experimental group suggests that the children involved in the project have started to increase their awareness of issues related to climate change, the consequences on urban environmental quality and psychophysical wellbeing, as well as their own capacity to act in favor of the environment, beginning to strengthen their motivation to take care of the neighborhood’s green spaces in order to contribute to a common long-term goal’ (Bonaiuto & Chiozza, 2023).

Ultimately the Microforest experience is both a project about environment and an invitation to learn about nature. A Microforest will not change the quality of the air of a neighborhood but it creates a microcosmos of wellbeing, knowledge and collaborative behavior, enhancing the capacity of all to increase their resilience and therefore to behave in a proactive way facing climate changes. Around this small patch of nature the biodiversity thrives, people will feel protected by the shadow of the trees and gather to check how the trees grow.



(a) (b)

Fig.12 Effects of the Eco-Pedagogical Pathway on the pupils of the Borsi school. (a) Civic Participation and (b) Nature connectedness

The Microforest constitutes a lever to spread knowledge and fundamental values to the benefit of children and adolescents to enable them to cope with the changes that will occur in the coming decades in the best possible way, improving their relationship with nature, their living environment, with others and with themselves.

As the case studies of Parco Malaspina and San Lorenzo demonstrate, the fact of planting trees and bushes does not make in itself an Eco-Pedagogical Microforest. The success of the project has been achieved only through a shared pathway dotted with places, people, experimentations and lectures all bounded together with the invisible thread of empathy.

Between difficulties and success, the Microforest becomes a training ground for implementing new forms of partnership that bring ‘value for people’ and become a more effective and valuable tool to meet the challenge of the UN 2030 Agenda.

6.2 What's next: Microforests for the 15 minute-city model a planning opportunity

With the successful realization of the Eco-Pedagogical Microforest in San Lorenzo, a new cycle opens for which the collaboration between Sapienza and the Councillorship of Urban Planning of the City of Rome is in progress. In 2022, the City of Rome, partner of C40, presents the Programme "15 Municipi – 15 Projects for the 15 minutes city" a model of a "city of proximity" developed in collaboration between the Councillorships of Urban Planning and of Decentralisation for the 15 minutes city. The strength of the Programme is that it starts from the bottom, actively involving the 15 Municipi of Rome to regenerate 15 neighborhoods, one for each Municipio, with a funding of EUR 22.5 million.

The novelty of a model that crosses the history of urbanism with continuity, from Ebenezer Howard's Garden City (1898) to the Clarence Perry's Neighboorhood Unit (1929) and more recentely the Peter Calthor's Transit Oriented Development (1993) and Richard Rogers' Urban Renaissance Neighbourhood Model (1999), is related to a new interpretation that emphasizes its sustainable potentialities.

In fact, the polycentric urban development underpinned to the concept of 15 minutes city suggests that cities are made by a number of local units that can be regenerated and transformed in sustainable neighbourhoods that cut emissions and improve urban quality, social cohesion and a healthy way of life while boosting city and nature integration. In this context, neighbourhoods provide a new focus to respond to the urgency of the global climate agenda.

So the innovative side of the strategy proposed by the city of Rome is to implement within a short timeframe, a regeneration programme centered on public space, green areas, soft mobility and inspired by the goals of Agenda 2030. The Programme intends to address the theme of eco-sustainability through the strengthening of green and blue infrastructures.

Within this framework a collaboration Comune di Roma – Sapienza University took place to create Eco-Pedagogical Microforests within the 15 Municipi Programme. In order to guarantee the final success of the Microforest project 4 conditions have been set up by the Sapienza team in order to outline that forestation, place-making and eco-pedagogy are inseparable aspects of the same process.

The success of the Microforest, as demonstrated by the case of San Lorenzo, is related to material goals and immaterial links and activities as well. The young people's pro-active involvement and the teachers' willingness have had the power to enlighten the pathway towards an urban, social, cultural and ecological regeneration. And this 'lesson learnt' on the field should be respected for the success and the future of Microforests and young people.

Acknowledgments

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Image sources

Fig.1 to 11: Author's elaboration;

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Spatial analysis of green space use in Tabriz metropolis, Iran

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Abstract

The growth and development of urbanization in the last few decades, as well as the land use changes around and inside big cities have been considered as one of the most essential challenges of global sustainable development. The increase in the desire for urbanization and improper management has changed the use of green spaces and gardens around and inside the cities to profitable residential and commercial uses. Accordingly, considering urban parks and green spaces and recognizing their spatial inadequacies is of utmost importance for optimal use by citizens. This research aimed to evaluate the use of green space in the city of Tabriz and the way it is distributed in the urban areas of Tabriz city. This study was an applied research, and its methodology was descriptive-analytical. Moreover, class difference limit model, cluster analysis, and GIS software were used to analyze the data. The results of the study indicated that the per capita use of green space in Tabriz city was much lower than the international and national standard, the spatial distribution of green space use was not the same in different areas of Tabriz city, and was more unbalanced. The results of the cluster analysis method showed that the regions in Tabriz city are at different levels in terms of green space indicators. The results of the class difference limit model showed that the regions of the city of Tabriz do not enjoy balanced green space, and the green space is not distributed evenly among different regions.

Keywords

Green spaces; Sustainability; Spatial distribution; Tabriz metropolis.

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1. Introduction

The world's population has overgrown in recent decades, and this increase in population has been more significant in the metropolitans of developing countries. Today more than 57% of the world's population lives in cities, while in Iran, the urban population has increased from 30% in 1956 to more than 74% in 2021 (Abedini & Kalili, 2019; Zanganehshahraki et al., 2011). It is anticipated that by 2050, the number of urban population will reach 6.3 billion, and nearly 90% of the urban population will grow in developing countries (United Nations, 2015). With the rise in global urban population and subsequent urban physical expansion, the importance of urban green spaces now and in the future can hardly be over-emphasized (Boulton et al., 2018; United Nations, 2018; Nor et al., 2017; Haase et al., 2014). Urban green spaces are defined herein as all spaces primarily covered by vegetation in urban areas including forests, parks, gardens, and greenery along riparian and transport corridors (Biernacka & Kronenberg, 2019; Nath et al., 2018; Wilkerson et al., 2018). Urban parks and green spaces are public capital (Macedo & Haddad, 2015). Urban green spaces are considered highly essential capital that can help cities decrease undesirable effects of rapid urbanism and urban development in a sustainable way (Abu Kasim et al., 2019), and they have significant effects on urban ecosystems (Cao et al., 2021). Green space, as an area in the urban environment, is dedicated to nature and can be utilized as a space for play, recreation, and socialization (Byrne & Sipe, 2010). Jane Jacobs (1961) believes that parks, are the most valuable urban spaces since they are often in direct contrast to hectic and dense urban living (Jacobs, 1961). At present, the concept of "a green city" is widely being propagated at various spatial and political levels (Grunewald et al., 2017). Some examples are the UN's Sustainable Development Goals (SDG 11) (United Nations, 2015), the Convention on Biological Diversity (CBD) (United Nations, 1992), the Biodiversity Strategy to 2020 (European Commission, 2021), and the Green Infrastructure Strategy (European Commission, 2013). This issue is of particularly importance, especially in cities where social and ecological components, including green space, are under urbanization pressure (Taylor & Hochuli, 2017).

Today, urban green spatial planning advances from creating landscaped areas with social and aesthetic value to the consideration of urban green as a kind of modern urban multifunctional infrastructure that supports both social, economic, and ecological processes and also allows cities to become more polycentric. The possibility to locate housing, work and leisure along and around ample landscaped public space which allows free transit movement without congestion and with guaranteed quality of healthy well-being (Wolf & Dagmar, 2019; Kazakov et al., 2018). The carried out scientific studies in the recent years have divided the advantages of urban green spaces into four categories of benefits related to economy, health, life quality and environment (Benedict & McMahon, 2002). Urban green spaces can have long-term positive economic effects (Crompton, 2005). Urban green spaces provide advantages for human health (Jansson, 2014), and the lack of these spaces might harm to human health (Coutts et al., 2010). Urban green spaces can increase the attraction of urban regions and neighborhoods for residents and provide the chance to improve their quality (Jansson, 2014). Results of different studies about different aspects show the importance and value of urban green spaces for the welfare of citizens (Jabbar et al., 2021). Ecologic benefits of urban green spaces include formulating services, decreasing pollution, adjusting weather, and decreasing global warming (Jansson, 2014). Unfortunately, these spaces and their roles have been neglected, especially by politicians and planners, and there are also several problems with their establishment (Hosseini & Sedighi, 2015).

To establish a live able and sustainable city, urban and environmental planners in emerging economies need to pay special attention to green spaces planning. However, the current process and practice of improperly dealing with urban green spaces, particularly in emerging economies, indicate that if this trend continues, destruction and undersupply of green spaces and agricultural lands will significantly threaten sustainable urban development and the ecological balance of our cities. Urban and population growths in Iran, like many other developed or emerging economies, resulted in environmental pollution, which requires policies to be controlled. Green space the expansion is one of the most essential factors in reducing environmental externalities. In this country, growth of urbanization – both as sprawling suburban development and infill densification – has been accompanied by declining levels of gardens and agricultural lands, which has led to a significant reduction of urban green spaces (Teimouri & Yigitcanlar, 2018).

Tabriz city has not been an exception and has suffered from such problems even more than many other Iranian metropolises. The city has been losing its green spaces swiftly for various reasons: a) Converting open spaces during the urban development process to, for example, residential, commercial, industrial, or mixed uses. Citizens of Tabriz, who once lived among massive gardens and green spaces, now face the perils of rapid urbanization; and b) Pressure of the construction industry on policymakers that have become the victim of wrong decisions. Subsequently, the quality and quantity of green spaces have been reducing dramatically almost daily to contribute to the personal profits of investors, land/property owners, and developers.

Additionally, the disproportionate distribution of these spaces at neighborhoods and city levels has resulted in unjustly planning of this vital land use type. This to study has been conducted with the objective of studying the situation of regions of the Tabriz metropolis in access to parks and urban green spaces. Parks and urban green spaces should be considered among the most essential factors of sustainability in the accelerating and irregular growth of urbanism; if they are managed and planned productively and correctly, they would have valuable and appropriate effects on the health, emotions and spirit of citizens and also on improving the view and perspective of the cities. Despite although in recent years, some projects have been launched in the city of Tabriz by urban managers for improvement and development of urban green spaces, some problems, such as turning the city into one of the most polluted metropolises in Iran, formation of unofficial residential areas in different regions of this city, etc. have made the need for balanced development of urban green spaces in this metropolis an inevitable issue.

1.1 Literature review

As rapid urbanization has changed human settlements into cities, far away from the natural environment, the need to contact nature has become a challenge for urban policymakers and planners. Access to UGS has been shown to contribute to human physical and mental well-being (Muller et al., 2018; White et al., 2017). Recently, attention has been drawn to the urban green landscape in urban issues, indicating that urban green prosperity should be a significant component of urban development policies and plans (Waldheim, 2006). Green spaces are part of urban open spaces, filled with other kinds of plants and vegetation and also activities for different age groups that contribute to health, feeling of safety, comfort, well-being, and aesthetic value of urban areas and communities (Groenewegen et al., 2006), providing ecosystem services such as climate regulation, capturing pollutants, or flood regulation (Geneletti et al., 2020), also promoting community integration, neighbors interactions, and delivering a favorable place for health, relaxation, and nature contemplation (Houlden et al., 2019; Ma et al., 2019). In general, urban green space is considered a public good that allows free access to all citizens and provides pockets of nature for all residents, including urban parks, squares, median strips, roadsides, sidewalks, etc. (De la Barrera et al., 2016). Given the importance of urban green space, unequal access to them is considered an environmental justice issue (Wolch et al., 2014), which in this case can be understood as the equal distribution of green infrastructure without discrimination within a city.

Byrne et al. (2009) showed that in the United States, urban parks have been distributed unfairly. Wolch et al. (2014) tried to compare urban green spaces especially parks in the green cities of the US and China. Results of this survey show that the distribution of such spaces is often unequally and inappropriately for the benefit of primarily white and wealthier communities. Nadja and Dagmar (2014) concluded that although most areas are supplied with more UGS compared to the per capita target value of 6 m^2, there is considerable dissimilarity by immigrant status and age. To address rising concerns about socio-environmental justice in cities and to evaluate the (dis)advantages of applying UGS threshold values for urban planning, visitor profiles and preferences of a site-specific case, the park and former city airport Berlin-Tempelhof are analyzed. Results from questionnaire surveys indicate that the identified dissimilarities on the sub-district level are not the same as socio-environmental injustice in Tempelhof, but point to a mismatch of UGS and user preferences. In addition to evaluating UGS distribution, the match between the quality of a park and specific cultural and age-dependent user needs should be considered for successful green infrastructure planning rather than focusing on target values.

Li et al. (2021) pointed out that spatial justice of parks was one of the main concerns in the environmental studies. The findings of this survey help urban planners and policymakers to set more reasonable policies and plans for the improvement of spatial equality and justice, in the case of parks in urban areas. Akbari (2022) in a study concluded that Region 10 of the metropolis of Shiraz by achieving 3.498 has the highest number of parks and green spaces. After region 10 in this city, region 4 with the score of 2.013, region 3 with 1.776, region 6 with 0.938, and region 9 with the score of 0.404 are in the next ranks. Other regions of the city of Shiraz achieved low scores, and region 8 of this metropolis with -3.167 had the lowest score. Region 8 which is considered to be the historical and cultural context of the city of Shiraz includes the lowest per capita of green spaces in the urban projects. Li and Fan (2022) in a study the evaluation simulation of urban green space landscape planning scheme based on PSO-BP neural network model concluded the PSO-BP neural network can combine the principle of landscape ecology, integrate more evaluation indicators of ecology and urban development into the urban green space landscape planning scheme, and simply understand and predict human behavior, to make a more comprehensive evaluation and prediction. Experiments show that PSO-BP neural network has smaller error and better generalization ability than BP neural network. The PSO-BP neural network rating model can analyze its more reasonable proportion according to the relationship between different types of green space and indicators, and give corresponding adjustment suggestions, which has guiding significance for the modification and adjustment of urban green space landscape planning scheme.

Puplampu and Boafo (2021) in a paper concluded that, the overwhelming number of stakeholders understand and are aware of the beneficial values of urban green spaces but highlight poor planning, coupled with land tenure challenges, as a threat to the conservation of green spaces. Land use and land cover change analysis shows that the urban built environment has expanded from 55.1% to 83.79% at the expense of the natural environment, including green spaces, which have declined from 41% to 15% over 27 years. Existing areas of green spaces, including the Achimota forest, the University of Ghana campus and street trees on major roads, were valued at US$ 37,610,980 for carbon sequestration and storage, US$ 1,478,173 for air pollution regulation, and US$ 458 for avoided runoff. A rapid assessment of the availability, accessibility and management of urban green spaces in the Accra metropolis can be an essential step towards identifying and mapping their consumptive and non-consumptive use-value and introducing appropriate interventions necessary for enhancing the city’s resilience in an era of climate change. Ghasemi and et al. (2022) in study for the purpose of analyzing the spatial distribution pattern of urban green spaces in Tehran, the nearest neighbor method and multi-distance spatial cluster analysis used. As a result, the spatial distribution pattern of this land use strongly resembled a clustered pattern, and the accessibility and distribution of green spaces in Tehran were unequal. Also, based on the Cocoso method, which was used to analyze access to green spaces and parks, districts 10 and 11 are by far Tehran’s most deprived districts. Distribution of services in the city based on per capita in the form of comprehensive and detailed plans, financial and technical problems of municipalities, lack of approach to planning and sustainable development on a national, regional and local scale in Iran’s planning system, lack of integrated urban management in the Tehran’s city management system, the emphasis of most urban planning theories in Iran on planning processes and ignoring social and spatial structures are some of the main reasons for this disparities. To reduce inequality between the districts of Tehran, it is essential to devise effective regional planning and adopt balanced and impartial policies for equal accessibility of resources in all urban districts. The findings enhance our understanding of the level of urban inequity and the potential causes of inequality concerning accessibility to green spaces in metropolitan areas. This study also sheds light on the critical role of policy-making in this process. These findings have implications for urban managers regarding of the accessibility, allocation, and distribution of urban services in different cities of Iran and the world.

Altunkasa et al. (2017), studies mapping and determining the effectiveness of green spaces and socio-cultural facilities as providers of urban ecosystem services and urban services in the case of Adana, Turkey. Firstly, green spaces and socio-cultural facilities per capita have been determined and indexed for the neighborhoods in the city. Then, a distance-based method for estimating the effectiveness of these facilities was used. The distances between the various neighborhoods and between a given facility and the farthest threshold have been measured and these values have been used to determine the facility effectiveness change value for each neighborhood. Then, effective values have been calculated and indexed by incorporating the green space and socio-cultural facility values and the effectiveness change values for the neighborhoods. Finally, point-based effective green spaces and socio-cultural facilities index values have been converted to continuous surface values in a GIS (geographic information system) environment in order to utilize as a base map for urban physical planning purposes. According to the outcomes of this study, the distribution of green spaces and socio-cultural facilities of the neighborhoods are imbalanced and index values of these facilities range in between 45 and 84 out of 100. Bianconi et al. (2018), in a study with issue of urban regeneration in contemporary cities, adopting a strategic vision which includes the use of vegetation and green infrastructure to create a network of public spaces. Especially, urban periphery lacks of public spaces, meaning a public use of urban space for outdoor activities and social networks. The extraordinary program for the Italian peripheries, addressed to all the metropolitan cities and provincial capitals in 2016, inspired to Renzo Piano idea of "re-sewing" urban fabrics, has been a good opportunity for testing new approaches to urban regeneration. The case study investigated in this study is the financed project for the city of Perugia, which provides different interventions aimed at improving (and developing new) public spaces through vegetation enhancement and a large area destined to vegetable social gardens as a strategy for urban infill. By recovering public spaces with social purpose and providing a comprehensive strategy for aesthetic improvement of the city, the case study provides a representative example, how greening the city may promote together biodiversity conservation and urban regeneration.

Basu & Nagendra (2021) concluded most users value the park as a recreational space, but are largely unable to access provisioning services such as food and fodder. This poses a particular challenge for low-income residents. In the large parks with high vegetation cover, visitors could identify a variety of trees, plants, and birds, while in the smallest neighborhood park which has the least amount of greenery; they could only identify a small number of species. Parks were visited more by men than by women, who cited challenges of lack of time, and lack of safety. Park entry fees also acted as barriers, for low-income groups. The two parks located in wealthy and gentrifying neighborhoods were almost exclusively accessed by middle class and wealthy visitors, because of the entry fee. Surveys of willingness to pay found that wealthy visitors were keen to pay an entry fee and did not seem to understand the implications of such a fee on exclusion, low-income visitors expressed negative views. A central role of the urban park as a 'public space' within a city is to nourish the sense of community. Yet some parks have been converted into landscaped and designed areas with high public investment, and entry charges, with limited provision for harvesting ecosystem services. Thus even in public spaces like parks, we observe stark gender and income inequalities, leading to the uneven access to green space. Scheiber & Zucaro (2023) concluded 2030 has been set as the target for achieving most of the sustainable development goals and in this path urban open and green spaces have been identified as drivers and accelerators for increasing resilience and adapting cities to climate change. The pandemic has acted as a further catalyst for the reorganization and re-assessment of the role of open spaces. This work focuses on the system of urban open and green spaces whose planning and design, through a systemic approach, can address current and future urban challenges such as climate change. The main aim is to provide local decision-makers with urban open and green spaces planning and design principles based on a mixed-method approach adopting Malta as a case-study. Findings suggest that EU and international strategies advocate open and green spaces as an indisputable requirement for increasing resilience, energy sustainability and adaptive capacity of urban systems. However, in comparison, there is still scope for improvement when considering Malta's planning framework. While there is a growing sentiment for the appreciation and need of green open spaces from the users, important characteristics are still lacking within the planning processes.

Khavarian-Garms et al. (2023) in a paper concluded the principles of the 15-minute city concept include the following: (1) Proximity. The 15-minute city highly values proximity, which has also been a fundamental principle of earlier movements such as the garden city and the neighborhood unit It follows a proximity-oriented strategy that focuses on the redistribution and relocation of urban amenities and resources within neighborhoods allowing residents to access the six core functions of living, working, commercial, health care, education, and entertainment with a 15-minute walk or bike ride. (2) Density. The 15-minute city views density as a critical strategy for ensuring that residents have adequate access to daily necessities without relying on private cars (3) Diversity. The 15-minute city aims to increase neighborhood diversity through two mechanisms: (1) software diversity, and (2) hardware diversity (Moreno et al., 2021). Software diversity is about creating communities that represent a diverse range of cultures, ethnicities, and economic and social classes. Hardware diversity aims to create multi-use neighborhoods that include residential, commercial, and recreational uses. Carlos Moreno, inspired by Jacobs, sought to transform the 15-minute city from the mono centric urban structure into a polycentric form. Based on the chrono-urbanism philosophy, he believed that job localization can improve people's quality of life by preventing them from wasting time on daily commutes and therefore lowering carbon emissions (4) Digitalization. While digitalization was not originally among the 15-minute city's principles, the capabilities provided by smart solutions during the pandemic. convinced advocates of the concept to leverage smart city technologies to supplement other principles. (5) Human scale urban design. The need to return to a human scale was one of the major lessons of the COVID-19 pandemic for cities. The scale and form of a 15-minute city are defined based on human needs and characteristics. This concept advocates redesigning public spaces for the benefit of citizens rather than cars. It promotes investment in walking and biking paths so that city dwellers can fulfill their daily needs within a 15-minute walking or cycling distances. (6) Connectivity. Making a connection between neighborhoods by public transportation helps to avoid isolated neighborhoods and ghetto enclaves. It ensures a continuous integration of individual neighborhoods into the broader urban structure. Within 15-minute city neighborhoods, active mobility modes like walking and cycling are combined with public transportation, increasing public transportation efficiency, and addressing first/last mile connections. (7) Flexibility. The 15-minute city concept advocates the transformation of single-function public and semi-public spaces into multi-purpose areas to maximize the utilization of buildings and spaces. It aims to assign multi-purpose roles to public and semi-public spaces that are already being used for a specific purpose at a particular time of day or on certain days.

2. Methodology

This study was applied research using descriptive-analytical method. The data had been collected using library-field studies and the spatial data of the study area. Class difference limit method, TOPSIS model, Cluster analysis method and GIS software were used for data analysis. The variables utilized to rank the areas of Tabriz city using the Cluster analysis model and TOPSIS model included: population, size, the area of green space, the area of permanent and seasonal green spaces, tree-planted spaces, the area of urban and local parks, the area of expanded green space, the ratio of green space to the population of the regions, the ratio of green space to the size of the regions, and the recreational space of the parks.

2.1 TOPSIS Model

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis method, which was originally developed by Ching-Lai Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative perfect solution. It is a method of compensatory aggregation that compares a set of alternatives, normalizing scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion. Criteria weight in the TOPSIS method can be calculated using the Ordinal Priority Approach, Analytic hierarchy process, etc. An of TOPSIS assume is that the criteria are monotonically increasing or decreasing. Normalization is usually required as the parameters or criteria are often of inconsistent dimensions in multi-criteria problems. Compensatory methods such as TOPSIS allow trade-offs between criteria, where a poor effect in one criterion can be negated by a good result in another criterion. This provides a more realistic form of modeling than non-compensatory methods, which including or excluding alternative solutions based on hard cut-offs. TOPSIS methods require the independence of criteria for being utilized real-life. However, independence of criteria is hard to guarantee in real applications as such, TOPSIS methods might produce biased rankings. TOPSIS is based on the premise that the best solution has the shortest distance from the positive-ideal solution, and the longest distance from the negative-ideal one. Alternatives are ranked using an overall index calculated based on the distances from the ideal solutions. The TOPSIS method can be explained as a set of stages shown below:

Step 1: data matrix

$$\begin{array}{c|cccccc|}
\ldots & C1 & C2 & \ldots & \ldots & \ldots & Cn \\
\hline
A1 & X1 & X2 & \ldots & \ldots & \ldots & Xn \\
A2 & X1 & X2 & \ldots & \ldots & \ldots & Xn \\
A3 & X1 & X2 & \ldots & \ldots & \ldots & Xn \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
AM & X1 & X2 & \ldots & \ldots & \ldots & Xn
\end{array}$$

Step 2: The data matrix is de-scaling using the following relation:

$$nij = \frac{Xij}{\sum Xij}$$

Step 3: Calculation of the entropy: The entropy of each index is calculated using the following relationship:

$$Ej = -K \sum_{i=1}^{n} \left(n_{ij} \mathrm{Ln(nij)} \right)$$

$$\mathrm{K} = \frac{1}{Ln(m)}$$

The entropy value of the indices is a value between zero and one:

$$0 \leq \mathrm{Ej} \leq 1 \rightarrow (\forall \mathrm{j} = 1, 2, \ldots, \mathrm{n})$$

Step 4: Calculation of the degree of standard deviation: The standard deviation of each index is calculated using the entropy value of that index through the following equation (Hekmatnia & Mousavi, 2015):

$$Dj = 1 - EJ$$

Step 5: Calculating the weight of each indicator: Using the following relationship, the weight of each of the indicators can be calculated:

$$Wj = \frac{Dj}{\sum Dj}$$

Step 6: Balance the de-scaling matrix:

$$\begin{bmatrix} n11 & n12 & \dots & \dots & \dots & n1n \\ n21 & n22 & \dots & \dots & \dots & n2n \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ nm1 & nm2 & \dots & \dots & \dots & nmn \end{bmatrix} \begin{bmatrix} w1 & \dots & \dots & \dots & \dots & \dots \\ \dots & w2 & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \end{bmatrix}$$

$$\begin{bmatrix} w1n11 & w2n12 & \dots & \dots & wnn1n \\ w1n21 & w2n22 & \dots & \dots & wnn2n \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ w1nm1 & w2nm2 & \dots & \dots & wnnmn \end{bmatrix} = \begin{bmatrix} v11 & v12 & \dots & \dots & \dots & v1n \\ v21 & v22 & \dots & \dots & \dots & v2n \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ vm1 & vm2 & \dots & \dots & \dots & vmn \end{bmatrix}$$

Step 7: Find positive and negative ideal solutions.

$$A^{+} = [v1, v2, \dots vn] = [\max\ vi\ j \in J+), (\min j \in J-) i = 1,2, \dots, m)$$
$$A^{-} = [v1, v2, \dots vn] = [\min\ vi\ j \in J+), (\max j \in J-) i = 1,2, \dots, m)$$

Step 8: Obtain the separation values: The separation measure is the distance of each alternative rating from both the positive and negative ideal solutions which is obtained by applying the Euclidean distance theory. Eqs. Show the process for positive and negative separation calculations respectively.

$$D+= \sqrt{\sum (\text{Vij} - \text{Vj}^{+})2}$$
$$D-= \sqrt{\sum (\text{Vij} - \text{Vj}^{-})2}$$

Step 9: Calculate the general preference score. The overall preference score CLi for each alternative Ai is obtained as shown in the following equation.

$$\text{CLi} = \frac{D^{-}}{D^{-} + D^{+}}$$

2.2 Class Difference Limit Model

This method can be implemented by using statistical formulas, especially by using the highest and lowest data values. The model includes the following steps:

Step 1. Determining the different frequencies of data:

$$R = \text{Max } xi - \text{Min } xi$$

Step 2. Determining the number of classes, using Sturges formula:

$$K = 1 + 3.3\text{Log}_{n}$$

Step 3. Determining the class difference limit value:

$$H=\frac{R}{K}$$

Step 4. Creating the data matrix.

2.3 Cluster Analysis Method

Cluster analysis is a statistical method for determining homogenous groups or clusters (Asayesh & Estelaji, 2013). It includes a wide set of techniques designed to find a group of similar items in a data set (Holand, 2006). The purpose of cluster analysis to divide the observations into homogeneous groups in which the observations of each group are similar and the observations of different groups are not that similar to each other (Hekmatifarid, 2003). In other words, cluster analysis is a multivariate analysis that seeks to organize the information related to variables in which the components of each cluster are similar to each other and the members of each cluster are not similar to the members of other clusters (Hajipour & Zabardast, 2005; Kalantari, 2008).

Accordingly, areas having the most similarities in terms of factor scores are grouped in one cluster (Melki & Sheikhi, 2018). In other words, cluster analysis divides the observations into homogeneous groups so that the observations of each group are similar to each other and the observations of different groups not are that much similar to each other (Goldasteh et al., 2010). The purpose of cluster analysis to divide a set of data into discrete clusters with common characteristics (Vermunt & Madison, 2002). Classifying homogeneous areas of this method is done in different ways. Determining the correlation coefficient and measuring the distance, especially the Euclidean distance, are among the most important methods of determining homogeneous regions (Bayat, 2018).

Therefore, there are different methods for combining components in clusters, including hierarchical cluster analysis. Hierarchical analysis is performed using condensing or discriminating method (Salehi et al., 2016). The steps of cluster analysis can be summarized as follows:

- (1) Collecting the data matrix in which the regions are placed in a column and are subjected to cluster analysis. Its rows are also made up of attributes that the desired areas are zoned on this basis;
- (2) Standardizing the data;
- (3) Calculating the similarity between the pairs of original data matrix areas and standardized data;
- (4) Using a cluster method for categorizing the similarities and forming a tree diagram or dendrogram. This diagram shows the similarity between all people both in pairs and hierarchically (Pourtaheri, 2019).

3. Study area

The city of Tabriz, one of the most ancient cities in Iran, is the capital of the East Azerbaijan Province. Tabriz city, located in the northwest of Iran, is in a mountainous area at an altitude of 1,350 meters at the junction of the Aji River and Quri River and is surrounded by mountains from the north to the south. This city with a population of 1,612,000 people in 2020 and an area of 237 km^2 is the fourth largest city in the country after Tehran, Mashhad and Isfahan.

Like other populated cities in Iran, Tabriz city has experienced the phenomenon of rapid urban growth leading to the formation of urban sprawl growth, an increase in the area of the worn-out texture, informal and slum settlements in peripheral areas of the city. During recent years, due to high numbers of immigrants and a high population growth rate, Tabriz city has undergone an irregular and rapid growth and has experienced incredible population and spatial change. This city has a strategic position in Iran, acts as a connection point between Iran and Europe and has always been considered to be one of the major cultural, political and economic poles of Iran (Rahimi, 2016) (Fig.1). Tabriz is divided into 10 districts according to the municipality regulations and the comprehensive plan. Urban green spaces in Tabriz are classified into two groups: a) Artificial green spaces a combination of equipped urban parks, urban squares, trees planted in residential areas, and green spaces on streets; b) Natural green spaces all the green spaces that are naturally existing and preserved (Teimouri & Yigitcanlar, 2018).

Fig.1 Location of study area

4. Results and discussion

4.1 The role of green space in urban sustainable development

Cities are alive and dynamic systems and green spaces are a part them; due to their effective role in reducing urban density, creating guiding and supplemental routes, as well as improving the performance of educational, cultural, residential facilities, and reserving lands for the future expansion of the city, they are considered valuable. The importance of green space ecology is because the oxygen needed by a person can be obtained in 30 to 40 m^2 of a green space (Izadi & Gorji, 2018). Green spaces are considered as the breathing lungs of the city; the lack or absence of which means the lack of physical and mental health of its citizens. Along with industrial development and increasing urbanization, its importance has also increased. Having urban parks and green spaces are among the practical strategies that have recently received more attention to deal with the problems of urban and modern societies.

The evidence shows that the existence of natural complexes (parks, forests and green belts) and their elements (trees and water) in the boundaries of cities has a significant impact on the quality of life of citizens from various aspects it also has social and psychological benefits in addition to ecological efficiency such as weather purification, the reduction of noise pollution, the reduction of wind effects and the stability of microclimate. Using the park reduces pressure and stress and deepens thinking; it also keeps city dwellers young and gives them peace and comfort (Cherisura, 2004). Undoubtedly, the creation of green spaces has long been one of the favorite issues of humans due to its special relationship with nature. Despite the disturbances that humans have unknowingly and perhaps knowingly created in nature through burning forests and turning pastures into agricultural lands by setting foot in the agricultural revolution, they have always sought to cure the nature by building gardens and planting scarab trees (Heidaribakhsh, 2007).

Paying attention to urban green space issues is more important the time that the considered urban use becomes related to urban sustainability. The new dimension of urban sustainability in today's heterogeneous and unsustainable cities is called social sustainability being interconnected with the role of parks in increasing the participation rate of citizens. Optimal distribution of urban green space is a factor for ecological (environmental, economic, social and psychological) efficiency for citizens it can prepare the context for ecological sustainability of cities (Deh Cheshmeh, 2016). Therefore, incorrect positioning of urban green spaces would ultimately lead to the creation of anomalies such as: low use of the created green space by users, limitations in providing suitable architectural design, limits in the selection and arrangement of appropriate plants, disturbances in the urban landscape, problems related to the irrigation and soil modification, the lack of proper social interaction, management and maintenance problems, reduction of psychological and social security, etc. (Varesi et al., 2007).

The importance of green space is not hidden for anyone; especially the essential of entertainment is evident. In most discussions, parks and green spaces are emphasized as an important factor that can increase the quality of life. Therefore, everyone's access to urban services and social justice dictates that all urban classes can equally enjoy green spaces and urban parks as well as leisure places and not certain classes of citizens choose parts of the most beautiful views of the cities for their lives so that gradually all these views become exclusive to these prosperous classes of the society.

4.2 Green space and urban planning

The functions of green space in the city are the followings:

- (1) Urban green space, as an alive part of the physical construction of the city, plays an essential role in coordination with the lifeless part of the body, texture and appearance of the city. The creation of wide green spaces between uses that are incompatible with each other stabilizes safety and plays an essential role in reducing the burden of environmental pollution.
- (2) Environmental functions: In this section, green spaces help to improve the ecological conditions and reduce the amount of pollution. Accordingly, the impact of urban green space on the quality of the city's bioregion should be emphasized more than any other factor. For this purpose, it should be noted that the effect of the green space on the bioregion of the city reaches its maximum level when, firstly, the green space is correctly located in terms of climate, secondly, trees and shrubs are used in the design of the green space (Rahimi, 2019).
- (3) Socio-psychological functions: Although the function of green space in the physical construction of the city and its environmental functions can also increase social and psychological efficiency, in the design of green space, the main goal is bringing man and nature closer to each other to achieve it is social and psychological effects. Every person in any situation needs a few hours of silence and peace every day. This need will increase in the future with population density in residential environments and apartment living. Therefore, from this point of view, the creation and development of urban green spaces where people can spend at least one hour a day in peace and away from the hustle and bustle of everyday life is an absolute necessity (Qurbani & Teimuri, 2014).

4.3 The structure of green space in Tabriz

- *Parks* The area of the park and green space is currently 578.8 hectares; the share of this land use is about 2.4% of urban land and its per capita is 3.8 square meters.
- *Gardens and agricultural lands.* This land use includes lands dedicated to gardens and agricultural lands inside the city, whose area is currently 2891 hectares. The share of this land use in the city is equal to 11.8% and its per capita is equal to 18.9 square meters.
- *Natural lands.* This use includes the areas dedicated to natural forests and human plantings whose area is 187.6 hectares in Tabriz. The share of this use from overall land of the city is 77.7% and it is per capita is equal to 1.22 square meters (Teimuri, 2015).

- *Natural spots.* These spots are not adequately distributed inside the city and the city is empty of big spots. While there are ample spots of mountainous lands in the outskirts and around the city (northeast and south of the city) and due to the northeast direction of the prevailing winds, air currents blow from part of these lands towards the city. Small green spots in some parts of the river bank are also among the few remaining spots. These spots have been destroyed and broken into pieces due to the construction and the passing of horse tracks on the river bank.

In general, the green space structure of Tabriz city can be divided into two general categories including artificial green spaces and natural green spaces: 1) Artificial green space: A combination of equipped urban parks, urban squares, refuges, trees planted inside and around residential areas, green spaces along the streets, etc. as well as all green spaces that have been cultivated and developed by people and city managers., 2) Natural green spaces: all green spaces that exist naturally and have been preserved.

4.4 Green space changes in Tabriz

The slow period in the changes of green space

The extent of urban green space in Tabriz during 1976 was distributed in different parts of the city suitably most parts of the city were located at reasonable distance from these uses. So the coverage of the city's green spaces and gardens in this period had an area equal to 5916.53 hectares for a population of 597976 people and it covered about 23.31% of the city area.

City population	Rate of changes in the area in hectares	Percentage of the total area of the city	Area in hectares	Year
597,976	-	23.31	5,916.53	1976
971,482	435.92	22.13	5,631.61	1981
1,089,000	655.58	20.19	5,125.03	1986
1,340,000	172.18	18.33	4,652.85	1996
1,398,060	278.89	17.23	4,373.96	2001
1,545,491	2257.87	8.34	2,116.09	2011
1,612,000	407.07	6	1,709.02	2021

Tab.1 Changes in the green space of Tabriz city since 1976-2021

In 1986, the area of green space in the city decreased by 5480.61 hectares, and an area equal to 435.92 hectares of green space was destroyed and changed in these 10 years period. These changes continued until 2006 and the area of green space decreased to 4373.96 hectares and 17.23% of the total urban area; these changes have been faced with an increase and decrease of the number of changes in different periods so in these 20 years period, i.e. from 1986 to 2006, the most significant amount of changes were related to the years 1986 to 1991 with 505.58 hectares of green space reduction. Therefore, despite the changes and destruction of green space in the mentioned period, the movement of changes has been slow during these 30 years study period, the percentage of green space has decreased from 23.31% to 17.23% of the total area of 25 thousand hectares.

The rapid course in the changes of the green space

The intensity of green space changes has increased in the last fifteen years. The percentage of green space in 2006 was 17.23%, which decreased to 6.73% in 2022. In fact, in this 15-year period of study, more than 2664 hectares of urban green space have been destroyed and it has turned into a great urban crisis. Most of these changes were also related to the years 2006 to 2011, where the area of green space has decreased from 4373.96 hectares to 2116.09 hectares. The intensity of changes in the green space of this period has been very fast and in 5 years (2006-2011), more than 50% of the urban green space has been destroyed, showing the lack of proper management of urban green spaces and the spread of rapid changes in this period.

4.5 Recognition of public parks and green space

Urban parks are considered a subset of public open spaces and green and open organs of the natural green structure of the city. This category of public open spaces has social efficiency and ecological benefits of the city and is designed and equipped for public use, leisure, recreation, meeting with friends and social and cultural gathering purposes. Bagh Golestan Park the area of Imam Khomeini Street and 22 Bahman Square, Valiasr Park and Baglar Baghi Park in the west of Valiasr street, El Goli Park in the southeast of Tabriz in the area of Shahid Bakri Blvd. Mashrouteh Park (Taleghani) in the south of the city and in the Shahid Kasai road, Kausar and Laleh parks also in the vicinity of the same highway, could be highlighted among the urban-scale parks. According to the Tabriz green structure development plan, Eram Park and Tabriz Grand Park in the north, the development of Eynali Mount. Park, the Shamim Complex and the development of El Goli and Abbas Mirza in the south of the city can form a coherent and intertwined structure of green spaces in urban and suburban areas which as effective in enriching the environmental qualities of Tabriz city. On a regional scale, parks such as Moallem, Bahar, Parvin Etsami, and Family could be identified.

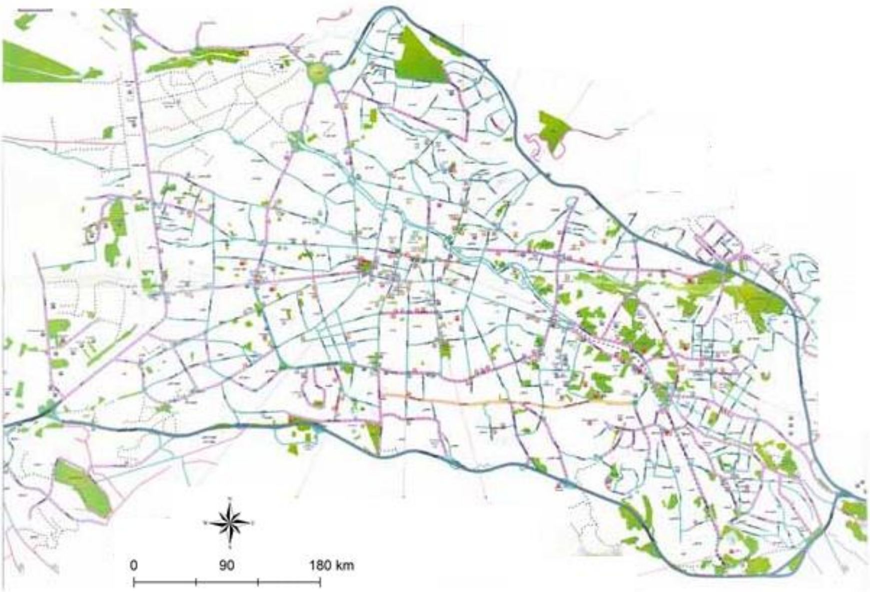

Fig.2 Distribution map of parks in Tabriz city

4.6 The analysis of access to green spaces

Examining the neighborhood green space of Tabriz city shows the lack of this use in old context. Therefore, due for the lack of parks and green spaces in this type of contexts, having access to them has problems to citizens. Hence, to achieve ecological development, as one of the principles of urban sustainable development, logical planning appropriate to the urban context is necessary for citizens to have access to these valuable urban parts. Network analysis is one of the tools that measures the time of having access to such urban vital elements based on the type of roads and, determines the areas outside service delivery their access radius, and also determines the appropriate places to create these valuable spaces in the heart of different neighborhoods of the city (Teimuri, 2015).

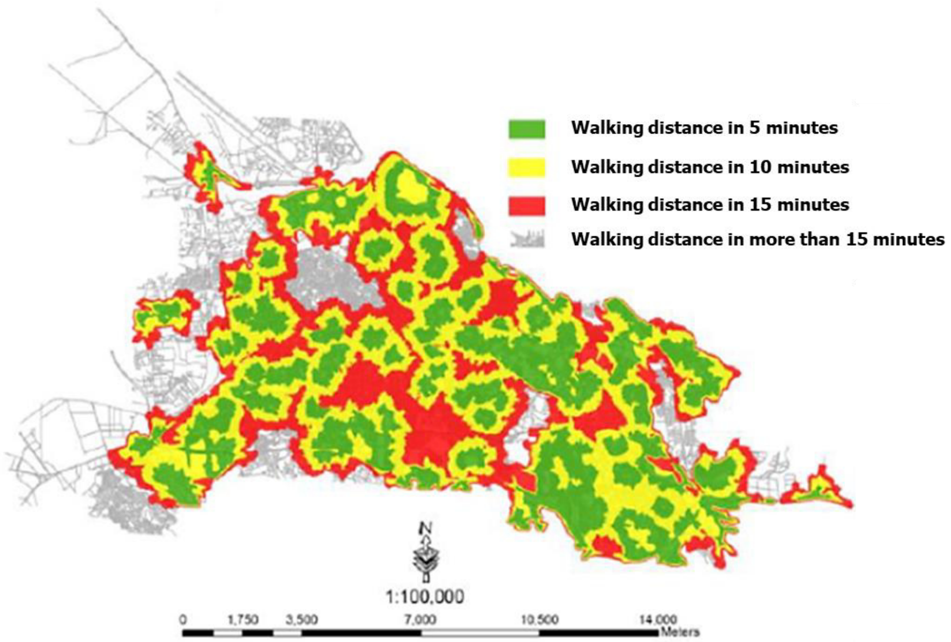

Fig.3 Walking access to urban parks in minutes

According to the considered network analysis in all the roads of Tabriz city, the attractive radiuses of parks have been calculated for the citizens. This radius has been analyzed in 5, 10 and 15 minutes and the maximum time a person can walk to the parking lots has been estimated to be 15 minutes. Using this analysis, the out-of-service areas of urban parks all over the Tabriz city have been estimated. The map shows that there is a small area of the city of Tabriz having access to the park within 5 minutes; however, the majority of urban parks are accessible within 15 minutes for citizens. Most urban contexts, with a higher density in buildings and population, have the least access to urban parks. District 8 has a small area due to its location in the historical, commercial and old context and the number of parks of this area is few. Districts 3 and 4, which are adjacent to district 8, also have more density in terms of urban construction and population. Therefore, planning to increase the number of parks in proportion to the population density of these areas seems essential.

4.7. Ranking of regions of Tabriz with TOPSIS Model

The result of the Topsis model shows that in terms of green space indicators, regions 6, 5, 7 and 2 are in the first to fourth ranks and regions 1, 3 are in the fifth and sixth ranks and regions 8, 10, 4 and 9 are in the following ranks.

4.8. Evaluation of the sustainability of green space in Tabriz

The results indicate that the regions of the city of Tabriz do not enjoy balanced green space and the green space is not distributed evenly among different regions.

x	fi	percent
388-2138	5	0.5
2139-3888	4	0.4
3889-5639	0	0
5640-7390	1	0.1

Tab.2 Distribution of green space between the regions of Tabriz city with class difference limit method

4.9. Classifying Tabriz districts using cluster analysis model

In this research, the hierarchical cluster analysis method has been used for further application in geographical studies. Accordingly, considering the purpose of the research and the data, the average link method, as one of the methods of forming agglomeration clusters in the hierarchical cluster analysis method, was utilized. This technique groups the districts that have the most similarity in terms of scores into a cluster. In this way, the scores of each factor indicators the degree of importance of each district.

Regions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Classifying	2	1	2	3	1	1	1	3	3	**3**

Tab.3 Classifying Tabriz districts based on green space indictors

The utilized classification in the cluster analysis showed that the places located in one level were very similar to each other, but they were significantly different from the places on other levels. The result of using the cluster analysis technique in grouping regions in terms of their green space indictors has been as described in Table 2 and Figure 4: meaning that regions 2, 5, 6, 7, were on the same level which is called the first level (having many and essential green space indictors), region 1, 3, were on one level, which is called the second level (having less green space indicators less than the first level) and regions 4, 8, 9, 10, were on one level which is called the third level in terms of having on green space indicators (Fig. 4 and 5).

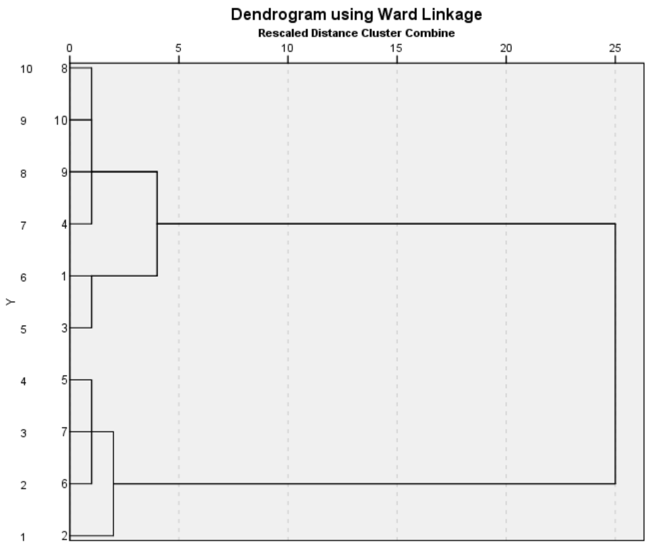

Fig.4 Tree diagram of Tabriz city regions based on green spaces indictors using Ward method

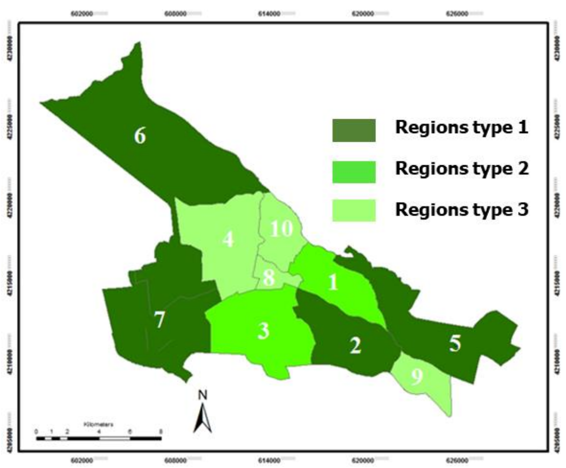

Fig.5 Map indicating the type of Tabriz regions in terms of having green spaces use

5. Conclusions

With the emergence of environmental crises in cities and the reduction of the general level of people's lives, the sanitation of urban environments and the preservation of the environment for future generations have become significant. Improving the productivity of green spaces should be considered with their ecological improvement, because valuable ecologic elements are significantly decreasing in cities. Urban green spaces as the urban breathing center play a key role in urban sustainable development and healthy urban environment, therefore, green spaces have a privileged position in the spatial development programs of cities to achieve a balanced, and sustainable development. At present time environmental pollution is increasing in most great cities, the coordinated and equitable expansion of urban parks and green spaces would play an influential role in creating environmental sustainability in cities. Having access to favorable per capita parks and green spaces for citizens, avoiding air pollution and noise pollution, air conditioning, and having a pleasant environment for urban life are among the ecological benefits that would be met with a principled design based on the climate and natural conditions of the city, which at the same time would lead to the visual beauty of the city and increase social interactions as well as suitable recreational spaces in the city, and create a favorable environment at all levels.

In the past, the city of Tabriz has been the attention of statesmen due to its gardens and suitable urban green spaces as well as favorable weather, and has functioned as the capital of the country. However, in recent years, due to the increase in the speed of construction and urbanization, Tabriz metropolis it has suffered from critical ecological elements, especially green spaces, and has lost these valuable spaces for economic gain in the form of development plans and urban physical developments of the city. The rate of changes in green spaces was somewhat slow from 1956 to 2006 and decreased from 5,916.53 hectares to 4,373.96 hectares. But after 2006, the changes occurred more quickly and more intensively, and the area of green spaces decreased to 1709.02 hectares in 2022, accordingly various factors played a role in these changes.

The lack of proper management of developments, directing the developments to the surroundings and gardens and green spaces, having income generation attitude towards green spaces by municipalities, and the lack of proper monitoring of the performance of municipalities on maintaining green spaces, were among the main factors in the changes of the green spaces of Tabriz city in the past years. The survey of the area and per capita of parks in the whole city showed the lack of parks and green spaces all over the city, especially in dense urban contexts, including districts 1, 3, 4, 8, 9 and 10. Moreover, using network analysis it was determined that citizens in districts 5, 7 and 3 had poor access to parks and green spaces. Also, using the TOPSIS model and class difference limit method, it was determined that the distribution of green spaces and parks in Tabriz has been unbalanced. Finally, with the continuation of this trend the lack of proper planning for the development of urban green spaces, environmental problems such as various kinds of urban pollution would spread and Tabriz would become an unhealthy and unsustainable city and the health of citizens would be endangered.

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Image Sources

Fig.1: Author's elaboration;

Fig.2: Tabriz Municipality;

Fig.3: Teimouri & Yigitcanlar, 2018;

Fig.4, 5: Author's elaboration.

Table Sources

Tab.1 to 3: Author's elaboration.

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Evaluating the urban heat island phenomenon from a spatial planning viewpoint. A systematic review

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Abstract
The increasing rate of urbanization and continuous population growth in urban areas leads to several problems, including the emergence of urban heat islands (UHI), defined as urban areas where temperatures are higher than in the surrounding rural areas. UHIs have negative impacts on the health of populations and lead to increased energy consumption for cooling. One of the main causes of higher temperatures in urban areas and, therefore, the creation of UHIs is impervious surfaces, which in turn lead to poor thermal comfort in cities. Ecosystem services and, in particular, the ecosystem service of local climate regulation are valuable tools to mitigate the effects of UHI. The contribution reviews the existing literature concerning the mitigation of heat island effects through ecosystem services, in order to understand how they are studied and analyzed in the international scenario. The proposed methodological approach is based on a framework of analysis of the scientific contributions published in the last fifteen years on the subject of UHI, investigating the phenomenon through an interpretation key based on the issues addressed, the methods used and the spatial scales to which these methods have been applied.

Keywords
Urban heat island; Local climate regulation; Spatial planning.

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1. Introduction

According to the United Nations Report (United Nations, 2019) in 2018 more than 55% of the world's population lived in urban areas and it is expected that by 2050, the percentage will grow to 64%-84%. The increasing rate of urbanization and the continuous increase of population in urban areas have entailed several problems which impact negatively on health and well-being of populations and the environment in general (EEA, 2017; Rosenzweig et al., 2018). Furthermore, urbanization often leads to negative impacts that are linked to other threats in areas with heightened natural risk, like hydrogeological issues (Mazzeo & Polverino, 2023).
Urban heat island (UHI) is defined as "...an urban area that is significantly warmer than its rural surroundings due to artificial infrastructure and human activities" (Copernicus, 2021). UHIs have negative impacts on the health of populations (Heaviside et al., 2017) and lead to increased energy consumption required for cooling (Santamouris et al., 2015). One of the main causes of rising temperatures in urban areas and, thus, the occurrence of UHIs is impervious surfaces (Irmak et al., 2017), which in turn lead to poor thermal comfort in cities (Morris et al., 2017). The thermal behavior of urban structures can be significantly improved through the implementation of measures that affect only the surface cover of the buildings (Icaza et al., 2016). In literature, several methodological approaches are used to study and assess the UHI phenomenon and climate vulnerability and risks, such as methods based on field observations (Nolte et al, 2022; Li et al., 2021), empirical methods (Oliveira et al., 2021; Su et al., 2021), remote sensing techniques (Almeida et al., 2021; Chen et al., 2006; Despini et al., 2021), modelling (Mahadavi et al., 2016; Marando et al., 2022), and simulation (Sobocká et al., 2020; Elliot et al., 2020).
The determination of thermal comfort in cities represents a fundamental element in the assessment of the urban microclimate (Kalogeropoulos et al., 2022). For this reason, the implementation of appropriate land management policies and modelling techniques aimed at analyzing these phenomena is of paramount importance (Evola, 2017). The current scientific debate focuses on the need to formulate effective policies for climate change adaptation and mitigation (Pinto, 2014). In fact, several studies focus on the mitigation of impacts due to heat islands. Some studies are based on physical-microclimatic models that allow to compare two or more different scenarios, such as in the case of the ENVI-met simulation tool (Magliocco & Perin, 2014). Other studies propose the use of materials and design methods based on nature-based solutions (NBSs) and Green Infrastructure (GI) in new urban settlements and in restoration sites. Green transition of urban areas makes cities more adaptable and more resilient to the effects of UHI. With regard to the risks associated with UHIs, appropriate short- and long-term planning and management measures are required (Biasin et al., 2023). GIs represent a strategically planned network of high quality natural and semi-natural areas (Fauk, 2023), and according to the European Commission, GIs "… are designed and managed to deliver a wide range of ecosystem services" (ESs) (2013, p. 3). Subsequently, EU 2030 Biodiversity Strategy encourages Member States to map and assess ecosystems and their services (Córdoba Hernández & Camerin, 2023)
Ecosystem services and, in particular, regulating ecosystem service such as local climate regulation, are a valuable tool for mitigating the effects of UHI. Numerous studies have highlighted the relationship between land cover types and its impact on surface temperature (Semenzato & Bortolini, 2023). The increase of vegetation in urban areas allows the regulation of the macro- and microclimate and the reduction of surface temperatures (van Oorschot, 2021). In general, the increase of permeable areas is implemented through the realization of new public green spaces, the requalification of existing green areas and the tree planting in the most sealed areas. Ecosystem-based adaptation approach to urban spatial planning can be a key element of establishing urban policies focused on natural resource management (Bush & Doyon, 2019). As a result, this approach incorporates the advantages provided by ESs also in terms of socio-economic development impacts (Chen et al., 2020). On the other hand, the integration of ES within spatial planning is still limited. Longato et al. (2021) evaluate the use of ES in spatial planning by means of a literature review in order to understand the integration level, and planning strategies addressed. According to Longato et al. (2021), although the

number of studies that focus on the integration of ES in spatial planning have increased, the systematic review of the literature highlights how the main benefits of integrating ES into spatial planning concern only practical issues, such as the promotion of stakeholder participation.

Starting from this theoretical framework, the study presents an in-depth analysis of the existing literature on the mitigation of heat island effects through ecosystem services, in order to understand how these phenomena are studied and analyzed in the international scenario. The proposed methodological approach is based on a systematic review of scientific studies published in the last fifteen years on the subject of UHI, investigating the phenomenon through an interpretation key based on four aspects: general context, reasons, methods and data, and implications for spatial and urban planning. Moreover, the proposed method represents a preliminary analysis aimed at defining key elements on which to base spatial planning policies at the municipal scale.

The contribution is structured in four sections. The first, introductory section focuses on the theoretical background. The second describes the proposed methodological approach, structured in two specific evaluation phases. The third section presents the results which are discussed in the fourth section, where final considerations are provided.

2. Materials and methods

The paper proposes a systematic analysis of a part of the existing scientific literature on the mitigation of heat island effects through ecosystem services, with the aim to understand how this phenomenon is internationally studied and analyzed. The sample of papers to be analyzed was selected from the Scopus database, (01/06/2023) using the combination of words "Urban AND heat AND island AND ecosystem AND services" within the field "Article Title; Abstract; Keywords". The preliminary paper selection resulted in the identification of 331 papers spanning a period from 2007 to 2023.

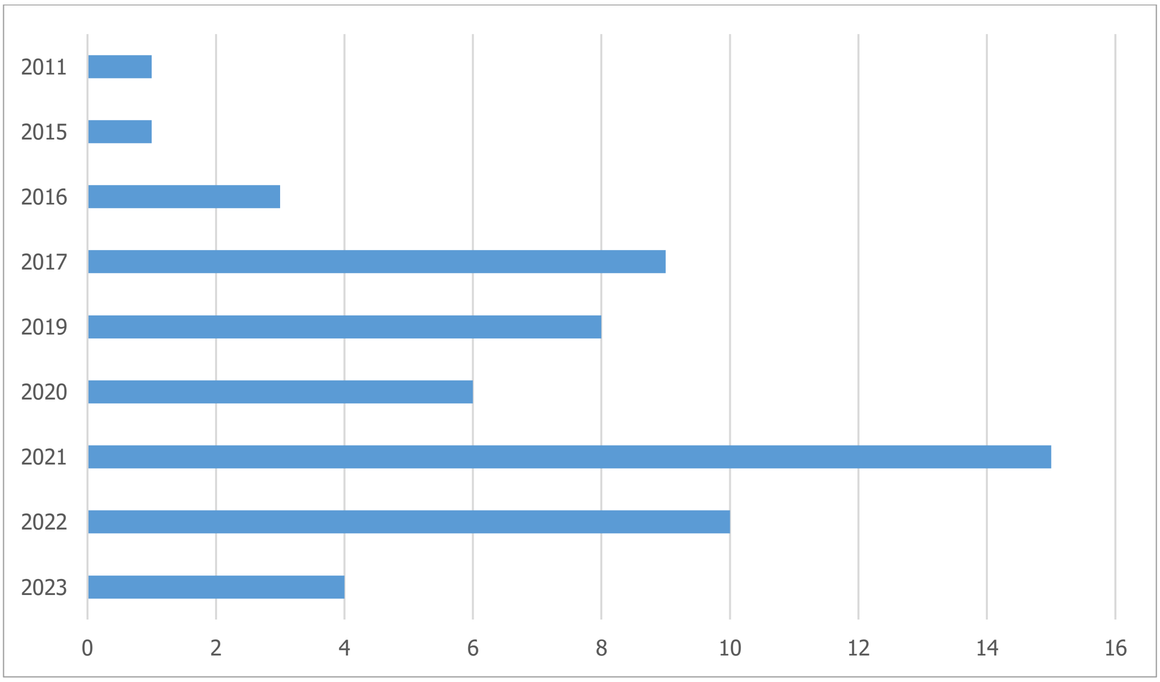

Fig.1 Time distribution of the 57 analyzed papers

The paper selection phase was structured into two evaluation steps. In the first step, all abstracts were analyzed in order to exclude papers not related to spatial and urban planning. As a result of the first step, 122 papers were selected. The second evaluation step involved a content analysis in which all 122 selected papers were analyzed. As a result of the second step, 57 papers were selected.

Source	Typology of the source	Number of paper
42nd Asian Conference on Remote Sensing	Conference Proceedings	1
Chinese Journal of Population Resources and Environment	Journal	1
Computers, Environment and Urban Systems	Journal	1
Ecological Indicators	Journal	2
Ecological Informatics	Journal	1
Ecological Modelling	Journal	1
Ecosystem Services	Journal	1
Environment, Development and Sustainability	Journal	1
Environmental Impact Assessment Review	Journal	1
Environmental Research Letters	Journal	2
Environmental Science and Pollution Research	Journal	1
European Journal of Remote Sensing	Journal	1
Forests	Journal	1
Frontiers in Sustainable Food Systems	Journal	1
GIScience and Remote Sensing	Journal	1
Journal of Urban Planning and Development	Journal	1
Journal of Soils and Sediments	Journal	1
International Journal of Applied Earth Observation and Geoinformation	Journal	1
International Journal of Environmental Science and Technology	Journal	1
Land	Journal	2
Land Use Policy	Journal	1
Landscape and Urban Planning	Journal	5
Lecture Notes in Computer Science	Volume	1
Remote Sensing	Journal	2
Science of the Total Environment	Journal	4
Spatial Information Research	Journal	1
Sustainability	Journal	5
Sustainable Cities and Society	Journal	5
Urban Biodiversity and Ecological Design for Sustainable Cities	Journal	1
Urban Climate	Journal	1
Urban Ecosystems	Journal	3
Urban Forestry and Urban Greening	Journal	3
Urban Planning	Journal	1
Urban Science	Journal	1

Tab.1 List of sources where the analyzed papers were published, type of source and number of papers

The remaining 65 papers were excluded because: (a) only the abstract was freely available or only the abstract was written in English (24 papers); (b) they were theoretical and did not deal with application cases (four papers); they focused on the building scale (29 papers); and (c) they focus on the influence of specific typologies of plant species on the mitigation of urban heat island effects (12 papers). Fig.1 shows the temporal distribution of the 57 analyzed papers. Most of the analyzed papers were published from 2017 to 2019, excluding the year 2023 because the results are only partial as they refer to papers published until 1 June.

Tab.1 shows the source on which the 57 analyzed papers were published, the type of source and the number of papers published in each journal or series. With the exception of two papers, all the analyzed papers were published in 34 different scientific journals. The journals where the highest number of the analyzed papers are: Landscape and Urban Planning, Science of the Total Environment, Sustainability, and Sustainable Cities and Society.

With regard to the data analysis, the main research question was broken down into four sub-questions that guided the content analysis of the papers. Tab.2 shows the sub-questions, specified through a description of the interpretation keys.

Sub-question	**Interpretation key**
A – General context	A1 – The scale to which the analysis refers (region, city, part of the city).
	A2 – Type and number of case studies analysed.
B – Reasons	B1 – Description of the reasons why the urban heat island phenomenon is studied.
	B2 – It is described whether the phenomenon was studied individually or within a larger study.
C – Methods and data	C1 – Description of the methods used (in situ observations, remote sensing techniques, modelling and simulation).
	C2 – Description of data retrieval with reference to three parameters concerning the season in which the data was retrieved, the duration of data collection and the period of the day to which the data refers.
D – Implications for spatial and urban planning	D1 – Does the study define strategies and/or suggest recommendations for planners and policy maker
	D2 – Do you dedicate a special section to such strategies?
	D3 – What kind of strategies are defined?

Tab.2 Sub-question and description of interpretation keys for the analysis of selected papers

3. Results

Below are the results for each sub-question shown in Tab.2.

3.1 General context

In relation to the general context, 49 papers refer to the municipal scale, two concern the metropolitan scale (Kowe et al., 2021; Lonsdorf et al., 2021), two focus on an inter-municipal scale, between municipal and regional territory (Gohr et al., 2021; Chaudhuri & Kumar, 2021), three refer to the regional scale (Ashwini & Sil; 2022; Bindajam et al., 2022; Schwarz et al., 2011), and one concerns the national scale (Bassett et al., 2020) (see Fig.2). For example, Bassett et al. (2020) study the thermal contribution of land cover change to climate regulation between 1975 and 2014 in Great Britain.

Furthermore, with reference to the 49 cases that refer to the urban scale, 29 cases study the entire municipal territory while 20 focus on parts of the territory. With reference to the 29 papers that consider the entire municipal territory, in six cases a comparison between several cities is made (Han et al., 2023; Marando et al., 2022; Degefu et al., 2021; Ramaiah et al., 2020; Meerow, 2019; Estoque et al., 2017).

For example, Marando et al. (2022) analyze the mitigation of the local microclimate offered by urban green infrastructure through a model that combines land surface temperatures (LST) with air temperature, taking 601 European cities with less than 50,000 inhabitants as case studies. With reference to studies analyzing parts of the city, twelve papers consider permeable areas such as urban parks (Permatasari et al., 2021; Li et al., 2021; Cheng et al, 2015), cemeteries (Okumus & Terzi; 2023), the urban green system (Feng et al., 2022; Wo et al., 2022; Yan et al., 2021; Wang et al., 2021; Yu et al., 2017; Vaz Monteiro et al., 2016), forest areas (Yosef et al., 2022) and urban gardens (Nolte et al., 2022). In the remaining eight cases (Murtinová et al., 2022; Chen et al., 2021; Ruiz-Aviles et al., 2020; Wu & Zhang, 2019; Petri et al., 2019; Bartesaghi-Koc et al., 2019; Zhang et al., 2017b; Mariani et al., 2016), urban areas characterized by a mixed fabric comprising both sealed and permeable areas are considered. For example, Murtinová et al. (2022) study the effect of the

Surface Urban Heat Island (SUHI) in the city of Zvolen (Slovakia), analyzing the LST within three urban areas during the summer months in the period 2010-2021.

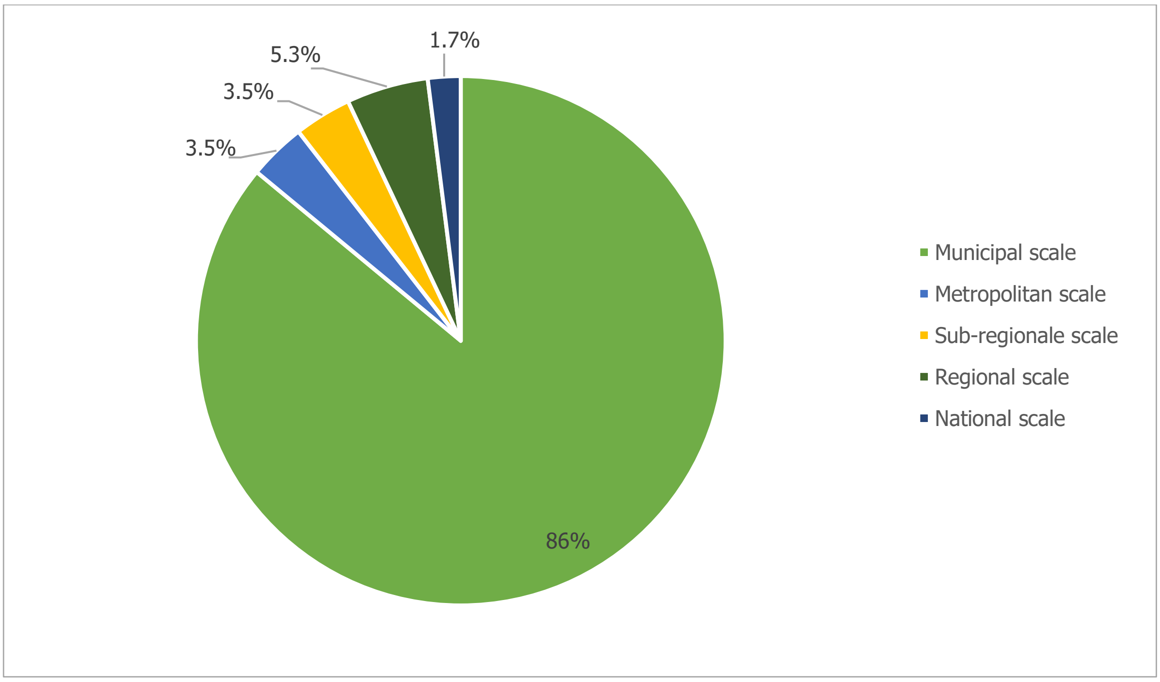

Fig.2 Scale of analysis of the papers analyzed in the study

Fig.3 shows the location of the case studies analyzed in those papers that focus on the municipal scale with the exception of the 601 European cities analyzed in the study of Marando et al. (2022). The most studied is Beijing, followed by Shenzen (China), Manila (Philippines), and Milan and Rome (Italy).

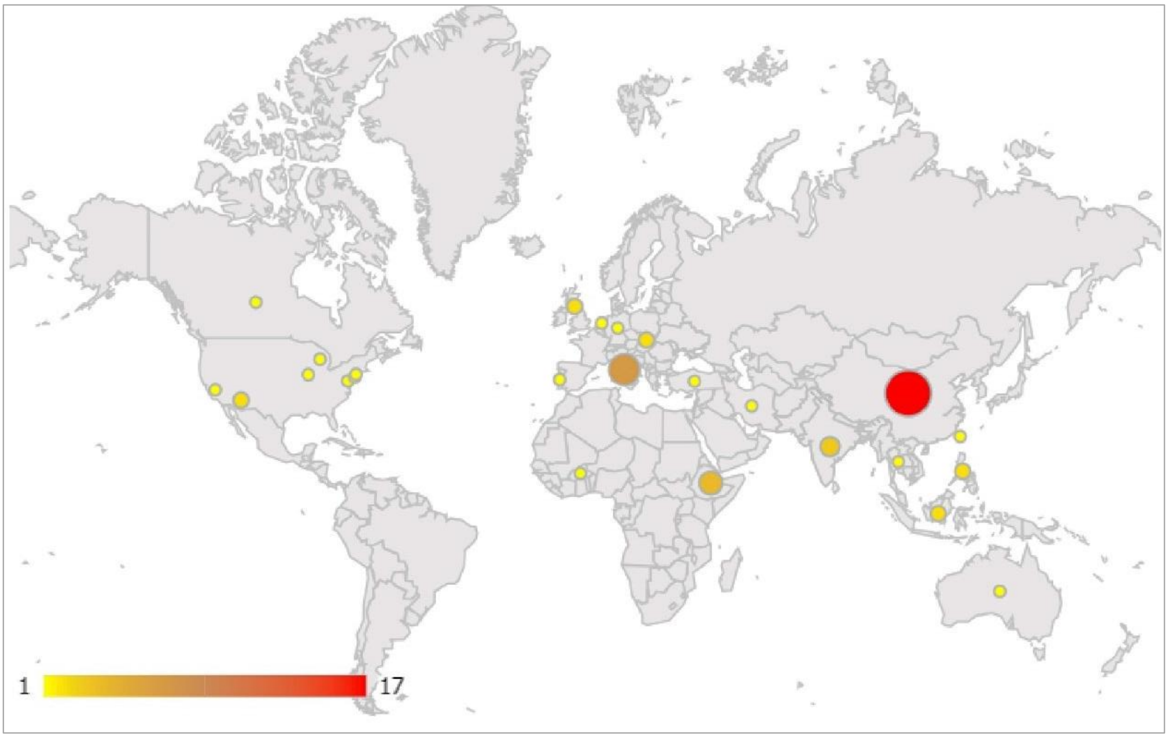

Fig.3 Localization of case studies in the case of papers focusing on the municipal scale

3.2 Reasons

With reference to the second sub-question 'motivations', 47 papers focus their study on the phenomenon of urban heat islands. In the other ten cases (Biasin et al., 2023; Feng et al., 2022; Yao et al., 2022; van Oorschot et al., 2021; Lonsdorf et al., 2021; Sebastiani et al., 2021; Meerow, 2019; Zidar et al., 2017; Meerow & Newell, 2017; Bodnaruk et al., 2017), the study of the urban heat island phenomenon is embedded within a broader study. For example, van Oorschot et al. (2021) study the best location of green infrastructure based on its ability to provide three benefits, that is three ecosystem services, one of which is the reduction of the urban heat island effect.

In reference to the papers that focus on the urban heat island phenomenon (Fig.4), 24 papers focus on the influence of permeable areas on the temperature reduction and, thus, urban heat island effects. Different types of permeable areas are studied such as urban green areas (Han et al., 2023; Murtinová et al., 2022), parks (Wo et al., 2022), forests (Yosef et al., 2022) and urban green infrastructure (Marando et al., 2019; Di Leo et al., 2016). In addition, nine papers (Amir Siddique et al., 2023; Ashwini & Sil, 2022; Bindajam et al., 2022; Permatasari et al., 2021; Li et al., 2021; Bassett et al., 2020; Elliot et al., 2020; Tayebi et al., 2019; Schwarz et al., 2011) focus on the influence of land use and/or land cover and their changes on temperatures and, thus, on reducing urban heat island effects.

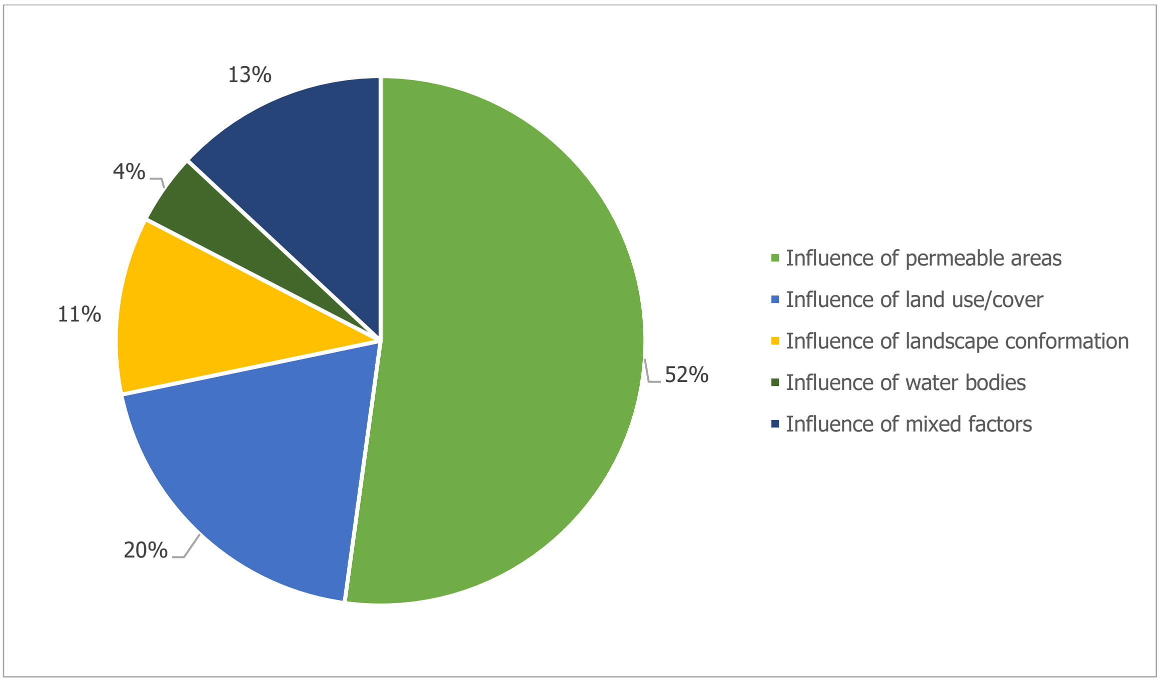

Fig.4 Factors studied by papers that focuses on urban heat island phenomenon

For example, Elliot et al. (2020) propose a study in which a simulation model of land cover changes was used to assess the effects of urban heat islands over time in the city of Lisbon. Five papers (Kowe et al., 2021; Chaudhuri & Kumar, 2021; Chen et al., 2021; Osborne et al., 2019; Estoque et al., 2017) study how landscape conformation influences temperatures and, thus, the reduction of urban heat islands.

Two papers (Ruiz-Aviles et al., 2020; Wu and Zhang, 2019) study the influence of water bodies on the urban heat island phenomenon. The remaining six papers focus on different factors (Gohr et al., 2021; Apicella et al., 2021; Ronchi et al., 2020; Shih & Mabon, 2020; Ramaiah et al., 2020; Zhang et al., 2017b). For example, Ramaiah et al. (2020) study how LST is influenced by three factors: built-up areas, vegetated areas and water bodies.

3.3 Methods and data

With reference to the "methods and data" sub-question (Fig.5), 37 papers (Okumus and Terzi, 2023; Yao et al., 2022) use remote sensing techniques to assess LST. In six papers (Nolte et al., 2022; Li et al., 2021; Lonsdorf et al., 2021; Bassett et al., 2020; Zhao et al., 2019; Vaz Monteiro et al., 2016) air temperatures are obtained through direct measurements. Two cases (Han et al., 2023; Marando et al., 2019) assess both land surface temperatures through remote sensing techniques and air temperatures through direct measurements. In the remaining twelve papers, the urban heat island phenomenon and local climate regulation are studied through other methods such as INVEST (Biasin et al., 2023; Ronchi et al., 2020) or the i-Tree cool air model (Pace at al., 2022).

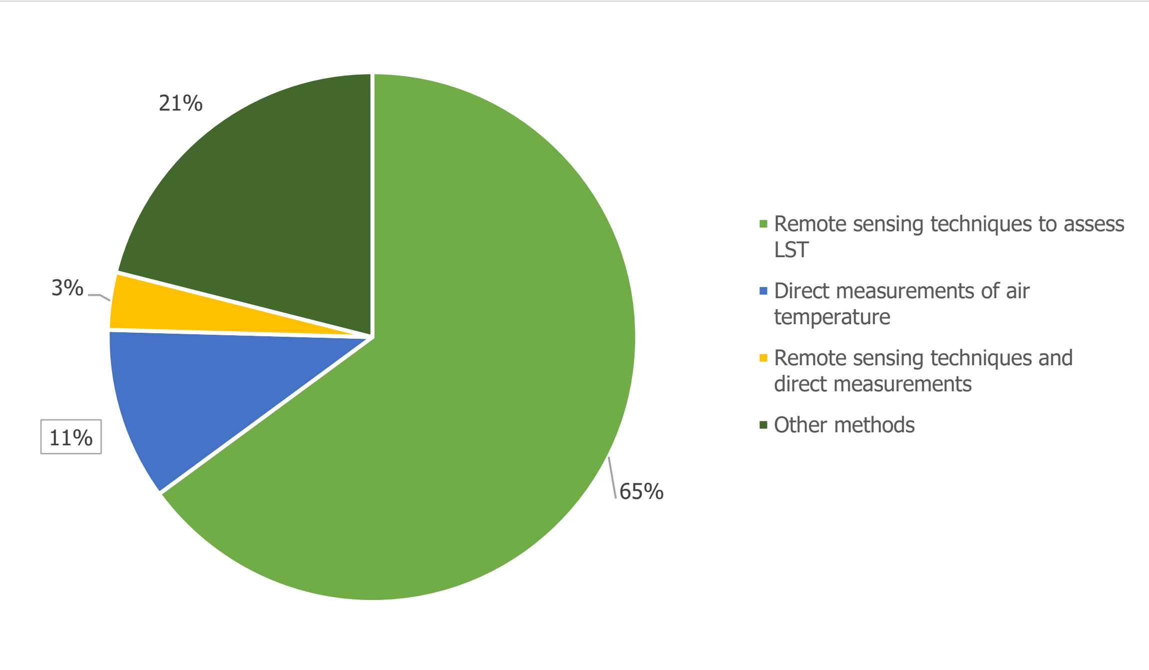

Fig.5 Methods used to study the urban heat island phenomenon

In relation to the 37 papers using remote sensing techniques, in twelve cases the images analyzed refer to a single date. Fig.6 shows to which time of day the twelve papers referring to a single date refer when assessing the urban heat island. Specifically, in five cases (Okumus & Terzi, 2023; van Oorschot et al., 2021; Yan et al., 2021; Wu & Zhang, 2019; Greene & Millward, 2019) the image refers to daytime, in one case to nighttime (Estoque et al, 2017), while in the remaining six cases the time of day to which the assessment refers is not made explicit (Feng et al., 2022; Chen et al., 2021; Permatasari et al., 2021; Sebastiani et al., 2021; Meerow, 2019; Cheng et al., 2015).

The remaining 25 papers that use remote sensing techniques analyze images that refer to several, often very distant years, of which nine (Murtinová et al., 2022; Gohr et al., 2021; Yosef et al, 2022; Wo et al., 2022; Shih & Mabon, 2021; Ruiz-Aviles et al., 2020; Ramaiah et al., 2020; Wu et al., 2020; Osborne et al., 2019) have acquired images that refer to daylight hours, two (Amir et al., 2023; Wang et al., 2021) to nocturnal hours, two (Apicella et al., 2021; Zhang et al., 2017a) to both nocturnal and diurnal hours, and in the remaining twelve cases (Ashwini & Sil, 2022; Bindajam et al., 2022; Yao et al, 2022; Degefu et al., 2021; Kowe et al., 2021; Chaudhuri & Kumar, 2021; Tayebi et al., 2019; Yu et al., 2017; Meerow & Newell, 2017; Sun & Chen, 2017; Zhang et al., 2017a; Di Leo et al., 2016) is not made explicit. Fig.7 shows the 25 papers evaluating the urban heat island phenomenon over a timeframe longer than one day using remote sensing techniques and, for each period, indicates the time of day to which the evaluations refer.

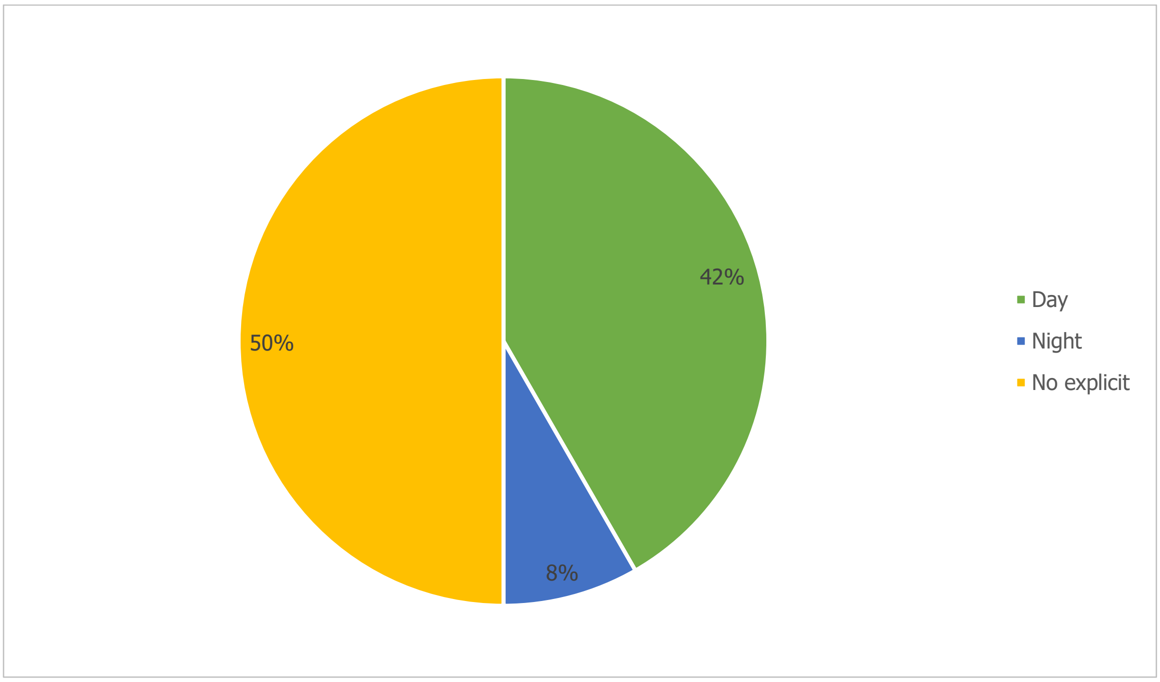

Fig.6 Time of day refers to the twelve papers considering a single date to assess the urban heat island

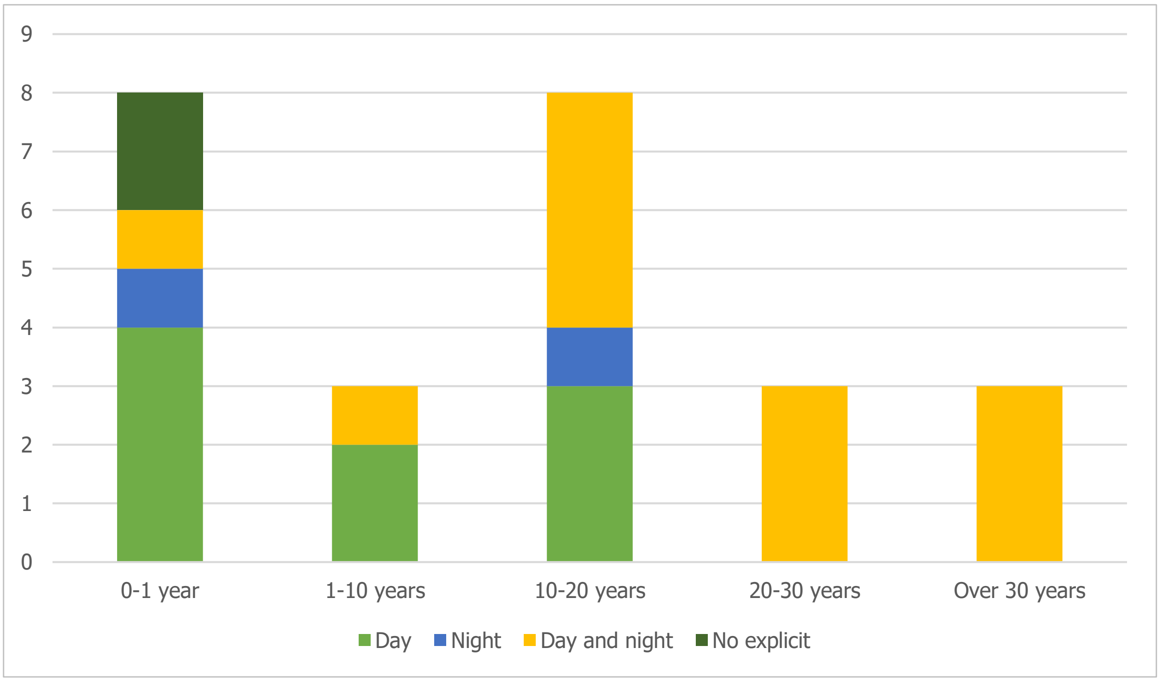

Fig.7 Identification of papers evaluating the urban heat island phenomenon over a period of time longer than one day, broken down by observation period and by time of day to which the evaluation refers

3.4 Implications for spatial and urban planning

With reference to the fourth sub-question "Implications for spatial and urban planning", 32 papers suggest strategies and/or recommendations for policy makers and planners. In thirteen cases (Han et al., 2023; Okumus & Terzi; 2023; Feng et al., 2022; Pace et al., 2022; Chen et al., 2021; Kowe et al., 2021; Li et al., 2021; Lonsdorf et al., 2021; Yan et al., 2021; Shih & Mabon, 2021; Yu et al., 2017; Zhang et al., 2017b; Di Leo et al., 2016) the authors decided to dedicate a special section to them. The 32 papers suggesting strategies and/or recommendations can be grouped into four types: strategies at the territorial scale, guidelines on individual interventions at the local scale, the methodological approach as decision support, and strategies and guidelines that address both the territorial and local scales (see Fig.8).

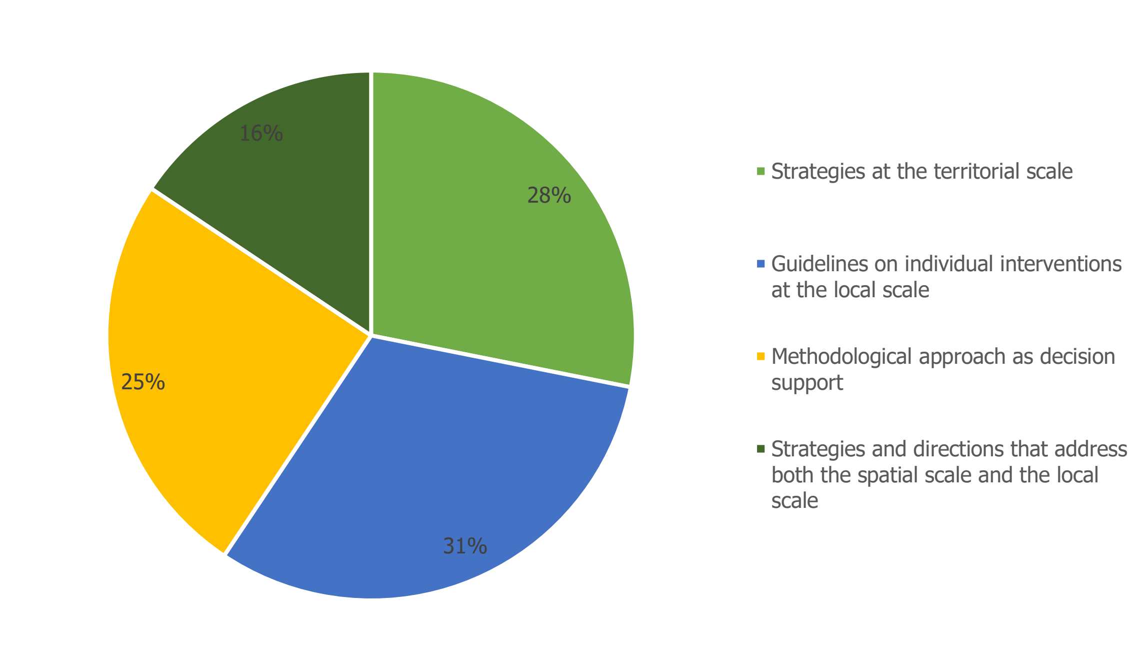

Fig.8 Type of strategies and/or recommendations suggested by the 32 papers providing them

In nine instances (Biasin et al., 2023; Yosef et al., 2022; Chen et al., 2021; Kowe et al., 2021; Lonsdorf et al., 2021; Shih & Mabon, 2021; Zidar et al., 2017; Sun and Chen, 2017; Di Leo et al., 2016), these recommendations and/or strategies refer to a spatial scale. For example, Shih & Mabon (2021) suggest favoring natural ventilation and protecting areas that promote temperature reduction.

In order to improve natural ventilation, the study suggests preserving mountain valleys from intensive urbanization by preserving green spaces along pathways where wind is channeled, especially those located along river corridors. With regard to areas that favor temperature reduction, such as agricultural land, wetlands and ponds, their continuity should be ensured within development plans also by providing forms of transfer of building rights.

In ten instances (Bindajam et al., 2022; Feng et al., 2022; Nolte et al., 2022; Yan et al., 2021; Li et al., 2021; Estoque et al., 2017; Yu et al., 2017; Zhang et al., 2017a; Greene & Millward, 2017; Vaz Monteiro et al., 2016), the recommendations and/or strategies refer to individual interventions at the local scale. For example, Ronchi et al. (2020) suggest design parameters for urban green areas, such as tree cover and area size. In relation to tree cover, the study suggests that the species planted, and the relative canopy cover are most significant elements despite the number of trees. In eight cases (Amir Siddique et al., 2023; Han et al., 2023; Ashwini & Sil; 2022; Yao et al., 2022; Marando et al., 2022; Murtinová et al., 2022; Mariani et al., 2016; Schwarz et al., 2011) the methodology is proposed as a decision-support tool, while the remaining five cases (Okumus & Terzi; 2023; Pace et al., 2022; Wang et al., 2021; Ronchi et al., 2020; Zhang et al., 2017b) provide recommendations at both the spatial and individual intervention scales.

4. Discussion and conclusions

The results of the content analysis conducted on the 57 papers highlight several important aspects. Firstly, the study of the urban heat island phenomenon in relation to ecosystem services has been a widely discussed topic in the literature for several years. The oldest analyzed paper dates back to 2011. Howard was the first scholar to describe the urban heat island phenomenon and its causes within his work "The Climate of London" where he described the study conducted from 1806 to 1830 during which he recorded the temperature every day for a year at three sites outside London (Plaistow, Tottenham and Stratford) and one within the city (Royal Society) (Mills, 2007). Howard defines the urban heat island as the difference between the air temperature within the urban settlement and the air temperature measured in the rural areas and assumes that this value increases as one moves closer from the city limits towards the center (Mills, 2007). Howard also defines possible causes, arriving at the conclusion that "the temperature of the city is not to be considered as that of the climate; it partakes too much of an artificial warmth, induced by its structure, by a crowded population, and the consumption of great quantities of fuel in fire" (Howard, 2007, p. 2).

The second aspect concerns the factors influencing urban heat islands. According to the study conducted by Voogt (2007), they can be traced to six aspects: i. geographic location; ii. time; iii. synoptic weather; vi. city form; v. city function; and vi. city size. Geographic location takes into account climate, topography and rural surrounds. Time considers time of day (day and night) and season (winter, spring, summer, and autumn). Synoptic weather considers wind and the presence of clouds. City form concerns materials, geometry, and green spaces. City function concerns the activities that take place in terms of energy use, water use and pollution and, finally, city size is connected with the shape of the city and the functions that take place in it. However, according to Voogt (2007), mitigation measures relate to city form and city function are the only parameters on which human being can operate.

For example, Okumu and Terzi (2023) study the cooling effect of 309 cemeteries in the city of Istanbul. The study showed that the optimal distance for cooling, beyond which this regulation service decreases, is 200 m for very small cemeteries, 250 m for medium-small cemeteries and 400 m for larger cemeteries. In terms of the time factor, the intensity of urban heat islands is influenced by the seasons and day and night variations. The influence of seasons concerns two aspects: amount of solar radiation reaching the earth and metabolic activity of vegetation (Deilami et al., 2018). In addition, the influence of the seasons also depends on geographical location. In the case of cities with arid and semi-arid climates, the intensity of temperatures is lower in urban areas than in surrounding areas characterized, for example, by the presence of desert areas (Shahraiyni et al., 2016). This phenomenon is called an urban cold island (Rasul et al., 2015, 2016). With regard to night and day variations, the cooling process in cities after sunset is slower than in rural areas. This behavior is due to the high thermal capacity of certain materials such as concrete and asphalt that characterize urban areas. These materials absorb high amounts of heat during the day, which is then slowly released during the night, resulting in very high UHI values during the night hours.

The third aspect concerns the techniques used. The vast majority of papers analyzes land surface temperatures through remote sensing techniques. The analysis of urban heat islands requires a reliable and consistent dataset. Prior to the use of remote sensing techniques, the process to obtain such data was particularly laborious and costly as it required the installation of meteorological stations (Baranka et al., 2016). The process has been simplified by the use of remote sensing satellites, which have made it possible to study large urban areas due to frequent wall-to-wall coverage (Deilami et al., 2018). Furthermore, thermal information is provided both as a scene/image and as individual products making the process of deriving urban heat island intensity simpler (Li et al., 2013).

Several satellites are used to acquire the images needed to obtain urban heat island intensities, including Landsat TM, Landsat ETM, MODIS, Landsat OLI (8), etc. According to a study conducted by Deilami et al. (2018), Landsat imagery is the most widely used as it is freely available, it has worldwide coverage with an acceptable resolution of 30x30 m, it has temporal coverage dating back to 1972 and it provides both thermal and thematic spectral bands. However, Landsat images also have disadvantages. Firstly, it takes sixteen days for the satellite to re-image the same area. As a consequence, assessing the effects of urban heat islands during a day or a week is not possible. The second disadvantage relates to processing time, which could be significant if mosaicking is required in order to process analyses on a national or regional scale, given the size of the images (Irons et al., 2012; Loveland & Dwyer, 2012). The use of MODIS imagery solves some of these critical issues, such as the time between two images of the same location (1-2 days for the Terra and Aqua MODIS satellite) and the processing time, as it provides some immediately available products that significantly reduce the time. For example, LSTs are produced daily and weekly. However, MODIS images have a low spatial resolution.

Despite the widespread use of remote sensing techniques at the expense of direct measurements, these techniques have limitations. Firstly, obtaining cloud-free images is difficult in some geographical areas (Deilami et al., 2018). In addition, the thermal and thematic bands of remote sensing have a spatial resolution of 30 m to 1 km that do not make it possible to process very detailed analyses, which would require costly downscaling and fusion approaches (Atkinson, 2013). Finally, the accuracy of the data is affected by several factors, including atmospheric effect, sensor noise, etc. For example, the study conducted by Jiménez-Muñoz and Sobrino (2006) showed that the main source of error for the determination of LST from satellite images is atmospheric effects. Krehbiel and Henebry (2016) conducted a study in which they compared urban heat island intensities obtained from direct measurements and those obtained from MODIS imagery. The urban heat island intensity during the day is much higher in the case of data derived from MODIS images than that determined from direct measurements, while the values for the night are quite similar.

The third aspect concerns the implications for spatial and urban planning. At the international level, the 2030 Agenda for Sustainable Development and the 17 Sustainable Development Goals (SDGs) provide an important framework for the identification of climate change adaptation measures. In particular, Goal 11 "Sustainable cities and communities" places resilience as a priority aspect in the future development of cities that adopt and implement climate change adaptation policies (EEA, 2020). Furthermore, Goal 13 "Climate action" in Target 13.2 calls for "Integrate climate change measures into national policies, strategies and planning" (General Assembly of United Nations, 2015). However, strategies defined at the international level have an indirect impact on adaptation at the local scale as these agreements have been negotiated and signed by national governments (Valencia et al., 2019). In fact, the adoption of these international frameworks does not lead to the implementation of concrete adaptation actions by cities. For example, the study proposed by Aguiar et al. (2018) examined 147 Local Adaptation Strategies/Plans in Europe, highlighting that the United Convention on Climate Change process promoted the elaboration of only 21 plans. Furthermore, the study shows that the issue of extreme temperatures is addressed by 35 plans.

At the national level, Athens and Stockholm represent two cities that have addressed heat islands in their climate change adaptation plans (Gancheva et al., 2022). Athens adopted the Athens Resilience Strategy for 2030 in 2017 and the latest Climate Action Plan was published in 2022. In particular, one of the main objectives of the Athens Strategy is to increase the area of green areas in order to decrease vulnerability to heat islands. To this end, Athens has quadrupled the budget for green areas, also thanks to the Greek state and European funds (Observatory On Non-State Climate Action, 2022). In 2019, Athens obtained funding on the Natural Capital Financing Facility, a new financing instrument of the European Investment Bank that finances cities for blue and green infrastructure projects. In addition, in 2021, the city of Athens signed the Urban Nature Declaration, which envisages de-impermeabilizing between 30 and 40 percent of impermeable surfaces and ensuring that at least 70 percent of the population has access to green or blue spaces within a 15-minute radius.

According to the EEA (2020), green infrastructure is one of the most effective adaptation measures to combat high temperatures. Several projects have been aimed at increasing green areas. For example, the LIFE Green Heart Project envisaged a significant increase in green areas in Toulouse, France, in order to reduce the temperature by approximately 3 °C during urban heat islands (Directorate-General for Climate Action, 2023). Furthermore, the LIFE@Urban Roof Project aims to increase green roofs in the city of Rotterdam, Netherlands.

The RESIN (Climate resilient cities and infrastructures) project funded by the Horizon 2020 Programme for the years 2015-2018 aims to improve climate resilience in European cities. The RESIN Adaptation Options Library is one of the tools developed by the Project. The library is a database on the effectiveness of adaptation measures, divided into three types (structural, social and institutional) based on an analysis of scientific studies published up to 2017 (EEA, 2020). The database is structured in four parts: general information, organization, effectiveness and cost-efficiency. The general information section provides the main information on each adaptation measure (type, scale, climate region, sector, etc.). Organization defines who should implement the adaptation measure. Effectiveness measures in terms of reducing the vulnerability and risk components. Finally, Efficiency considers the costs and benefits of implementing the adaptation measure (Mendizabal et al., 2015).
In conclusion, the study is a preliminary research that attempts to provide an overview of how urban heat islands are studied in literatures by analyzing some key issues related to the general context, rationale behind the study, materials and data, and implications for land-use and urban planning.
With reference to the general context, almost all papers focus on the municipal scale. In relation to reasons, only a small percentage of the papers analyzed study the heat island phenomenon within a broader approach that investigates other aspects. In relation to methods and data, the vast majority analyze land surface temperatures through remote sensing techniques. Finally, not all papers use their findings to propose strategies and recommendations for policy makers and planners.
The originality of the proposal consists in the construction of a framework that connects the issues due to UHI with the ES and GI topic at the municipal scale. In fact, if the urban setting represents the place where the effects of climate change are most perceived, the construction of an analytical system on which to base a climate-proof urban planning policy turns out to be a useful and important tool. It must be emphasized that adaptation will not be cross-cutting and ubiquitous (Pio, 2023), so specific analysis will be needed for each urban context.
Future research developments could concern the definition of climate-proof methodological approaches that integrate ES within spatial planning with particular reference to the local scale. The principle of climate proof-planning at the local level can be a guiding factor in territorial governance processes but, above all in the definition of a regulatory framework aimed at improving the quality of space and life in urban contexts.

Authors' contribution

Federica Isola (F.I.), Federica Leone (F.L.), and Rossana Pittau (R.P.) collaboratively designed this study. Individual contributions are as follows: F.I. wrote Section 1; F.L. wrote Sections 2, 3, 3.1, 3.2, 3.3, and 3.4. F.I. and F.L. jointly wrote Section 4. F.L and R.P. jointly analyzed data.

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Image Sources

Fig.1 to 8: Author’s elaboration.

Table Sources

Tab.1 to 2: Author’s elaboration.

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TeMA
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Special Issue 2024

What transition for cities?
Scientific debate, research, approaches and good practices

(Rosa Anna La Rocca)

(Under publication)

The current challenges (climate change, pandemic, social divide, lack of resources, economic crisis, population ageing, depopulation of inland areas) affecting cities require a global renewal of methodologies, approaches, tools, policies and behaviours, calling into action all urban actors (planners, decision-makers, investors, city-users, citizens). The convergence point identified as a possible solution, both in the academic and political spheres, refers to the "transition" towards more sustainable, resilient and compatible management, governance and use of cities. With this input being accepted, TeMA Journal aims to investigate possible scenarios of urban transition inviting scholars, professionals, technicians, and urban actors to present contributions that address numerous topics. The call for contributions for this Special Issue, also in a critical/provocative key, aims to delve into the state of art regarding a goal/challenge (the transition) that risks being a new "label" hard to define and implement.

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Unveiling shoreline dynamics and remarkable accretion rates in Lake Eğirdir (Turkey) using DSAS. The implications of climate change on lakes

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Abstract
Lakes and their shorelines are important ecosystem areas with the diversity of living species they host. In addition, lakes are an almost indispensable resource for humans as a source of fresh water. Global climate change causes changes in lake surface conditions such as ice cover, surface temperature, evaporation, and water level. To understand the vulnerability of lakes to global climate change, researchers study the temporal rates of change that occur on lake shorelines. Shoreline monitoring contributes to important steps such as lake shoreline management, shoreline change, erosion monitoring, flood forecasting, and water resource assessment. Therefore, in this study, Landsat ETM+ multi-temporal images of the east part of Isparta Eğirdir Lake were obtained and the change in the shoreline over a 10-year period (2013-2022) was examined using the DSAS (Digital Shoreline Analysis System) tool. As a result of the study, very high levels of accretion were observed in the entire 82 km area examined in Eğirdir Lake. The highest EPR (53.79 m/year) in transect ID 149 and the highest LRR (60.87 m/year) in transect ID 26 were observed. These values are well above the +2m/year EPR (End Point Rate) and LRR (Linear Regression Rate) values, which means very high accretion.

Keywords
Lakes; Shoreline monitoring; Climate change; DSAS; Accretion.

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1. Introduction

The shoreline represents the dynamic boundary between land and water, and shoreline change analysis refers to the methods and approaches used to study and quantify the shifts in shoreline positions over time, starting from the 1970s. While initially focused on coastal environments, shoreline change analysis has also been applied to lake shorelines, particularly in larger systems like the Great Lakes (such as Lake Erie, Lake Michigan, and Lake Tahoe) (Li et al., 2001; Adams & Minor, 2002; Kilibarda & Shillinglaw, 2015; Burningham & Fernandez-Nunez, 2020). Lakes are ecologically significant areas that harbor a wide array of living species. They play a vital role in influencing the local climate, serving as freshwater sources, and supporting agricultural activities (Aksoy et al., 2019). However, lakes are currently experiencing intensified disturbances of both natural and human origin. These include increased evaporation due to climate change and the unsustainable exploitation of resources (Nassar et al., 2019). Accordingly, urbanization, inadequate water management policies, industrial pollution, and the effects of climate change have necessitated a re-evaluation of water resources. This re-evaluation involves critically analyzing past protection and prevention plans, aiming to develop more effective strategies for safeguarding lakes and their ecosystems (Keskin et al., 2015).

Agricultural activities practiced in closed basins of Turkey greatly damage the lakes in the basin areas, under the conditions that the current precipitation situation is not considered. The ecosystem related to the lakes is also affected by the same amount of damage (Aksoy et al., 2019). In addition, urbanization and anthropogenic land use carried out indiscriminately in shoreline areas lead to problems such as soil degradation in the region (Mazzeo, 2020), water pollution, and local climate change (Dinç & Gül, 2021). The basic structure of the European Union (EU) Water Framework Directive dated 22 December 2000 is holistic watershed management, which is put forward as the main tool in achieving the directive's objectives. Holistic watershed management enables different sectors and resource users to be considered together, for long-term evaluation of threats and opportunities, and to monitor the positive and negative effects of an intervention in an area within the basin (European Parliament and Council, 2000).

Research is needed to narrow the uncertainties about climate change over the Great Lakes and about the sensitivities of the lakes and resources they support to climate. One of the most helpful components of future research on global warming and the Great Lakes would be better estimates of regional climate change (Smith, 1991). Monitoring the temporal variation of surface water and obtaining data on surface water dynamics are essential for policy and decision-making processes (Giardino et al., 2010; Sarp & Ozcelik, 2016). Monitoring the temporal-spatial changes of lakes can help to understand the spatial distribution of water level reduction, to predict development trends (Nassar et al., 2019), and support mechanism research on countermeasures against desertification. Further improvements in remote sensing (especially in small lakes) and in situ data are an important step toward improving global understanding of lake processes and their responses to climate change (Woolvay et al., 2020). In recent years, geographic information systems (GIS) and remote sensing data integration have been used in shoreline extraction and mapping (Frey et al., 2010; Pardo-Pascual et al., 2012; Sarp & Özçelik, 2017).

Significant recession can be observed in recent years on the shores of Lake Eğirdir, which is in the Lakes Region of southwestern Turkey and is the second largest freshwater lake in Turkey. Therefore, regular measurements of the lake shoreline are needed in future studies for a sound watershed management process and the determination of the right policy decisions. In this context, the aim of this study is to reveal the temporal changes on the eastern shore of Lake Eğirdir and conduct a situation analysis through the observation of these changes, while also identifying risk factors. This, in turn, contributes to comprehensive watershed management by enabling planners to take measures against the effects of climate change and ensure ecological sustainability. Factors such as agricultural activities and urbanization that disrupt the ecological system and result from human impacts in the lake basin system can be easily detected, and a rapid recovery process can be initiated when these impacts are mitigated. However, the observation of climate change, even leading to the drying of lakes, becomes challenging when considering the presence of anthropogenic effects, and once identified, it often leads to a difficult-to-reverse process. Therefore, this study aims to highlight the impact of drying in a region with minimal anthropogenic activities around a drying lake, enabling the early detection of the power of climate change.

This study focuses on the analysis of multi-temporal Landsat ETM+ images using automatic shoreline delineation and change detection techniques. The researchers employed the Modified Normalized Water Difference Index (MNDWI) to extract water areas from the Landsat ETM+ data. The MNDWI utilizes bands 3 and 6 of the satellite images to identify water bodies. The method allows for the analysis of shorelines extracted from multiple Landsat satellite images acquired at different times. By comparing the extracted shorelines, the study provides valuable data for investigating changes in shoreline positions over time. The MNDWI index has been previously tested and utilized in various applications, including surface water mapping and land use and land cover change analysis. Its effectiveness in these applications has contributed to its adoption in this study for shoreline analysis and change detection (Duan, 2013; Feyisa et al., 2014) land use and land cover change analysis (Davranche et al., 2010), and ecological research (Poulin et al., 2010, Sarp & Ozcelik, 2017).

Then, the changes in the shoreline were examined using the Digital Shoreline Analysis System (DSAS). The Digital Shoreline Analysis System (DSAS) GIS software extension was first originated by the USGS in the 1990s and is a useful system due to its seamless integration and accessibility within the ArcGIS framework (Burningham & Fernandez-Nunez, 2020). The quantitative dataset of shoreline change largely focuses on the derivation of five key measures (net shoreline movement [NSM], shoreline change envelope [SCE], endpoint rate [EPR], linear regression rate [LRR], and weighted LRR) (Burningham, & Fernandez-Nunez, 2020). The data obtained in the study were first graphed according to the NSM method. The NSM method reveals shoreline changes by measuring the total distance between the nearest shoreline and the earliest timeline at the time of measurement. According to the NMS method of the DSAS applied on the lake shore of Eğirdir, the average distance is 299.75 m, and the maximum distance is 484.13 m in the 26th Transect. Shoreline change trends were mapped according to the geometric interval of the EPR and LRR values. As a result of the study, it was revealed that there was a great change rate from 2013 to 2022 in the 82 km shoreline determined as the study area. In Lake Eğirdir, the accretion values were observed to be well above the +2m/year EPR (End Point Rate) and LRR (Linear Regression Rate) values, which means very high accretion. This excessive accretion on the shore of Lake Eğirdir is largely associated with Climate Change by the author. Global climate change is widely acknowledged as a major catalyst for environmental transformations, including shifts within lake ecosystems. The effects of climate change, such as rising temperatures and changing precipitation patterns, have direct implications for lake dynamics. These changes can directly impact the rate of shoreline accretion, leading to notable alterations in the lake's boundary.

2. Study area

The Lakes Region extends to the provincial borders of Konya, Isparta, Burdur, Denizli, and Afyonkarahisar in the southwest of Anatolia. The Lakes region stands out not only with its wetland feature but also because it has been a significant settlement area since the Paleolithic Age (Uysal, 2018; Aksoy et al., 2019). Lake Eğirdir, a part of the Lakes region, is Turkey's second largest freshwater lake after Lake Beyşehir. The area of Lake Eğirdir is 62,621 hectares and the height of the area where it is located is 915 meters above sea level. The lake is within the scope of a natural protected area, and besides being a drinking water basin, it is a wetland with high biological diversity. While there are 514 different bird species in Europe and 454 in Turkey, 225 of the bird species in Turkey live in and around Lake Eğirdir (Aksoy et al., 2019).

The lake's recharge sources are precipitation falling on the lake area, drainage area runoff, and groundwater flow (including springs). Its discharge is through the lake bottom, evaporation, sinkholes, and artificial discharge (irrigation energy generation and drinking-utility water supply) at the southern end. The date of announcement of drinking and utility water of Lake Eğirdir is 26th February 1991 (Special Provisions of Lake Eğirdir, 2012).

The protection of Lake Eğirdir is carried out within the framework of the special provisions for Lake Eğirdir that came into effect in 2012. This protection consists of three zones: the absolute protection zone (30 m), the short-distance protection zone (700 m), and the mid-distance protection zone (1,000 m). The absolute protection zone includes the Lake Green Belt Area, the Geology-Based Absolute Protection Area, and the Lake Protection Areas. Within the absolute protection zone, the areas nourishing the lake, such as the Taşevi spring, Aşağıtırtar spring, Kemerdamları spring, along with the limestone surfaces that come into contact with the nourishment area, and Kayaağzı spring, are included. According to the regulations, all tree and plant species in the absolute protection zone are preserved. No construction or mining activities are allowed in this area. Furthermore, no new industrial establishments or tourism facilities are permitted in this area (Special Provisions of Lake Eğirdir, 2012).

It has been recently brought to the agenda by researchers that the water level in Lake Eğirdir is decreasing day by day. According to the study conducted by Aksoy et al., (2019), it is seen that there is a local water withdrawal of 300 m on the opposite shore of Akkeçili village (east of the central part of the lake). The southern part of the shoreline area covering the study area is used for agricultural activities, whereas the northern part exhibits natural vegetation, with no development or agricultural activity (Alp et al., 2020).

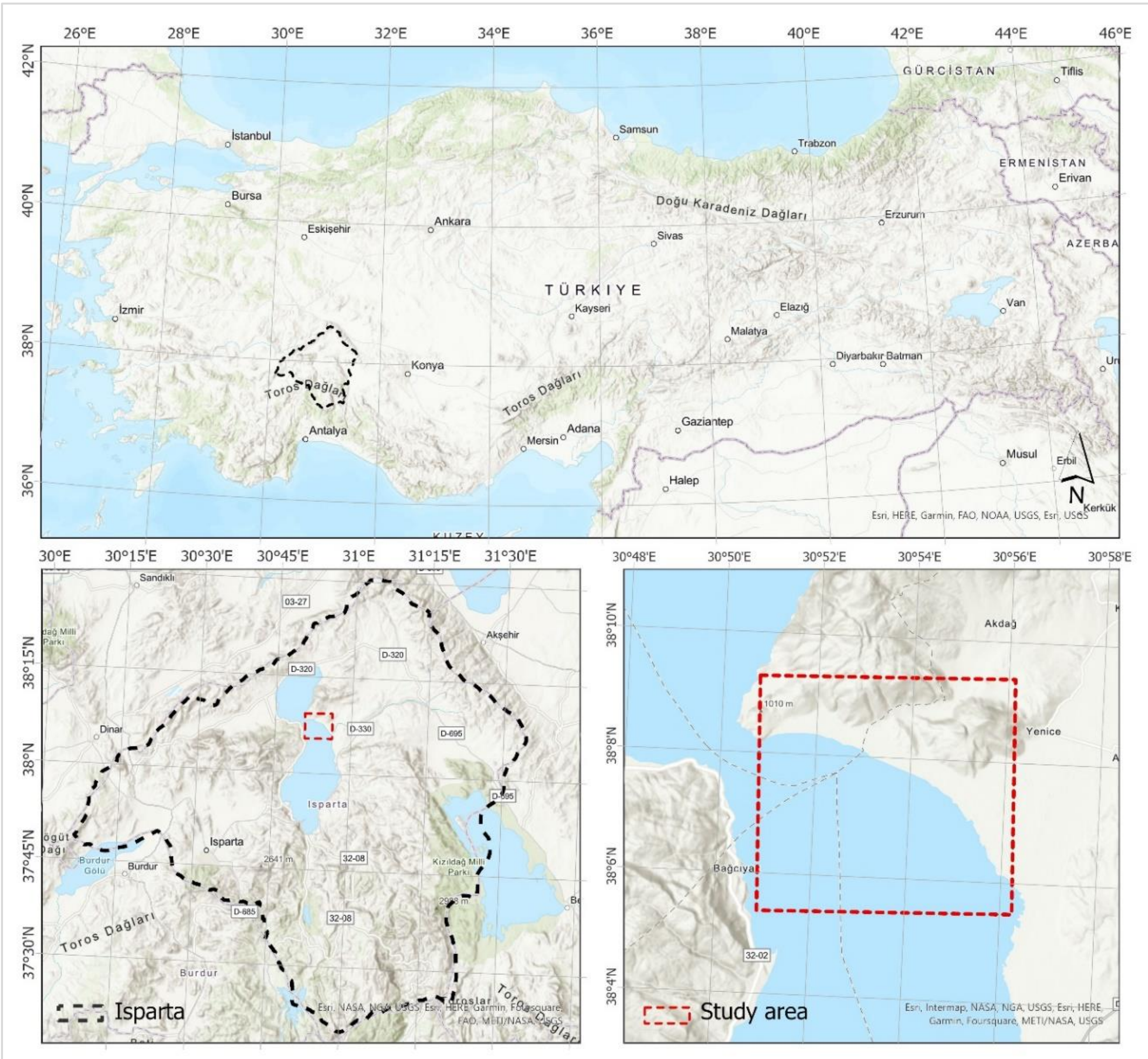

Fig.1 Study area (East shoreline of Eğirdir Lake, Isparta, Turkey)

The nearest settlement to this coast is Yenice village with a population of 870. The distance of Yenice village, located in the south of the study area, from the coast is approximately 4 km. Since agricultural activities and discharge are low in the area where intense withdrawal is observed in the middle part of the lake, the withdrawal observed along a line in this area is mostly associated with global climate change. Therefore, in this study, this shoreline in the east of the lake was examined (Fig.1).

3. Material and methods

This study utilized the Digital Shoreline Analysis System (DSAS) to assess shoreline changes along the eastern shore of Lake Eğirdir. The DSAS, developed by the United States Geological Survey (USGS), is a Geographic Information System (GIS)-based tool that enables the calculation of shoreline change rates using time series shoreline data. The DSAS implementation in this study involved six main steps: (1) data collection, (2) extraction of shorelines, (3) creation of a baseline, (4) generation of transects, (5) computation of distances between the baseline and shorelines at each transect, and (6) calculation of shoreline changes rates (Thieler et al., 2005). To perform these procedures, Landsat ETM+ satellite images of Lake Eğirdir were obtained for the years between 2013-2022. The process of collecting, processing, and comparing remote sensing satellite images obtained as research data involves ensuring a regular periodic dataset over a limited research period. In this context, the satellite images obtained in this study from 2013 to 2022 cover a period during which Landsat 7 ETM+ satellite images were accessible and provided a secure and comparable dataset for the examination of annual changes. Within this scope, a 10-year period has been considered appropriate for examining the changes along the lake shoreline in this study. The images, acquired at a spatial resolution of 30 meters, were selected based on availability, considering the challenges of obtaining cloud-free images for the necessary analysis at regular intervals. Subsequently, all satellite images were imported into ArcGIS software for shoreline digitization.

Modified Normalized Water Difference Index (MNDWI) was used to extract the shoreline from Landsat ETM+ satellite images. Shorelines represent the high-water line surveyed using GPS units in kinematical mode (Moore, 2000). The MNDWI method suggested by (Xu, 2006) has been commonly used and is a convincing index that can extract water bodies (Ji, Zhang & Wylie, 2009; Lu et al., 2011). It is expressed by equation (1).

$$MNDWI = \frac{band\ 3 - band\ 6}{band\ 3 + band\ 6} \tag{1}$$

Values in the water feature are positive in band 3 due to their higher reflectance than in band 6, and non-water features are in negative NDWI (Xu, 2006). A threshold value for MNDWI (e.g., simply a value of zero) is set to divide the MNDWI results into two classes (water and non-water properties).

After extracting the shorelines in the 10-year period starting from 2013 until 2022 (Fig.2), the baseline line was created by the buffering method. The method employed in this study for baseline delineation is considered highly valid and accurate. It adopts the sinuosity shape of the nearest shoreline, making it well-suited for creating the baseline in the analysis. By following the natural contours and curves of the shoreline, this approach ensures that the baseline accurately represents the land-water interface in the study area (Nandi et al., 2016; Nassar et al., 2019). Accordingly, the baseline in this study is established by creating a buffer zone at a distance of 150 meters from the nearest shoreline of the lake.

Then, transects that are cast perpendicular to the reference baseline were generated with DSAS to intersect shorelines at 50 m intervals alongshore. 165 sections were generated along the 82 km of the study area.

In the Digital Shoreline Analysis System (DSAS), the software calculates the distance between the established baseline and each intersection point where a shoreline intersects a transect section. By considering the date information and incorporating spatial uncertainty for each shoreline, DSAS generates change data.

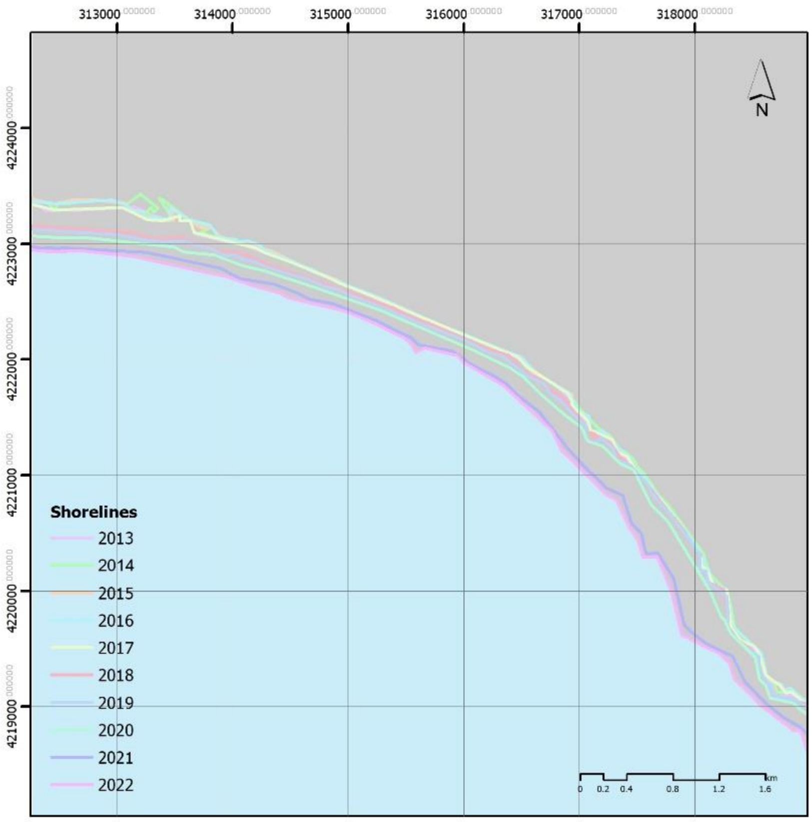

Fig.2 Multi-temporal shoreline data of Lake Eğirdir (2013-2022)

This process involves quantifying the distance between the baseline and shoreline intersections along designated sections. DSAS then combines this spatial information with the temporal data associated with each shoreline, considering the uncertainty or variability in the spatial measurements. By integrating these factors, DSAS provides comprehensive change data that considers both the spatial and temporal aspects of shoreline dynamics (Himmelstoss et al., 2022). DSAS generates a lot of statistical data to evaluate the change in the shoreline. These are Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression (LRR) (Thieler et al., 2009; Mutaqin, 2017).

SCE refers to the greatest distance between all shorelines without adding the year of the shoreline (Mutaqin, 2017). Net Shoreline Movement (NSM) is shoreline shift. Therefore, the NSM method shows how much the shoreline has changed, not the rate of change (Kurniawan & Marfai, 2020). EPR and LRR calculate shoreline change rate data for each transect. EPR refers to the shoreline shift distance divided by the time difference between the first and last shoreline (Mutaqin, 2017). The EPR is simply calculated by dividing the distance (m) separating the two shorelines by the number of the two shorelines between dates (Equation 2) (Nassar et al., 2019).

$$EPR = \frac{L_1 - L_2}{t_1 - t_2} \quad (2)$$

In the EPR method, the distance between the shoreline and baseline is represented by L_1 and L_2. These values indicate the separation between the established baseline and the positions of two shorelines. Additionally, the dates of the two shoreline positions are denoted as t_1 and t_2, respectively (Nassar et al., 2019). LRR, on the other hand, is computed by fitting the least squares regression line to all shoreline points for a particular transect (Mutaqin, 2017). In this calculation, the method performs the fitting of a least squares regression line to multiple shoreline position points for transects (Nassar et al., 2019). The regression line is positioned in such a way that it minimizes the sum of squared residuals. These residuals are obtained by squaring the vertical distance between each data point and the regression line, and then summing up all the squared residuals. The linear regression rate, on the other hand, corresponds to the slope of the regression line (Himmelstoss et al., 2018; Singh et al. 2022).

Researchers focus on two types of shoreline changes namely accretion and erosion. As a result of DSAS, EPR, and LRR are obtained as positive and negative values, where a positive value indicates accretion of the shoreline and a negative value indicates erosion of the region (Mutaqin, 2017; Nassar et al., 2019; Singh et al., 2022). Erosion and accretion levels on the shorelines are classified according to Nassar et al. (2019) as in Tab.1.

Category	Rate of shoreline change (m/year)	Shoreline classification
1	>-2	Very high erosion
2	>-1 and <-2	High erosion
3	>0 and <-1	Moderate erosion
4	0	Stable
5	>0 and <+1	Moderate accretion
6	>+1 and <+2	High accretion
7	>+2	Very high accretion

Tab.1 Shoreline classification based on EPR and LRR

In this study, first, the total distance between the shoreline and the earliest time at the time of measurement was revealed by the NSM method to evaluate the change of the Eğirdir eastern shoreline. Then the change trends in the shoreline were demonstrated according to the EPR and LRR data. Finally, the effect of climate change on this change is discussed.

3. Results of the DSAS

NSM, EPR, and LRR data from the DSAS results made on the 82 km shoreline determined in Lake Eğirdir reveal the changes in the shoreline. Shoreline erosion refers to retreating towards the land or if the resulting NSM value is negative (Kurniawan & Marfai, 2020).

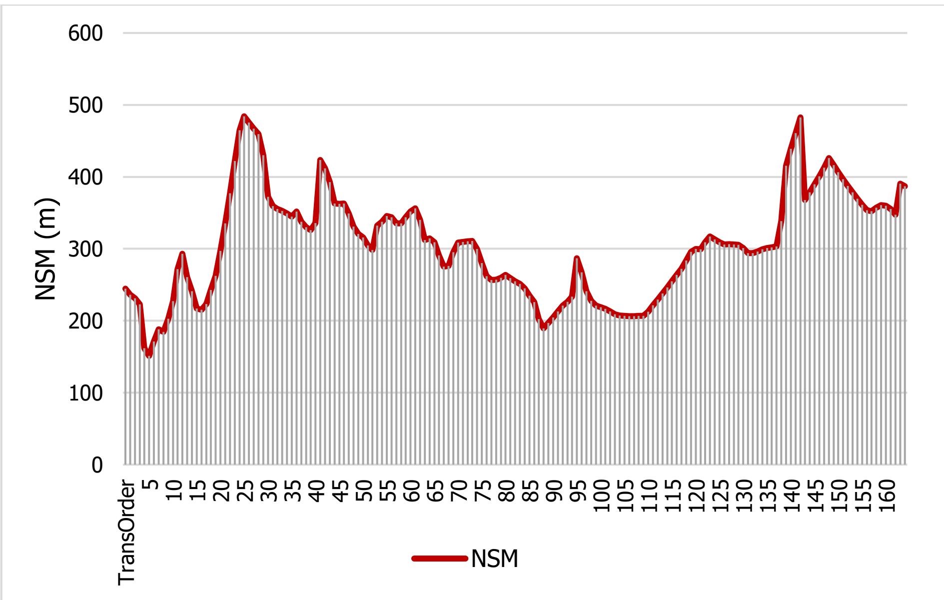

Fig.3 Net Shoreline Movement (NSM) of the Eğirdir Lake shoreline

Furthermore, the analysis of the Normalized Shoreline Movement (NSM) values allows us to observe shoreline behavior, particularly regarding accretion or erosion. Positive NSM values indicate shorelines that have expanded or advanced towards the lake, suggesting accretion. Conversely, negative NSM values indicate shoreline retreat or erosion.

In this study, the oldest shoreline considered is from 2013, while the most recent shoreline is from 2022. By calculating NSM values for each shoreline, the study examines the temporal changes and dynamics of the shoreline. The results, illustrated in Fig.3, provide valuable insights into the overall trend of shoreline evolution and whether it has experienced erosion or accretion over the specified time period. In terms of NSM, EPR, and LRR values, it is seen that there is accretion on the entire shoreline.

According to the NSM method of the DSAS applied on the lake shore of Eğirdir, the average distance is 299.75 m and, the maximum distance is 484.13 m in the 26th transect. In addition, all shoreline sections have positive distances.

Shoreline change trends were mapped according to the geometric interval of the EPR and LRR values in Fig.4 and Fig.5 respectively for the Shoreline of Eğirdir Lake. Geometrical interval generates class breaks based on class intervals that have a geometric series.

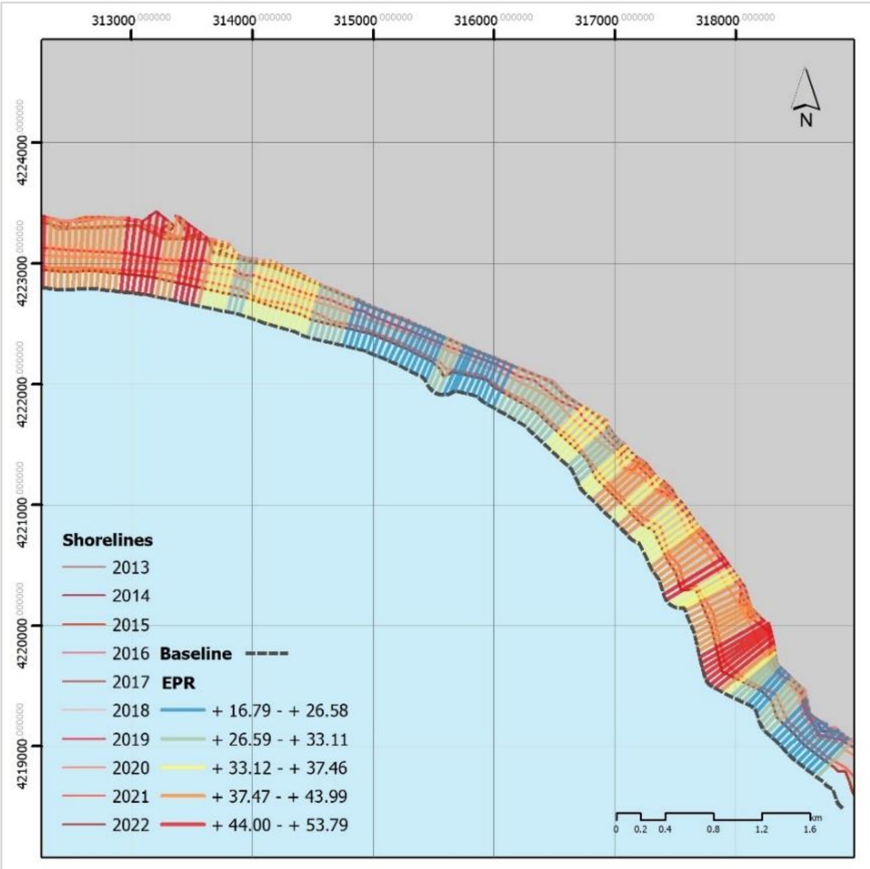

Fig.4 The map of EPR method with geometric interval

In Lake Eğirdir, the accretion values were observed to be well above the +2m/year EPR (End Point Rate) and LRR (Linear Regression Rate) values, which means very high accretion (Fig.4 and Fig.5). In addition, it is seen that the change is more in the north of the shoreline.

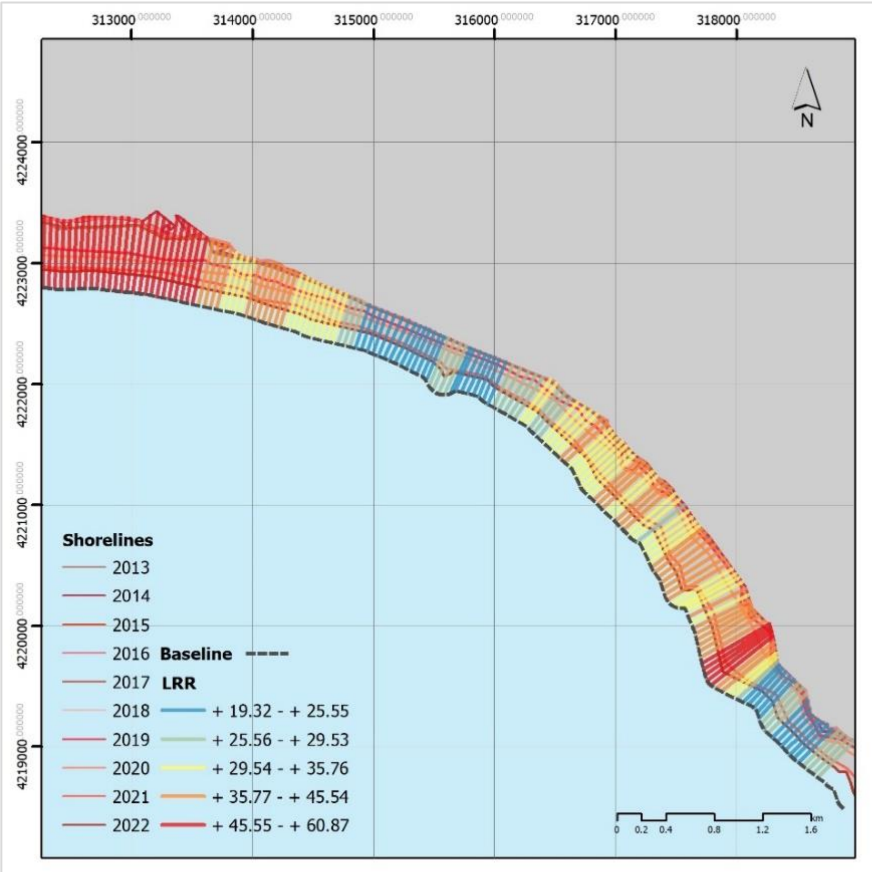

Fig.5 The map of LRR method with geometric interval

EPR and LRR data are graphically shown in Fig.6 According to this, transect ID 149 had the highest LRR (60.87) and transect ID 9 had the lowest LRR (19,32). Transect ID 26 had the highest EPR (53.79) and transect ID 6 had the lowest EPR (16,79).

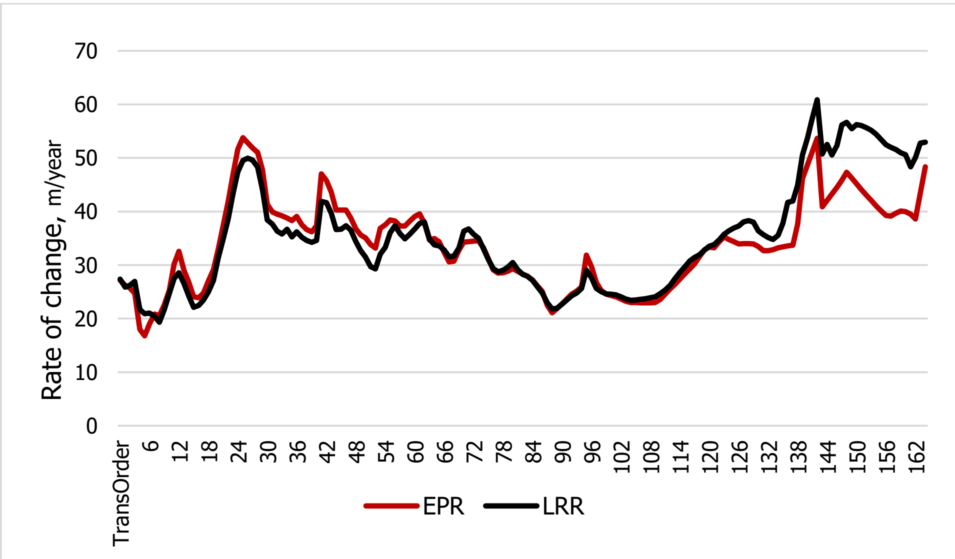

Fig.6 Shoreline trends of the Eğirdir Lake with EPR and LRR value

As a result of the study, it was revealed that there was a great change rate from 2013 to 2022 in the 82 km shoreline determined as the study area. In summary, shoreline change rates in Lake Eğirdir are much higher than the shoreline erosion and accretion scale (Tab.1) stated by the experts. This is an indication that a great change is taking place in the lake. The fact that high values at this level are unlikely to occur only with anthropogenic effects necessitates the examination of the effect of climate change on the lake and a holistic basin assessment.

4. The Implications of climate change on Eğirdir Lake

Researchers state that global climate change is one of the most important threats to lake ecosystems. This change in average weather patterns can cause changes in lake surface conditions such as ice cover, surface temperature, evaporation, and water level. The decrease in the ice cover and the increase in the lake surface temperature during the winter months change the lake mixing regimes and accelerate the lake evaporation. When not offset by increased average precipitation or inflow, higher evaporation rates result in lower lake levels and surface water. Researchers state that these spatial and temporal changes will continue for a long time and in some cases will continue at an accelerated rate (Woolvay et al., 2020).

The variability in the storage of water in lakes, influenced by climate, stems from alterations in the availability of water sources within the lake's surrounding watershed. This variability arises from a delicate balance involving precipitation, evaporation, and fluctuations in terrestrial water storage. (Watras et al., 2014). As air temperatures begin to increase faster than seasonal values, the lake's ice cover will likely decrease, and the lake's surface water temperature will increase. The warming of the surface waters will cause the lake ice to disappear and the evaporation process to start earlier (Woolvay et al., 2020). The amount of water stored in certain lakes may increase, decrease, or not experience significant cumulative changes in a warming climate (Notaro et al., 2015; Pekel et al., 2016; Rodell et al., 2018; Busker et al., 2019).

The attribution of water storage change in lakes to climate change is facilitated by the fact that changes occur consistently in many lakes across large geographic regions (Watras et al., 2014), and other anthropogenic hydrological impacts are calculated and combined. In addition to all these, as it is known, besides global climate change, other human effects can also be effective in shoreline change. The true magnitude of hydrological changes that can certainly be attributed to climate change remains unclear, given the main impact of human dewatering in terms of the global hydrological cycle (Hegerl et al., 2015). Nevertheless, these increases can be attributed to climate change, as they are corroborated by years of ground survey data (Ma, et al, 2010) and recent observations from the Gravity Recovery and Climate Experiment (GRACE) satellite mission (Rodell et al., 2018; Wang et al., 2018), and because there are very little irrigated agriculture operations or water diversions that could confound the trend (Rodell et al., 2018; Woolvay et al., 2020). Therefore, research and projects focus on reducing and adapting to climate impacts (Balletto et al., 2022).

In this context, considering the number of lakes that have dried up recently in Turkey, it is possible that climate change influences this. It is stated that nearly seventy lakes have dried up in the last sixty years in Turkey by researchers (Hürriyet, 2020). In addition, Eğirdir is in the Lake's region of Turkey, and research on lakes in this area highlights that there are significant reductions in the water mass of the lakes. In their study in the Burdur basin located in the Lakes Region, Taş and Akpınar (2021) determined that the lake waters in Burdur Lake, Karataş Lake, Acı Lake, Sıralı Lake, and Ak Lake have been withdrawn largely in the last 36 years and Ak Lake in the basin has completely dried up in 2021. In the study of Dönmez (2018) on Akşehir Lake, which is in the Lake's region, the air temperature being higher than the average temperature after March in 2006, 2007, and 2008 is associated with the complete drying of Akşehir Lake in 2008.

As a result of this study, it was determined that the accretion that occurred in the examined 10-year period (between 2013-2022) was very high. It can be observed that this change has increased remarkably especially in recent years. This situation is interpreted by the author as the possible impact of climate change has become apparent in recent years. Intensive use of the lake and global climate changes have brought about various changes in the water level. The effects of climate change, such as rising temperatures and changing precipitation patterns, have direct implications for lake dynamics. These changes can directly impact the rate of shoreline accretion, leading to notable alterations in the lake's boundary. By amplifying the natural processes responsible for shoreline accretion, climate change exacerbates the phenomenon, resulting in an accelerated rate of change. If preventive measures are not taken, it is estimated that the lake level will decrease by 24% after 100 years (Keskin et al., 2015). Therefore, interactions between climate and other human-related stressors affecting Lake Eğirdir lead to unnatural changes in the Lake Eğirdir shoreline, further complicating the development of climate-resilient and effective management strategies.

5. Conclusion

In this study, the 82 km shoreline to the east of Lake Eğirdir was investigated by DSAS. As a result of the investigations, it is seen that there is a large amount of accretion on the shoreline. As a result of the comprehensive study conducted by Aksoy and others in Turkey's lake region in 2019, similar high accretion was observed in the area. This research and other studies reveal that a holistic watershed management process should be developed for the protection of biological diversity in the lake and the sustainability of the lake. The protection status, approved in 2012, includes some measures and regulations for the preservation of the lake and its surrounding ecosystem. However, this study's results indicate that large-scale accretion events along the lake's shore have caused significant changes in the lake's boundaries.

These findings demonstrate that, despite the existing conservation measures, Lake Eğirdir is under the influence of climate change. Climate change can accelerate natural processes at the lake's boundaries, affecting shoreline changes, which can have significant consequences for the lake ecosystem. In particular, increased surface temperatures and changing precipitation patterns due to climate change can directly impact changes in the lake level and the rate of shoreline accretion. Approaches such as examining these effects and the sensitivity of the lake are important in the adaptation process to climate change (Beltramino et al., 2022). As a result, the protection status of Lake Eğirdir should be considered to enhance resilience against ecological threats brought about by climate change and to develop more effective strategies for sustainable lake management. Also, research about Eğirdir frequently focuses on the anthropogenic effects of the lake (Şener et al., 2023). According to Aksoy et al. (2019), the problems and disruptions in the agricultural policies implemented in Lake Eğirdir can be accurately determined by the temporal change analysis.

These determinations can be used as inputs to the planning processes in agricultural activities. The right working decision mechanism is very important for the protection and sustainability of the ecosystem. In this context, since this study is the first to examine the temporal change on the lake shore of Eğirdir using DSAS, it both provides important literature for taking precautions against climate change and provides temporal data to examine the effects of human activities on Lake Eğirdir. As a result, the data showing the drying up of the lake in the lakes region of Turkey, where Lake Eğirdir is located, and the dense accretion on the lake shoreline obtained as a result of this study, reveal the effects of climate change.

It is important that decision-makers of the lakes and related resources consider the potential for climate change. This can be done by analyzing the potential vulnerability of Lakes to climate change with DSAS. The DSAS tool used in this study can be employed to understand changes in water bodies and water levels and to assess the sustainability of water resources.

In this context, it can be used to monitor coastal or shoreline erosion, develop shoreline protection strategies, and manage shoreline areas. Such studies address topics like safeguarding shoreline infrastructure, evaluating erosion risks, and ensuring the sustainability of shorelines (Mutagin, 2017; Himmelstoss et al., 2018; Nassar et al., 2019). These studies form a part of the need for integrated and adequate tools in both the analysis and design phases to consider the parameters and issues characterizing shoreline area planning (Chieffallo et al., 2022). Thus, managers can determine what anticipatory action should be taken. In this case, understanding potential impacts will help decision-makers make sensible planning decisions to minimize the potential effects of climate change on the lakes.

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Image Sources

Fig.1 to 6: Author's elaboration.

Table Sources

Tab.1: Author's elaboration.

Author's profile

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The Water-Energy-Food Nexus in the Mediterranean Region in a scenario of polycrisis

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Abstract

Multiple global crises, including climate change, the COVID-19 pandemic, and Russia's war on Ukraine, have recently linked together in ways that are significant in scope, devastating in effect, but still poorly understood, triggering what experts call a real polycrisis. In particular, climate change and the Ukraine conflict, acting together, are increasingly putting at risk the availability and access to fundamental resources to human survival and well-being: water, energy and food. The Mediterranean region could be considered both a water, energy and food (WEF) nexus and a climate change 'hotspot'. Since Russia and Ukraine are central players in global commodity markets, the ongoing war and accompanying sanctions are dramatically unsettling energy and food markets, with ripple effects likely to extend well into 2024. The new global systemic risks call for a paradigm shift by adopting measures to reduce exposure and strengthen resilience turning the conventional WEF nexus into a virtuous circle. To face these challenges, three main actions are identified: mainstreaming climate change into the WEF nexus; decouple water, energy and food production from fossil fuel; develop sustainable WEF intra-regional and regional cooperation/integration models based on the principle of comparative advantages. To illustrate these mechanisms the cascading impacts of interactions between the Ukraine-Russia war and climate change on the WEF nexus in the Mediterranean countries are illustrate.

Keywords

Mediterranean; Climate change; Ukraine war; WEF nexus.

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1. Introduction

According to experts, the world has recently plunged into a new era of interconnected crises, reminiscent of the tumultuous periods at the end of the 1920s and the beginning of the 1970s, as well as the financial, political and food crises that marked the beginning of the new millennium. This phenomenon, known as a "polycrisis", occurs when multiple global crises converge, creating a combined impact that surpasses the sum of their individual effects.

The Mediterranean region has borne the brunt of this polycrisis over the past fifteen years. It has been hit by a series of systemic risks, including the financial crisis, the food crises of 2007-2008 and 2010-2011, the Arab Spring, the migration emergency, and, more recently, the COVID-19 pandemic. Additionally, the region faces the compounding challenges of climate change and the ongoing global crisis sparked by the Ukraine war.

In the Mediterranean region, the adverse effects of climate change primarily impact the water, energy, and food (WEF) sectors simultaneously. Given that Russia and Ukraine play pivotal roles in global commodity markets, a multifaceted resource crisis is emerging, which has a cascading impact on the WEF nexus. Supply crises, coupled with increasing demand for WEF resources, can be profoundly destabilizing. They expose the vulnerability of states and can lead to a deterioration in well-being, widespread violence, political upheaval, and involuntary migration. Recognizing this, it is imperative to shift our paradigm and implement measures aimed at reducing exposure to these risks and enhancing resilience at both national and regional levels.

This article seeks to emphasize the repercussions of the global polycrisis on the Mediterranean region, with a particular focus on the Water-Energy-Food (WEF) nexus, and how the interplay of climate change and the Ukraine conflict is affecting it. The study's objective is to uncover the obstacles and possibilities for transforming the WEF nexus from a vicious circle of trade-offs into a virtuous circle of synergies that mutually reinforce each other.

To address this challenge, several actionable steps are delineated, and concrete recommendations are formulated to guide the path forward.

2. Conceptual framework

In recent decades, it has become increasingly evident that global systems, ranging from finance and security to food, energy, and health, are highly vulnerable to systemic risks. As recent history has illustrated, systemic risks tend to transcend their point of origin, interacting, amplifying, cascading, and influencing one another in a way that gives rise to a complex, interconnected polycrisis. This polycrisis produces consequences that are more profound than the sum of what each individual crisis would generate in isolation. The concept of a polycrisis underscores the intricate web of cause-and-effect relationships among crises across global systems, and it identifies three key causal pathways: common stresses, domino effects, and inter-systemic feedbacks. These pathways interconnect multiple global systems, culminating in synchronized crises (Lawrence et al., 2022). Studies have demonstrated that the extended health, social, and economic impacts of the Covid-19 pandemic, the specter of stagflation, volatility in global food and energy markets, geopolitical conflicts, political instability, civil unrest, and the growing frequency and severity of weather events linked to climate change are all constituent crises contributing to the global polycrisis currently unfolding worldwide. This is not humanity's inaugural encounter with a polycrisis. In the past, we've grappled with similar multifaceted challenges. For instance, the oil shocks of the 1970s were born out of conflicts in the Middle East and gave rise to severe international energy shortages, which, in turn, contributed to and interacted with stagflation in the global economy (Homer-Dixon et al., 2015). However, the present-day polycrisis shares certain common elements with past crises but is remarkable in several unprecedented ways. Unlike the 1970s, where price shocks were primarily confined to oil, today's crisis encompasses all fossil fuels. Furthermore, this energy crisis has unfolded in a markedly different global landscape compared to the one characterizing the oil crisis of the previous century. The world today is far more interconnected, which, while beneficial in many respects, also makes it more susceptible to cascading effects and spillover. Lastly, the contemporary polycrisis is truly unparalleled in that human pressure on ecosystems and natural resources has pushed Earth's physical and ecological systems well beyond their previous equilibria. This poses a significant threat to the stability of many other global systems that are crucial for human well-being (Lawrence et al., 2023).

The enduring impacts of climate change and the ongoing Russian invasion of Ukraine are mutually reinforcing, causing reverberations across the globe. These events are disrupting worldwide supply chains and causing a surge in energy and food prices, while also exerting direct and indirect influences on water resources.

In this precarious situation, encompassing concerns about water, energy, and food security, it is crucial to recognize that water, energy, and food are intricately interconnected through various nexus linkages.

The WEF nexus concept has gained widespread usage in order to facilitate the comprehension of the interconnections between these three systems and how they can be sustainably managed to meet the increasing demand. It has been particularly promoted as a means to resolve conflicts among these sectors.

One of the most prominent relationships within the WEF nexus involves direct dependencies. For instance, energy relies on water for power generation, the extraction, transportation, and processing of fossil fuels, as well as the irrigation of biofuel crops. In turn, water is dependent on energy for its abstraction, purification, and distribution. Meanwhile, food production requires both water and energy to nurture crops, support livestock, and process food.

Beyond these direct dependencies, the nexus is further complicated by the fact that WEF systems are influenced by numerous dynamic exogenous variables (Burnett & Wada, 2018). Population growth, migration patterns, socio-economic development, human-made pressures, and the repercussions of climate change collectively shape the demand, allocation, availability, and accessibility of WEF resources over time and space (Fig.1).

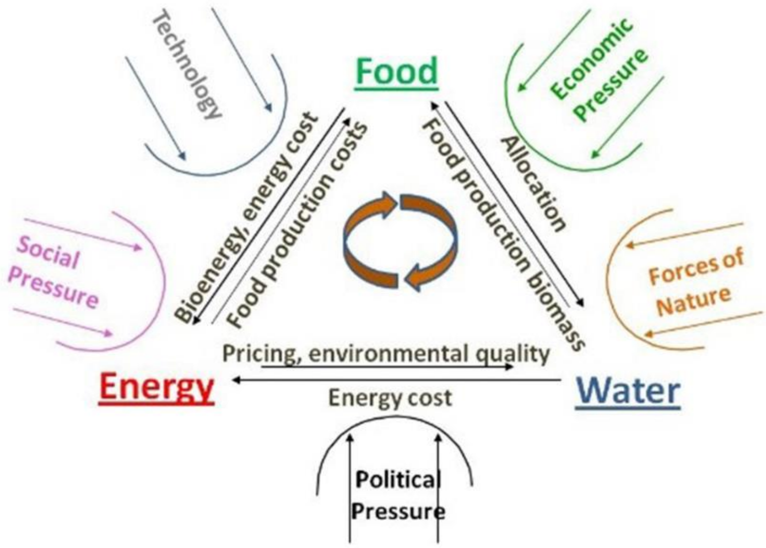

Fig.1 Direct and indirect interlinkages within the WEF nexus

As the demand for these resources rises within the constraints of scarcity and climate change effects, the interconnections within the WEF nexus become more pronounced. Furthermore, this heightened demand often leads to direct conflicts and trade-offs between sectors, thereby constraining nations' capacity to meet the essential needs of their populations sustainably (Markantonis et al., 2019). Climate change both affects and is affected by the WEF nexus, giving rise to a complex web of bidirectional interactions which initiates a chain of events that adversely impact water, energy and food security, intensifying conflicts within the nexus (Rasul & Sharma, 2016). Rising temperatures, shifts in precipitation patterns, the intensification of extreme weather events, and rising sea-levels, gradually disrupt the equilibrium among WEF resources and even transform the

dynamics of their interactions (Cramer et al., 2018). Furthermore, it is important to note that existing mitigation and adaptation strategies can sometimes exacerbate rather than alleviate negative externalities and trade-offs within the nexus. While certain measures focused on specific sectors can create synergistic "win-win" possibilities across one or more of the other components of the nexus, other strategies like hydropower, first-generation biofuels, non-conventional water resources, and agricultural intensification are not always nexus-smart.
In situations where there is a lack of nexus-oriented thinking in the planning and policymaking processes related to WEF resources, the interactions between these systems have often been neglected. Such siloed approaches have led to disjointed policymaking, conflicting strategies, and the inefficient utilization of our natural resources. In recent years, the growing concerns over resource scarcity and the looming impact of climate change have prompted policymakers and planners to place a stronger emphasis on the connections between water, energy, and food systems. A comprehensive, integrated approach to the management of WEF resources, which a nexus approach demands, requires coordination, harmonising public policies, and the alignment of strategies, regulations and incentives as well as platforms for cross-sectoral coordination, decision- making and implementation. Advocates of the WEF nexus as a planning and resource management approach underscore the importance of enhancing resource utilization efficiency to curtail environmental degradation and optimize the social and economic advantages derived from the progressively limited natural resources. The governance framework, encompassing both formal and informal regulations that guide resource allocation decisions, plays a crucial role in shaping the outcomes of a nexus approach. This framework involves various stakeholders, including civil society, the private sector, and the public sector (Howells et al., 2013).
Responding to the rapidly growing WEF demand in an increasingly resource-constrained climate change scenario, associated with the impact of Ukraine war is fueling a vicious circle in the Mediterranean countries. These challenges call for a paradigm shift to turn the conventional WEF nexus into a virtuous circle, one that aligns harmoniously with the objectives outlined in the United Nations Sustainable Development Goals (SDGs) and the commitments established in the Paris Agreement. In order to fully capture existing potential for benefits and synergies, the development and management choices in the WEF sectors require enhanced integration at the knowledge, policy, legislative and institutional levels/frameworks.
Using the WEF nexus as an indicator, in the next section the social implications of the ongoing conflict are assessed. Given that Russia and Ukraine are significant global providers of energy resources, food, and fertilizers, the imposition of limitations and the subsequent increase in prices pose new threats. Through an analysis of relevant data, the profound impacts on the Mediterranean societies are highlighted, particularly noting that nations that depend on the countries engaged in the conflict for their energy and food resources are particularly vulnerable to the WEF challenges.

3. Results

The "Global Risk Report 2023" by the World Economic Forum (WEF) illustrates a complex network of interconnections among various global risks and crises, underscoring the possibility of a "polycrisis" emerging (WEF, 2023). Within this intricate web of risks, it's challenging to identify an area that is not relevant for the Mediterranean. Additionally, the WEF nexus is notably pronounced in the Mediterranean region, with a particular emphasis on the Middle East and North Africa (MENA) countries. The MENA region includes approximately 21 countries, according to The World Bank: Algeria; Bahrain; Djibouti; Egypt; Iran; Iraq; Israel; Jordan; Kuwait; Lebanon; Libya; Malta; Morocco; Oman; Qatar; Saudi Arabia; Syrian Arab Republic; Tunisia; United Arab Emirates; West Bank and Gaza; and Yemen.
The region has vast reserves of oil, petroleum, and natural gas, which position MENA as a significant global source of economic resources. Nevertheless, the region grapples with ongoing conflicts in countries such as Syria, Iraq, Iran, Libya, and Yemen. With the United States and Russia supporting opposing factions and supplying military resources, the region continues to serve as a proxy for global economic influence.

Vulnerabilities in the WEF nexus within the region are the outcome of a combination of natural, demographic, socio-economic, and political factors, which collectively amplify the interconnected nature of the nexus. Nexus studies point out that the MENA region grapples with water scarcity, food shortages, high energy demands, and a significant vulnerability to the effects of climate change. Despite possessing 43% of the world's oil reserves and significant renewable energy potential, 35 million people in the region still lack access to electricity. Furthermore, the region has a mere 1.4% share of the world's freshwater resources. Persistent conflicts and security challenges in the region hinder the sustainable management of natural resources, underscoring the urgent necessity for WEF Nexus solutions. In addition, the imperative to meet the growing demand for water, energy, and food within a context of climate change and mounting resource constraints, compounded by inefficiencies in resource utilization and WEF sectoral policy, has given rise to a detrimental cycle. This cycle, instead of fostering synergies between sectors, has tended to perpetuate trade-offs, carrying substantial consequences at the local and regional levels (Giordano & Quagliarotti, 2020; FAO, 2014; Borgomeo et al., 2018). Furthermore, the conflict in Ukraine, due to its repercussions on major global commodity markets, presents an added threat to the various components of the nexus, affecting them both directly and indirectly.

3.1 The WEF nexus and the impact of climate change in the Mediterranean region

Water, energy, and food security share an intricate and inseparable connection in the Mediterranean countries, and this bond is even more evident in the MENA region. Here, the confluence of rapid population growth, accelerated socio-economic development, and the presence of market distortions has significantly amplified the demand for these resources and exacerbated inefficiencies within the WEF nexus. Inefficiencies are particular evident in fossil fuel producing countries, where the WEF nexus is predominantly dominated by oil. In such nations, the relatively abundant energy resources play a vital role in bolstering the availability and affordability of water and food, which can mask underlying scarcities in the other components of the nexus. The capacity to augment water supply and support domestic agricultural production is greatly contingent on revenue generated from oil resources. This financial capacity enables these countries to invest in the production of non-conventional water sources, such as seawater and brackish groundwater desalination, as well as the cultivation of agricultural goods in highly controlled environmental conditions within closed agricultural systems. This strategic approach allows them to overcome inherent geoclimatic constraints.

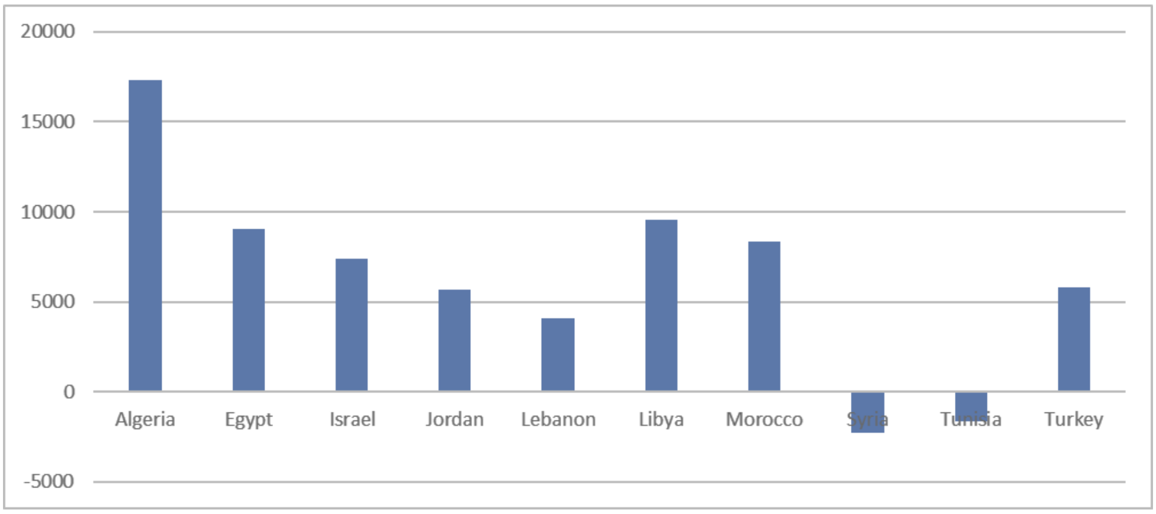

Fig.2 Net Virtual water imports in several MENA countries

At the international level, the trade dimension of the WEF nexus also looks like an effective solution to face domestic nexus challenges. Recognizing that domestic production of water-intensive food can be an inefficient utilization of scarce natural resources, many governments have adopted a trade-oriented food security strategy that aligns with the neoclassical theory of international comparative advantages. In this way, they have externalised the pressure on nations' own water resources importing water in virtual form (Allan, 1998) as illustrated in Fig.2.

Once again, the international dimension of the WEF nexus is particularly evident in oil-producing nations. These countries, fueled by revenue from oil exports, possess the means to rapidly offset their limited food production and the scarcity of water resources by engaging in virtual water imports.

The difficulties in fulfilling the increasing demand for WEF resources are anticipated to be exacerbated by the consequences of climate change. The Mediterranean region is considered a hot-spot of climate change. Various climatic scenarios concur that by 2050, several countries will face a 10% reduction in water sources, resulting in heightened food insecurity. Predictive models indicate an uptick in the intensity and frequency of extreme climatic events, with droughts and floods ranking at the top. Looking further ahead, long-term projections paint an even more dire picture: by 2100, a projected temperature increase of approximately 6 °C is expected, along with a 20% decrease in rainfall and a 100% increase in the land affected by wildfires.

While there may be variations in the conclusions drawn by different climate models, almost all of them concur that the Mediterranean region will undergo significant desertification, primarily driven by a substantial decrease in winter season precipitation, particularly in some areas where it could approach a 40% reduction (Guida & Pennino, 2022).

In order to assess vulnerability of the Mediterranean countries to climate change, the Notre Dame-Global Adaptation Index (ND-GAIN) has been used, which summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. The index assesses countries annually from 1995-2019 on a scale from 0 to 100, with higher numbers indicating that the country is better poised to respond to climate disruptions. As data show, the MENA countries are more susceptible to the impact of climate change than the countries on the northern shore due to their combination of high vulnerability and limited adaptive capacity (Tab.1).

In the face of rising demand for WEF resources amidst the backdrop of climate change, the interconnections within the WEF nexus become more pronounced. This heightened demand doesn't just intensify the nexus linkages, but also leads to a rise in direct competition and trade-offs between different sectors, ultimately constraining a country's capacity to meet the increasing demand in a sustainable manner (Markantonis et al., 2019). Additionally, it's important to recognize that climate change both exerts an impact on and is influenced by the WEF nexus through numerous bidirectional interactions that intricately interweave within the network of WEF connections. Global warming drives a series of feedbacks that negatively affect water, energy and food security that have detrimental consequences for water, energy, and food security, thereby intensifying conflicts within the region: rising temperatures, changes in precipitation patterns, extreme weather events, and sea-level rise gradually disrupt the balance between the nexus resources, and even transform the dynamics of their interactions (Cramer et al., 2018).

Simultaneously, the production of water, energy, and food can lead to increased greenhouse gas (GHG) emissions, further contributing to global warming. Additionally, it's worth noting that current sectoral approaches to climate change mitigation and adaptation may inadvertently exacerbate, rather than reduce, negative externalities and trade-offs within the nexus (Zucaro & Morosini, 2018). Although certain sector-specific mitigation and adaptation measures hold promise for creating synergistic "win-win" situations that benefit one or more sectors within the nexus, it's important to recognize that other measures, like hydropower, first-generation biofuels, the transition to non-conventional water sources, and agricultural intensification, may not always align with a nexus-smart approach. Furthermore, efforts to curtail GHG emissions, in line with the goals set forth in the Paris Agreement can have an impact on the demand for oil and, consequently, its price.

This, in turn, can reduce the revenue generated from oil and gas exports in oil-producing nations, thereby limiting their capacity to import food and engage in desalination for water supply.
What becomes evident is a rather stark scenario, depicting a WEF nexus fueled by a vicious cycle and particularly vulnerable to the impact of climate change.

Country	ND-GAIN Index		Vulnerability		Readness	
	Rank	***Score***	***Rank***	***Score***	***Rank***	***Score***
France	17	66.7	7	0.297	23	0.631
Slovenia	19	65.9	23	0.340	20	0.658
Spain	24	62.9	10	0.308	33	0.566
Portugal	26	62.0	31	0.348	29	0.589
Israel	29	61.4	19	0.338	32	0.567
Italy	32	60.6	15	0.320	40	0.533
Greece	36	58.3	29	0.347	48	0.512
Cyprus	38	57.9	35	0.360	46	0.518
Malta	41	57.0	33	0.355	52	0.494
Croatia	42	56.9	45	0.373	49	0.511
Turkey	47	56.3	21	0.339	66	0.464
Macedonia	53	54.9	39	0.366	64	0.465
Montenegro	57	54.1	63	0.389	61	0.470
Serbia	70	51.1	82	0.410	78	0.431
Albania	73	50.6	91	0.423	76	0.434
Morocco	73	50.6	51	0.380	102	0.393
Jordan	81	50.0	50	0.378	108	0.378
Tunisia	84	49.6	71	0.393	106	0.385
Bosnia and Herzegovina	87	49.1	42	0.371	117	0.352
Egypt	98	46.1	93	0.426	119	0.348
Lebanon	106	45.2	78	0.408	133	0.311
Algeria	109	44.5	41	0.370	166	0.260
Libya	125	40.9	56	0.382	183	0.200
Syria	134	39.2	102	0.439	179	0.222

Tab.1. Notre Dame-Global Adaptation Index (ND GAIN)

3.2 The impact of the Ukraine war on WEF resources in the Mediterranean region

Russia's unwarranted conflict with Ukraine has exerted a significant influence on global energy and food markets, resulting in diverse consequences for the Mediterranean countries depending on their underlying conditions and vulnerabilities.
Prior to the outbreak of the conflict, European nations relied heavily on Russia for their energy needs, with approximately 40% of their gas supply and nearly a third of their oil supply originating from Russia, as reported by the European Union (2023). Therefore, the decision by EU leaders to reduce their dependence on Russian fossil fuels has carried significant implications for the availability and accessibility of energy sources.
The energy crisis has presented a range of pivotal challenges, leading to substantial trade-offs between short-term energy security objectives and long-term climate-mitigation goals, as well as trade-offs between supply security and the cost of energy. existing energy matrix. From a climate change perspective, the war is contributing to two contrasting dynamics. Firstly, numerous European nations are scrambling to identify alternative sources of fossil fuels, which includes reopening coal-burning plants and making investments in oil

and gas ventures abroad. Consequently, in the short term, one aspect of the energy trilemma – sustainability – appears to be potentially overlooked in favor of prioritizing energy security. However, simultaneously, the disruptions in global energy markets have heightened the sense of urgency regarding the energy transition and the imperative to reduce dependency on fossil fuel supplies (Mecklin, 2023).
Narrowing our analysis to the potential impacts of the war on food security, while the availability of essential food supplies for European countries remains secure due to the stability of the Single Market, the significant rise in energy and fertilizer prices has led to an increase in agricultural production costs (European Union, 2023). Consequently, the affordability of food for low-income households, which was already under strain due to the pandemic, may be further jeopardised.
In the MENA region, the repercussions of the Ukraine crisis concerning WEF resources are intricately linked to its socio-economic and agro-ecological attributes. This region is typically characterized as being highly dependent on energy, facing water scarcity, experiencing food deficits, and exhibiting substantial vulnerability to the effects of climate change (Al-Zubari, 2016). As a result, rising energy prices translates into increased petrodollar inflows for the MENA region, to the point that the International Monetary Fund (IMF) has had to revise its forecast for growth in the region as a whole by 0.9 percentage points to 5 percent (IMF, 2022). Nonetheless, this favorable outcome conceals several adverse consequences within the region. The surge in oil and gas prices may tempt governments in oil-exporting nations to postpone crucial structural fiscal reforms aimed at broadening their revenue sources and scaling back substantial subsidies. This delay can mean missed opportunities to capitalize on the elevated energy prices and implement much-needed reforms to foster economic diversification and facilitate the transition to cleaner energy sources. Furthermore, while oil and gas exporting nations in the MENA region reap the rewards of increased oil export revenues, non-oil-importing economies in the same region are burdened by mounting energy import costs. This, in contrast, triggers inflation and erodes purchasing power.

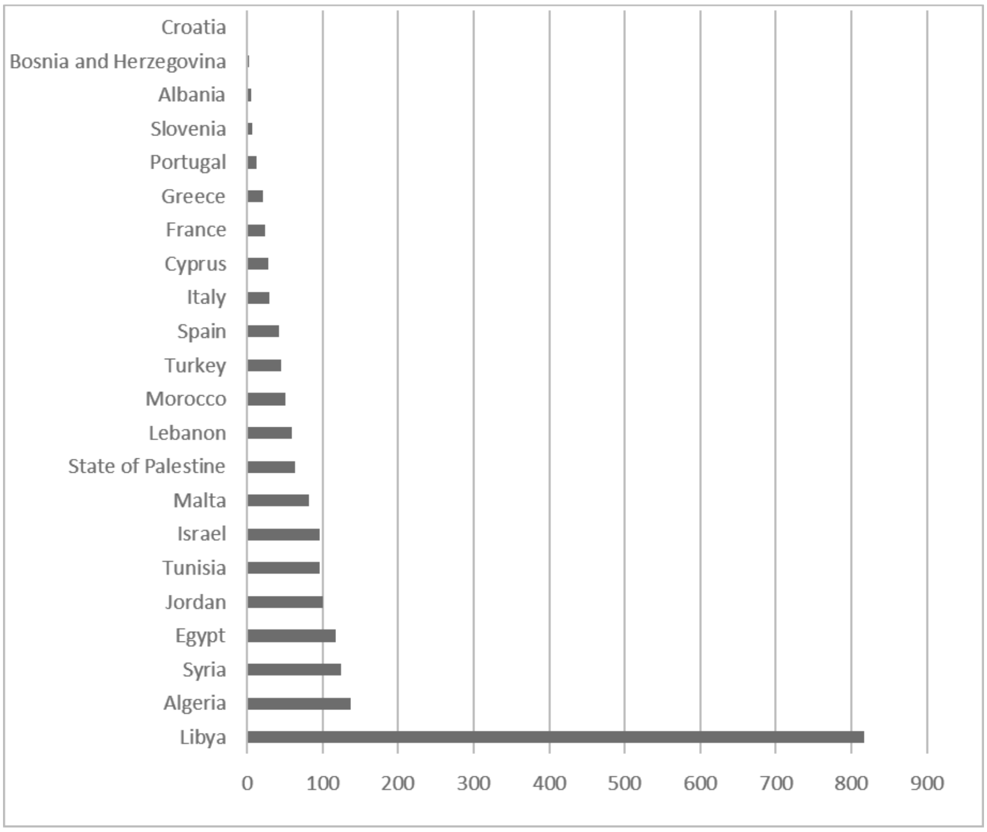

Fig.3 Water stress index in the Mediterranean countries in 2020 (%)

The repercussions of the Ukraine conflict also extend to other facets of the WEF nexus, as the MENA region stands as one of the world's most water-scarce areas. Natural water resources are relatively abundant in the northern Mediterranean countries, while in the MENA countries, 83% of the population is exposed to very high-water stress. Libya, Algeria, Syria, Egypt, Jordan, Tunisia and Israel particularly suffer from low resource availability showing a water stress index, defined as the ratio of total annual freshwater withdrawal to total renewable freshwater resources, ranging from 95 to 820% (820% means that the annual water withdrawal is eight times higher than the water supply from renewable resources) (Fig.3).
Given this bleak water scarcity picture in the southern and eastern parts of the Mediterranean, it is evident that nonconventional water supplies, including wastewater recycling and reuse and desalination, will need to be significantly augmented to meet growing demands and achieve water security. According to the World Bank, considering current technologies and production costs, over $40 billion will be required for investments in nonconventional water sources within the broader MENA region by 2050.

Country/Region	**Arable land (% of land area)**	**Arable land (ha per person)**
Albania	22.40	0.21
Bosnia and Herzegovina	20.10	0.29
Croazia	15.10	0.20
Francia	33.70	0.28
Greece	17.30	0.21
Italy	22.40	0.11
Portugal	12.40	0.11
Slovenia	9.10	0.09
Spain	24.70	0.27
NMCs	19.65	0.18
Israel	13.70	0.04
Jordan	2.60	0.02
Lebanon	12.90	0.02
Syria	25.40	0.25
Turkey	26.80	0.26
West Bank and Gaza	10.60	0.01
Middle East	15.30	0.10
Algeria	3.10	0.19
Egypt	2.90	0.03
Libya	1.00	0.28
Morocco	18.20	0.23
Tunisia	18.70	0.26
North Africa	8.78	0.20
SEMCs	12.40	0.15

Tab.2 Arable land in the Mediterranean countries

A significant portion of these investments will be directed towards developing desalination infrastructure (Borgomeo et al., 2018). Indeed, desalination plays a crucial role in the interlinkage between water and energy, as it involves energy consumption to increase water supply. According to the IRENA (2015; 2016), the Middle East hosts nearly half of the global installed desalination capacity, primarily concentrated in the wealthier Gulf countries. Projections indicate that desalinated seawater production in the MENA region will be 13 times higher in 2040 compared to 2014. Currently, the use of desalination for municipal purposes is gaining significance, particularly in islands and coastal cities with limited water resources. In terms of absolute production, the Mediterranean region's largest freshwater production through desalination occurs in Algeria in Algeria (0.62 x 10^9 m^3/yr), Egypt (0.20 x 10^9 m^3/yr), Israel (0.14 x 10^9 m^3/yr) and Italy and Spain (both 0.10 x 10^9 m^3/yr). However, in relative terms, Malta stands out as the desalination leader, with over half of its drinking water supply being sourced from desalination.

Water scarcity, coupled with limited agricultural land (Tab.2), renders the MENA region one of the most reliant regions in the world on food imports (Tab.3).

Particularly, in Arab countries, because of their limited agricultural potential, international trade has always played a key role in achieving macro-level food security. Due to scarce resources endowments, domestic production of water-intensive food, especially of cereals, has never been considered an efficient way of using natural resources and countries have generally adopted a trade-oriented food security strategy based on the neoclassical theory of international comparative advantages.

This awareness has generally pushed governments' choices to focus on the production of other goods (oil, manufactures, services, or less-water-intensive crops) and use foreign exchange earnings to import most of their food requirements. Consequently, the MENA countries have acutely felt the repercussions of the Ukraine conflict, which have disrupted global food production and exports. However, fiscal disparities between oil-exporting and oil-importing nations also extend to the realm of food security.

Oil-rich states possess significantly greater purchasing power compared to their regional counterparts. While the MENA countries are actively exploring alternative markets for their cereal supply, especially in countries like India, the USA, Canada, Argentina, and Uruguay, this transition is not immediate and comes with additional costs due to longer shipping distances and the spike in fuel prices (WFP, 2022).

Country/Region	Food self-sufficiency ratio (%)			Cereal self-sufficiency ratio (%)		
	2005	2011	2014	2005	2011	2014
Jordan	56.26	53.09	66.60	5.05	3.66	3.70
Lebanon	73.23	61.03	74.70	18.05	10.96	13.80
Syria	85.23	80.62	84.30	74.00	57.98	47.86
Palestine	81.55	72.26	79.30	19.69	10.00	9.48
West Asia	74.07	66.75	76.23	29.20	20.65	18.71
Algeria	53.48	70.04	75.20	29.88	31.96	21.65
Egypt	83.68	78.96	88.00	69.63	56.30	66.04
Libya	44.95	43.09	38.30	10.79	7.06	9.49
Morocco	89.60	80.40	100.00	46.09	58.96	68.00
Tunisia	71.78	68.49	89.50	47.82	46.79	42.42
North Africa	68.70	68.20	78.20	40.84	40.21	41.52
Total	71.38	67.47	77.21	35.02	30.43	30.12

Tab.3 Self-sufficiency ratio in total food commodities and cereals in several MENA countries

As the global food crisis continues to worsen, especially in a context of growing climate variability that hints at the possibility of multiple breadbasket failures, MENA governments are increasingly aware of the risks associated with their heavy reliance on food imports. This has prompted a sense of urgency in implementing robust measures to tackle the underlying causes of food insecurity.

4. Discussion

The conflict in Ukraine, compounded by the effects of climate change, is having a profound impact on both energy and food security, and it is also causing direct and indirect implications for water resources. As a result, it is crucial to identify effective solutions that can ensure the supply of water, energy, and food while minimizing the interconnected consequences across the nexus.

MENA countries need to tailor their responses to the food security challenges arising from climate change and the Russia-Ukraine war, taking into account varying timeframes and the prevailing environmental, socio-economic, and institutional circumstances.

In the short term, it is essential for these countries to expand their existing social protection programs to encompass a broader spectrum of households. Social safety nets emerge as the most effective mechanisms for aiding low-income individuals in coping with rising food prices, and several nations have already recognized their importance in this regard (WFP, 2022).

In the long term, amidst the increasing volatility in food markets, MENA governments must reassess their food security strategies to strike a balance between the advantages of trade openness and the potential drawbacks of susceptibility to trade shocks. This evaluation should include a consideration of the possibility of increasing food self-sufficiency. While this approach might be politically and strategically justified due to its potential to stabilize domestic food prices and reduce dependence on international markets, it does come at a substantial economic cost. This is primarily because the resource endowments of most MENA countries are not well-suited for food production, especially cereal crops, and their comparative advantages are found in other economic activities. To address these challenges, nations should focus on what could be called "macro food sovereignty". This strategy involves blending self-sufficiency with trade-oriented food security measures, with a strong emphasis on encouraging the cultivation of crops that align with their specific geoclimatic conditions (Quagliarotti, 2023).

Given that energy plays a pivotal role as a fundamental input at various points in the water and food supply chain and is also the primary contributor to GHG emissions, it is imperative to regard the energy transition as the initial and crucial step toward establishing sustainable integrated solutions. These solutions have the potential to bolster security and sustainability within the WEF sectors while concurrently supporting global climate ambitions. The joint development of unconventional water and energy sources, such as desalinated water and renewable energy, offers a promising approach to tackling the dual challenges of water and energy security. This approach not only enhances economic efficiency and social equity but does so while adhering to the imperative of environmental preservation (Giordano & Quagliarotti, 2020). The MENA region boasts substantial potential for the development of renewable energy, particularly solar power. Generally, renewable energy technologies are less water intensive than conventional options. According to IRENA, the water requirements for solar photovoltaics (PV) are almost negligible when compared to conventional thermoelectric generation, using up to 200 times less water to generate the same amount of electricity (IRENA, 2015; 2016). Clean energy not only contributes to substantial water conservation but can also be harnessed to enhance non-conventional water supply in a more sustainable manner, particularly in the production of desalinated water. The latter has traditionally incurred high economic and environmental costs due to the significant amount of fossil energy required for reverse osmosis. Hence, the adoption of renewable energy sources can serve a dual purpose. It can not only meet the energy requirements of countries lacking abundant oil reserves but also enhance the resilience and adaptability of nations facing environmental constraints and grappling with the scarcity of two critical resources essential for human well-being, namely water and food. These countries are more susceptible to the adverse effects of climate change, making the shift to renewables a pivotal step in their sustainable development.

Furthermore, considering the unequal distribution of WEF resources across the Mediterranean region, it is crucial for countries to enhance their collaborative efforts in addressing WEF challenges in a mutually supportive manner. In this context, the application of the principle of comparative advantages within the WEF nexus can serve as an effective mechanism for amplifying synergies and complementarities among nations. By taking into account countries' diverse factor endowments, nations can specialize in the production and exchange of goods for which they have a comparative advantage, resulting in lower opportunity costs compared to other countries. The Pre-Feasibility Study for Mid-East Water-Renewable Energy Exchanges carried out jointly by EcoPeace Middle East and the Konrad-Adenauer-Stifttung (Katz & Shafran, 2017) serves as a compelling illustration of the advantages that can be harnessed when the nexus approach extends beyond national borders, enabling countries to cooperate to attain increased economic efficiency in resource management. Recognizing the challenges related to energy and water security, coupled with the disparities in factor endowments between countries, the project adopts a strategic approach. It uses the relative abundance of resources in each state as a basis to construct a non-conventional water-energy exchange model to create interdependencies rather than dependencies among the three participating countries.

Great opportunities could also emerge from a Euro-Mediterranean partnership in the realm of renewable energy. Considering the advantageous geo-climatic conditions in the MENA region for harnessing solar energy, the expansion of renewable energy sources could be leveraged to establish a mutually beneficial and integrated EU/MENA WEF system, driven by a North-South exchange of technology, expertise, capital, and agricultural products (virtual water), along with a reciprocal flow of clean energy. A significant byproduct of the expansion of solar power plants in MENA nations could be the desalination of a substantial volume of seawater, which could help mitigate the projected water shortages in the region (Kennou et al., 2018).

This innovative model of Euro-Mediterranean cooperation holds the potential to serve as a proactive response to the challenges posed by the Ukraine crisis and climate change, addressing both the increasing energy needs of European countries hungry for non-fossil energy sources and the rising water demands of Arab nations thirsty for virtual and non-conventional water resources.

5. Conclusions

Climate change and the conflict in Ukraine stand as quintessential examples of the systemic risks that our world is currently grappling with. Since the agricultural and industrial revolutions, humanity has shaped the face of the Earth to such an extent that today's geological epoch has been called "Anthropocene". In this critical situation for the future of our planet, on February 24, 2022, the world faced a violent geopolitical conflict involving major powers, which has altered the dynamics of the international system.

These dual crises underscore the profound vulnerability of the Mediterranean countries concerning their water, energy, and food security, all of which are intricately interconnected in this region. Particularly in the MENA countries, the WEF nexus presents an escalating challenge, primarily due to a negative feedback loop that exacerbates trade-offs rather than fostering synergies across sectors (Zhang et al., 2018).

The consequences of climate change and the aftermath of the Ukraine conflict are conveying distinct messages to the two shores when it comes to WEF components.

In the European countries, the ongoing energy crisis, exacerbated by the repercussions of the Ukraine conflict, is generating mixed signals. On one hand, the need to secure immediate energy requirements has spurred a frantic pursuit of readily available, conventional energy sources like oil and gas. On the other hand, this unfolding energy security crisis serves as a stark reminder to member states of the crucial importance of developing energy self-sufficiency, achievable through an accelerated integration of renewables into the national energy mix.

In the MENA region, the impact of the conflict has unfolded differently, with oil and food importers primarily bearing the brunt of the economic shockwaves caused by the war. Despite a reduction in food prices to pre-war levels, the region, heavily reliant on food imports, remains exposed to trade disruptions as an ongoing concern.

As a result, the main challenges today revolve around providing Europe with clean energy supplies while ensuring the MENA region's access to increased food and water resources.

Given the stressors and drivers outlined above, delivering water, energy and food for all in a sustainable way is one of the major challenges that the Mediterranean countries face. Overall security can be achieved by creating intelligent synergies and fair trade-offs among sectors to minimize risks and enhance resource efficiency and equity.

The application of a WEF nexus approach in the Mediterranean region, guided by the principle of leveraging comparative advantages, presents a unique opportunity to mitigate trade-offs and address the urgent water, energy, and food challenges at both national and regional levels.

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Image Sources

Fig.1: Mohtar (2022);

Fig.2: Mekonnen & Hoekstra (2011);

Fig.3: FAO (2023).

Table Sources

Tab.1: University of Notre Dame, https://gain.nd.edu/our-work/country-index/;

Tab.2: World Bank, World Development Indicators. https://databank.worldbank.org/source/world-development-indicators;

Tab.3: Saab (2017).

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Analysis of strategic natural resources: the FEW Nexus model applied to Irpinia (Italy) and implications for regional planning

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Abstract
Natural resources are strategic resources. They are becoming increasingly important in policies combating climate change. Moreover, their protection and enhancement are fundamental for actions of sustainable development. The paper analyses specific types of natural resources (soil, water and energy) and identifies their potential contribution to local development in a perspective of reduced environmental loads. General attention to the three systems of resources is evidenced by the development of research based on the FEW Nexus model which, since the 1970s, has explored the connections existing between them, as well as the development of parallel research lines. The latter can directly impact on regional planning and bring about necessary changes in currently applied plans so as to adapt them to evolving circumstances. A case study of interest is the area of Avellino, one of the inland provinces of Campania. The paper shows that the regional planning tool for the province only partially considers such resources, failing to assign to them any strategic importance. This may be considered a weakness both in regional planning and in land management because it excludes in advance, from analyses and forecasts, resources that can make a major contribution to the sustainable economic development of the province. To this end, the last section of the paper proposes changes in regional planning policy.

Keywords
Natural resources; FEW Nexus model; Sustainable local development; Regional planning.

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1. Introduction

The meteorological events of 2022 and 2023 clearly highlighted some of the extreme consequences that climate change can cause on a regional basis. In 2022, the scant rainfall during the spring months, accompanied by a long period of much higher-than-average temperatures, reduced water availability for irrigation, resulting in the crisis of several agricultural production chains – those most dependent on water –, and led to the destruction of flora and fauna caused by summer wildfires. The symbolic image of the summer of 2022 was the low level of the River Po, whose flow reached all-time lows thanks also to other systemic phenomena, including the scarce flows of its main tributaries, the lowering of the level of Alpine lakes, and salt water intrusion from downstream. Contrasting with this prolonged drought was the severe flooding that affected the regions of the Marche in September 2022 and of the Emilia-Romagna in May 2023.

The alarm phase appears to have brought an end to the state of alert. This is typical of the normal approach of a community after a critical phase: choosing to ignore extreme phenomena instead of considering them as alarm bells and as a starting point for planning and structuring more sustainable management of natural resources.

Summer 2022 was also marked by a significant energy crisis. The sector has come under great pressure due to the war unleashed by Russia against Ukraine, even if previously there had been a series of speculative phenomena tending to increase the cost of raw materials required for energy production, especially gas and oil. The crisis has become an opportunity to think in depth on the energy question and on the different time frames on which it is measured: in the short to medium term there is a fundamental need to identify alternative energy sources to those from Russia; on a longer term basis, fossil fuels will have to be replaced with renewable sources so as to make individual countries self-sufficient and to take a decisive step forward in neutralizing emissions (Fistola et al., 2023).

This leads the reasoning back to the starting point, i.e., the severe drought and climate conditions of summer 2022 and 2023, with the aim to establish a very close systemic interrelation between all the processes linked to food and energy production and to the balanced use of water resources.

2. Literature review

This paper focuses on the relationship between natural resources, land use planning and management, and on the observation that resources are in a fragile state in the face of climate change. The scientific community pays considerable attention to the topic, which is being developed through several different lines of study, all worthy of further elaboration.

Among them we cite the FEW (Food-Energy-Water) Nexus model (Hoff, 2011; Zhang et al., 2019; Newell et al., 2019; Abdi et al., 2020), a theoretical framework used to analyze the interconnections and interdependencies among food, energy, and water systems (Fig.1). It recognizes that these three essential resources are strictly linked and that changes in one system can have significant impacts on the others. Furthermore, this model deepens the methodological and analytical tools to quantify the intensity of the relationships between them both locally and globally.

The main characteristics of the FEW Nexus Model include an interdisciplinary approach, an holistic perspective – which considers the entire lifecycle of food, energy, and water resources, from production and distribution to consumption and waste generation and which helps in identifying potential trade-offs and synergies between these systems –, and a systems thinking, which involves analyzing how changes in one component of the system can affect other components and the overall system.

Other characteristics are linked to environmental and geographical issues. The FEW Nexus Model recognizes that increasing global population, urbanization, and climate change are putting pressure on the resources, leading to scarcity and competition. Furthermore, the interactions among food, energy, and water systems can vary significantly based on geographic location and local conditions (D'Odorico et al., 2018). A potential answer is to achieve sustainability and resilience in the face of changing environmental and socioeconomic conditions. This involves identifying strategies to ensure the long-term availability of food, energy, and water resources while minimizing negative impacts on ecosystems and apply them at different scales.

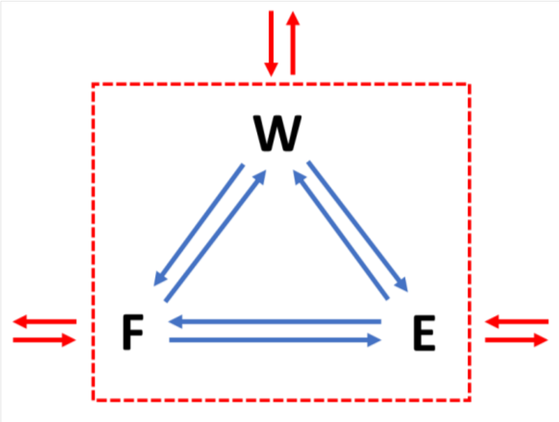

Fig.1 FEW Nexus model: theoretical scheme

The FEW Nexus Model is often used as a tool to inform policy and decision-making, with the aim to understand the complex interactions among these systems, and to inform choices to balance competing demands and promote sustainable resource management. In this way the FEW Nexus Model often involves engaging various stakeholders, including government agencies, industry representatives, NGOs, and local communities.
Last but not least, to build and apply the FEW Nexus Model effectively, access to accurate and up-to-date data is crucial, as is important to involve scenario analysis to explore potential future outcomes under different conditions and policy interventions.
Overall, the FEW Nexus Model provides a structured framework for understanding the complex interactions among food, energy, and water systems and is a valuable tool for addressing the sustainability challenges associated with these critical resources. For this model, the need to think in systemic terms derives from the interrelations between the three subsystems and from the evidence that population growth and its ever-greater shift towards urban systems increases the demand for these resources, in turn causing increased greenhouse gas emissions. The existence of relationships between these three subsystems means that changes in one of them have effects on the others, impacting, more generally, on climate change, environmental systems, socio-economic conditions and hence on policies and plans.
Another interesting line of research focuses on natural capital, defined as the stock of natural resources of an area (soil, air, water, living organisms) able to produce value through goods or services (Costanza & Daly, 1992; Moro, 1997; Dendena, 2018; Ministero dell'Ambiente, 2020). For this reason, natural capital must be the subject of particular attention.
Some types of natural capital provide communities with free goods and services, termed ecosystem services (Costanza et al., 1997; Daily & Matson, 2008; Turner & Daily, 2008; Scolozzi et al., 2012; Zoppi, 2020; Castellar et al, 2021). Two of these – water and soil – are the basis of economic and social systems and make community existence possible. To ensure that ecosystems continue to produce a flow of services, they need to be efficient and functional to avoid their degradation into non-renewable or inert natural capital. Hence the structure and variety of ecosystems is an important component of natural capital.
The presence of natural resources entails the need of proper planning and management with new rules and regulations able to ensure protection of the natural and agricultural environment, the reduction or cessation of soil consumption, and enhancement of environmental quality. The capacity of an area to respond to critical events resulting from climate change processes is thereby increased (Córdoba Hernández & Camerin, 2023).
If a geographical area has the ability to respond resiliently to the extreme events caused by climate changes, it is more capable of reducing potential damage to people and goods. The notion of resilience is connected to

the idea that an urban or rural system and its components can recover their functionality more quickly following negative events (Boyd et al., 2008; Molavi, 2018) and it is strictly connected to adaptation and mitigation processes (Muller, 2007). Resilience can be described in different ways but there are common factors that can be measured; it comprises diversity, flexibility, adaptive governance, and the ability to learn and to innovate, namely typical elements of processes related to innovation.

Climate change plays a specific role among the various causes of disastrous events that can affect a certain area. Climate change can cause rapid events, such as heavy rain, continuous events of medium duration, such as periods of drought, and continuous events of long duration, such as the average rise in temperatures. Based on an analysis of the scientific literature, Leichenko (2011) identifies four types of approaches and responses in terms of resilience: (1) ecological resilience; (2) reduction in hazard and risks from disasters; (3) the resilience of urban and regional economies; (4) the promotion of resilience through governance and institutions.

The ability of institutions to develop governance mechanisms that are most suited to respond to such problems, reducing risk for citizens, will be critical. According to studies in this regard, there is no single applicable system of governance, despite the presence of an extensive sample of good practices, and the best solution varies on a case-by-case basis (Ostrom, 2010).

3. Case study. Natural resources in the province of Avellino

The province of Avellino, sometimes referred to as Irpinia, is an inland province of the region of Campania in southern Italy (Figure 2). The area is rich in natural resources: it contains regional nature reserves and protected areas, its soil favours high quality agricultural production (Province of Avellino, 2004), and weather conditions are conducive to a significant generation of electricity from renewable sources. Furthermore, the main springs feeding the Apulian Aqueduct (Ciervo, 2016; Balacco et al., 2017) and supplying water to the Metropolitan City of Naples originate in southern Irpinia.

Fig.2 Province of Avellino in the Italian peninsula

Part of the province lies within the Alta Irpinia Pilot Area, one of the four inland areas selected by the Campania Regional Authority as part of the National Strategy for Inland Areas (SNAI). In 2017, the relative Strategy Document was approved by the Regional Authority (Regione Campania, 2017).

3.1 Soil, agriculture, food

The province of Avellino is 2,806.07 km^2. According to 2019 data, soil consumption in the province amounts to 7.3% of the total area, compared to a regional average of 10.3% (Munafò, 2020). There are significant differences between inland and coastal areas: for example, the Metropolitan City of Naples has an urbanized land percentage of 33.9%. The proximity of the regional average to the lowest figure is affected by extensive sparsely populated inland areas.

The most recent data from 2021 does not change the situation. According to the Webgis of ARPA Piemonte[1], soil consumption country-wide amounted to 7.13% of Italy's surface area, while the data for Campania and Irpinia are 10.49 and 7.36, respectively. In the latter there was a 47-hectare increase in soil consumption between 2020 and 2021 (Munafò, 2022), which brings the total amount of soil consumed to 20,536 hectares. Soil not consumed comprises basically natural and agricultural soils. The data relating to agricultural land are contained in the agricultural censuses. In 2013 the Campania Regional Authority, starting from these data, divided the region into 28 Rural Territorial Systems (STRs). 10 of them contain, in whole or in part, municipalities belonging to the province of Avellino, namely Colline del Fortore (STR3), Colline Sannite-Conca di Benevento (STR7), Colline dell'Ufita (STR8), Colline dell'Alta Irpinia (STR9), Colline dell'alta Valle dell'Ofanto (STR10), Piana Campana (STR13), Monte Partenio-Monti di Avella-Pizzo D'Alvano (STR18), Colline Irpine (STR19), Valle dell'Irno (STR20) and Monti Picentini (STR22). We note that these 28 STRs do not coincide with the 45 Territorial Development Systems of the Regional Land Use Plan approved in 2008.

According to the data published by the Campania Regional Authority in 2013, based on the Sixth Agricultural Census of 2011, the utilized agricultural area (UAA) amounted to 124,455.5 ha (34.92% of the province of Avellino, while the total agricultural are (TAA) was 150,162.3 ha, equivalent to 53.51% of the whole province. On the ISTAT website, the data relating to the 2010 Census are slightly different. The UAA accounts for 122,621 ha, while the TAA is 148,689 ha.

STR	**Municipalities in the STR (no.)**	**Municipalities in the STR and in the province of Avellino (no.)**	**Area of the municipalities in the province of Avellino (Km^2)**	**Area of STR in the province of Avellino (%)**	**Population of STR in the province of Avellino in 2011 (%)**
3	24	3	87.0	10.5	5.3
7	17	4	26.2	7.8	3.4
8	29	25	671.7	84.0	87.1
9	9	9	540.2	100.0	100.0
10	13	11	358.6	94.0	96.3
13	33	3	22.2	5.7	1,3
18	23	15	230.3	72.4	71.1
19	39	39	466.8	100.0	100.0
20	11	2	40.0	20.2	15.7
22	8	6	323.2	60.9	57.2

Tab.1 Rural Territorial Systems (STRs) of the Province of Avellino

1 https://webgis.arpa.piemonte.it/secure_apps/consumo_suolo_agportal/index.html

The Seventh National Agricultural Census took place in 2021[2]. To date, only regional data are available, and they show that between 2011 and 2021 there was an overall decrease in UAA of 5.74% (546,948 ha in 2010 vs. 515,544 ha in 2020).

Irpinia has extensive forest cover while its farmland is noted for its high quality products. Each of the Rural Territorial Systems is characterized by specific production and specific areas. For example, in the central part of the province there are internationally acclaimed winemakers, while eastern Irpinia is almost devoid of designation of origin products even in the presence of specific produce of great interest (Mazzeo, 2005). The exception is the Montella chestnut.

STR	Municipalities in the STR and in the province of Avellino (no.)	Farms in the municipalities of the province of Avellino (no.)	Area of the municipalities in the province of Avellino (Ha)	Utilized agricultural area (UAA) (Ha)	Total agricultural area (TAA) (Ha)
3	3	400	8,700	4,924.1	5,756.1
7	4	169	2,620	305.3	406.8
8	25	9,476	67,170	40,755.9	45,167.2
9	9	3,181	54,020	33,822.6	37,216.7
10	11	2,611	35,860	13,696.8	16,780.4
13	3	494	2,220	1,000.9	1,078.6
18	15	2,165	23,030	6,321.9	7,840.5
19	39	5,416	46,680	13,079.1	17,023.4
20	2	304	4,000	797.6	991.2
22	6	1,540	32,320	9,751.3	17,901.4
TOTAL	117	25,756	276,620	124,455.5	150,162.3

Tab.2 Utilized agricultural area (UAA) and total agricultural area (TAA) in the Rural Territorial Systems (STRs) of the province of Avellino

The local system of agricultural production must be framed within a broader horizon that sees agriculture being transformed into a sustainable sector able to reverse the current state in which it is viewed as a non-secondary source of emissions of climate-changing gases. In this regard, Community policies are very pressing. "The European Green Deal and its Farm to Fork Strategy treat agriculture as more than an economic sector: it also contributes to sustainability goals such as social well-being, ecosystem health, and food and nutrition security" (European Environment Agency, 2021).

3.2 Water

In terms of the organization of water resources, the provinces of Avellino and Benevento are part of the Optimal Territorial Area 1 (ATO-1) of Campania, known as the Calore Irpino. It forms part of the former Basin Authority of the rivers Liri, Garigliano and Volturno. It includes the areas pertaining to the land reclamation consortia of Ufita and Valle Telesina, as well as the territories of mountain communities, namely Alta Irpinia, Serinese-Solofrana, Ufita, Vallo di Lauro, Baianese, Partenio and Terminio-Cervialto (Fig.3).

The Plan of ATO-1 Campania dates to 2012. It shows that the province of Avellino has significant water resources deriving from the presence of numerous natural springs. The main springs are those of the upper Sabato valley (Serino), the upper Calore valley (Cassano Irpino and Alto Calore springs), and the upper Sele valley (Caposele). All these springs are fed by the mountain ranges of Terminio-Tuoro and Cervialto. Other springs are in the upper Solofrana valley (Bocche di Solofra), and in the Avella and Partenio mountains (Avella and Sirignano).

[2] https://www.istat.it/it/censimenti/agricoltura/7-censimento-generale.

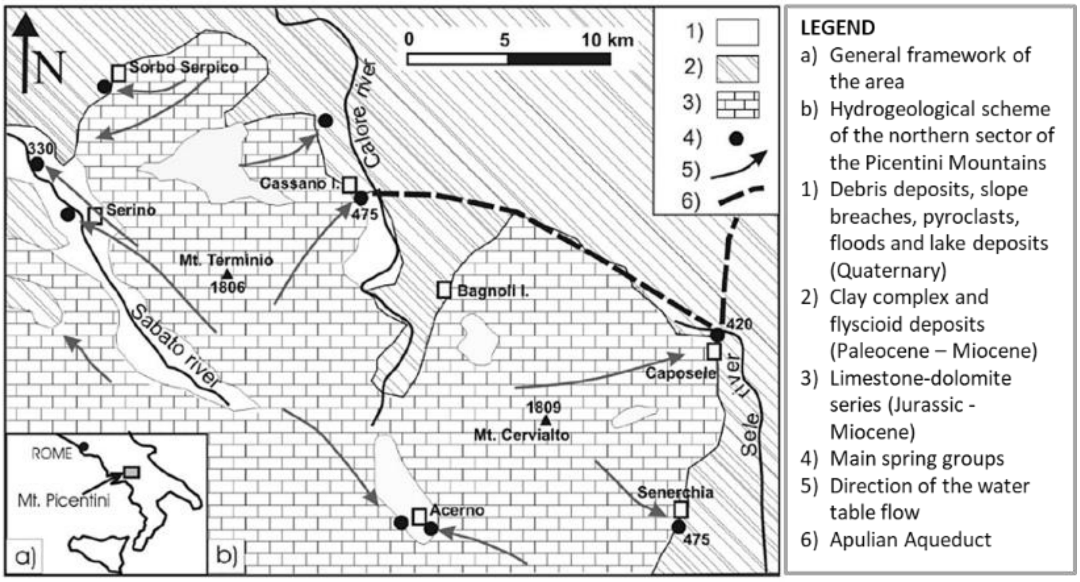

Fig.3 Geological overview of the Picentini mountain area (Monte Terminio –Monte Cervialto) and hydrogeological scheme of its northern sector

Most of Irpinia's water resources are used to supply drinking water to areas outside the province: the water of the Caposele and Cassano springs are channelled towards the region of Puglia, while the water of the Serino springs are channelled towards the metropolitan area of Naples (Fig.4). Overall, 91% of water resources come from springs and 9% from wells. Water production in 2012 was estimated at approximately 9,524 litres per second (Campania Regione, ATO-1, 2012).

Figure 4 shows the water balance of the ATO in 2012. It shows that 33% of the spring waters are used to supply drinking water for the ATO itself, while the remaining part (67%) is used by communities outside the province. The water resources drawn from wells are instead all allocated to the population of the ATO. Extra-regional water supplies (about 4% of the total) should be added to the overall balance.

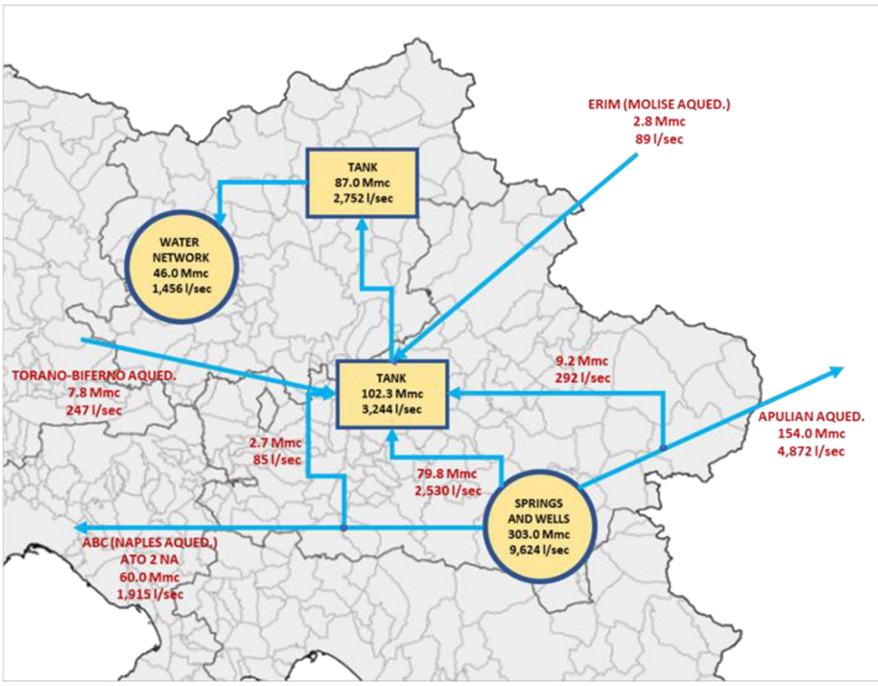

Fig.4 Water balance at 2012

Overall, the average flow rate available in the ATO-1 area should be 3,244 litres per second. In practice, given that water infrastructure censuses reveal average losses of 15% for the adduction network and 47% for the distribution network", the effectively distributed flow to users is approximately 1,458 litres per second (Regione Campania, ATO-1, 2012, 91). Tab.3 shows the total size of the flow rates within the area of the ATO-1.

	Springs	Wells	Surface water	Total
Supplied water flow rate (l/s)	3,965.2	1,955.5	0.0	5,920.7
Mean derived flow rate (l/s)	6,642.2	1,153.2	0.0	7,795.3
Maximum derived flow rate (l/s)	9,245.2	1,121.8	0.0	10,367.0
Minimum derived flow rate (l/s)	3,652.3	483.3	0.0	4,135.6
Annual mean derived volume (mc)	204,664,377.0	33,855,115.0	0.0	238,519,492.0

Tab.3 Full data of the resources available in ATO-1

The ATO-1 Plan highlights several critical elements. Despite the presence of numerous underground water bodies, the province's hydrological balance is negative, and it cannot be modified by using springs not yet connected to the water network. The latter, in fact, are modest or supply aqueducts outside the province, while the river waters are already excessively exploited by intensive agricultural and industrial activities. According to the Campania Regional Authority (Regione Campania, ATO-1, 2012, 65), in this context it is therefore essential to adopt measures to rationalize the management of water resources, aimed at partial recovery of the resource currently piped out of the region and focus on its regional distribution, as well as modernisation of existing works, to ensure the reduction of losses from aqueducts.

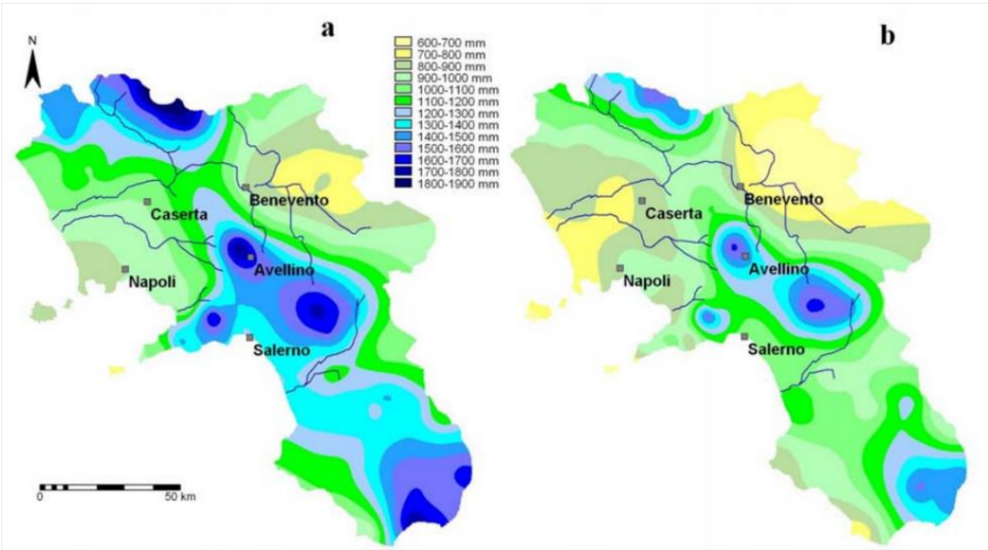

Fig.5 Average annual rainfall (mm/year) for the period 1951-1980 (a) and 1981-1999 (b)

An aspect of great importance is annual rainfall (Fig.5). Irpinian springs owe their water flows to winter and spring precipitation affecting the southern and western mountain areas. In this regard, Ducci and Tranfaglia (2005) showed that in the period 1981-1999 rainfall in Campania decreased by 15% compared to the previous 20 years. This decrease is not evenly distributed over the region, but has a greater impact in mountain and hill areas. Over the same period, the number of rainy days has decreased by a similar percentage.

The authors attribute this negative variation in the rainfall to global climate change. To support this hypothesis, they report that, in the same period, analysis of temperatures in Campania reveals an overall average increase of 0.3 °C, resulting from +0.2 °C in the flat coastal areas and +0.5 °C in inland and mountainous areas.

Returning to water resources, the two authors state that in Campania there have been decreases in flows from sources and lowering of the piezometric surface, important indicators of both the depletion of underground water resources and an increase in their exploitation. If this trend continues, they conclude that "a 70% decrease in groundwater resources could occur in the next 50 years, and groundwater management in Campania should be overhauled. In 2050, according to the scenario set out above, a population of several million people (population of Campania and Puglia, currently supplied with groundwater from Campania) may be in a critical situation"[3] (Ducci and Tranfaglia, 2005, 11).

3.3 Energy

Production of electricity from sustainable sources represents a sector with significant potential impact (Mazzeo, 2013). The inland areas of Campania and stretches of Molise and Puglia extending as far as the Adriatic coast account for some of the main production areas of renewables, namely solar and wind power. The plants built so far in Irpinia produce approximately 14% more energy from renewable sources than that actually consumed (1,513.7 GWh vs. 1,329.3 GWh), as can be seen from Tab.4 and Tab.5 (Terna, 2022). Wind power generation represents the dominant share of renewable energy production.

Source	Campania		Province of Avellino	
	2000	2020	2000	2020
Wind	329.8	3,209.2	55.0	1,289.9
Solar	4.1	981.5	0.0	101.9
Water	1,916.8	844.0	16.5	10.7
Thermoelectric	2,906.9	6,708.7	0.0	111.2
Total	5,157.6	11,743.4	71.5	1,513.7
% of regional total	=	=	1.4	12.9

Tab.4 Electricity generation by source. Gross production (GWh)

The development of this production chain has also triggered a rise in local protests against the construction of new wind farms accused of generating a strong environmental impact, of being a vector of landscape fragmentation and, ultimately, of sometimes being based on poorly transparent business initiatives.
The current EU directive on the promotion of renewable energy (Directive 2018/2001) establishes that Member States must achieve by 2030 a share of energy from renewable sources equal to 32% of gross final consumption, and that the share of the transport sector must reach 14%. The Integrated National Plan for Energy and Climate (PNIEC, 2019) sets the Italian targets at 30 and 22%, respectively.

Sector	Campania		Province of Avellino	
	2000	2020	2000	2020
Agriculture	212.5	311.0	8.0	12.4
Domestic	5,263.0	5,532.3	332.0	365.3
Industry	5,088.9	4,572.9	650.1	605.8
Services	3,783.8	5,407.8	242.1	345.8
Total	14,348.2	15,824.0	1,232.2	1,329.3
% of regional total	=	=	8.6	8.4

Tab.5 Electricity consumption by sector (GWh)

At the Community level, there is discussion on an acceleration of this process ("Fit for 55") that will raise the general target from 32 to 40% in 2030. This means that the focus on renewable energy can only grow further,

[3] Translation from the original text in Italian.

and will make it necessary to build new production plants, as well as boost research activities in the sectors of energy production, conservation and distribution.

3.4 Preliminary scenario

The Food-Energy-Water (FEW) Nexus model can be further enhanced through the development of a scenario analysis. This analytical approach aids stakeholders and decision-makers in exploring potential future outcomes and evaluating the potential consequences of different actions and policies, as suggested by Kosow & Gaßner (2008), Alcamo (2009), and Paltsev (2017).

The analysis starts from the current state of resources assuming possible evolutionary trajectories. The considerations are split into two sections: the first section expresses assessments to date, while the second section refers to a possible future scenario. Both the first and second use the same four types of qualitative indicators: (1) flows of goods; (2) quantity; (3) local impact; and (4) outlook. For each indicator, one opinion was expressed for two different states: the current state and the future state. Some judgments are followed by trend indications placed in square brackets. Figure 6 shows the results of the assessment both verbally and graphically. The building of the scenario is based on the data presented in the sections above, and on the hypothesis that in the near future there will be a strong step change in the decision-making system, such as to modify current area trends.

Current state

At present the province produces food resources exported in significant quantities. Yet imports are also significant. The local impact of this resource can be considered significant, even if it does not yet express all its potential in terms of impact on the province. The outlook is positive.

Since the energy produced is higher than that consumed in the province, the latter may be said to be a net exporter even if the quantities are not significant. Although the local impact of this resource is limited in economic terms, it is critical from the social point of view due to opposition from some local communities. The outlook is positive.

The province is a net water exporter, even if in this case the exported quantities are decidedly greater and more significant than those consumed locally. Of the resources analysed, water is the most important and strategic, especially in consideration of its impact on some communities outside the province. Prospects for the future are stable.

Potential forecast

Turning to the outlook, the considerations that can be hypothesized give rise to substantially different scenarios from those relating to the current state. As regards food, import/export flows between the province and outside areas will continue. Quantities could change significantly: they could grow if agriculture gains weight within land use development policies. This could have a high local impact both in economic and social terms. The positive outlook could consider the negative impacts of climate change or other events that could create critical situations within one or more agricultural production sectors.

The energy sector confirms the judgment on flows, with a province that can strengthen its position as a net exporter. Due to its characteristics, it should significantly increase the amount of energy produced. The local impact of the sector is more nuanced, which should be taken into due account within future investment policies. Local impact means the possibility that energy will be used locally to develop specific economic sectors, but also the possibility that local communities can self-produce and market increasing amounts of energy. The prospects, however, appear positive.

CURRENT STATE

	FLOWS OF GOODS	QUANTITY	LOCAL IMPACT	OUTLOOK
FOOD F	Import/Export	Significant	Significant	Positive
ENERGY E	Export	Limited	Limited	Positive
WATER W	Export	High [Steady]	Significant	Neutral

POTENTIAL FORECAST

	FLOWS OF GOODS	QUANTITY	LOCAL IMPACT	OUTLOOK
FOOD F	Import/Export	Significant [Growing]	High	Positive [Critical]
ENERGY E	Export	Signiticant [Growing]	Significant	Positive [Neutral]
WATER W	Export	High [Reduction]	Significant	Negative [Critical]

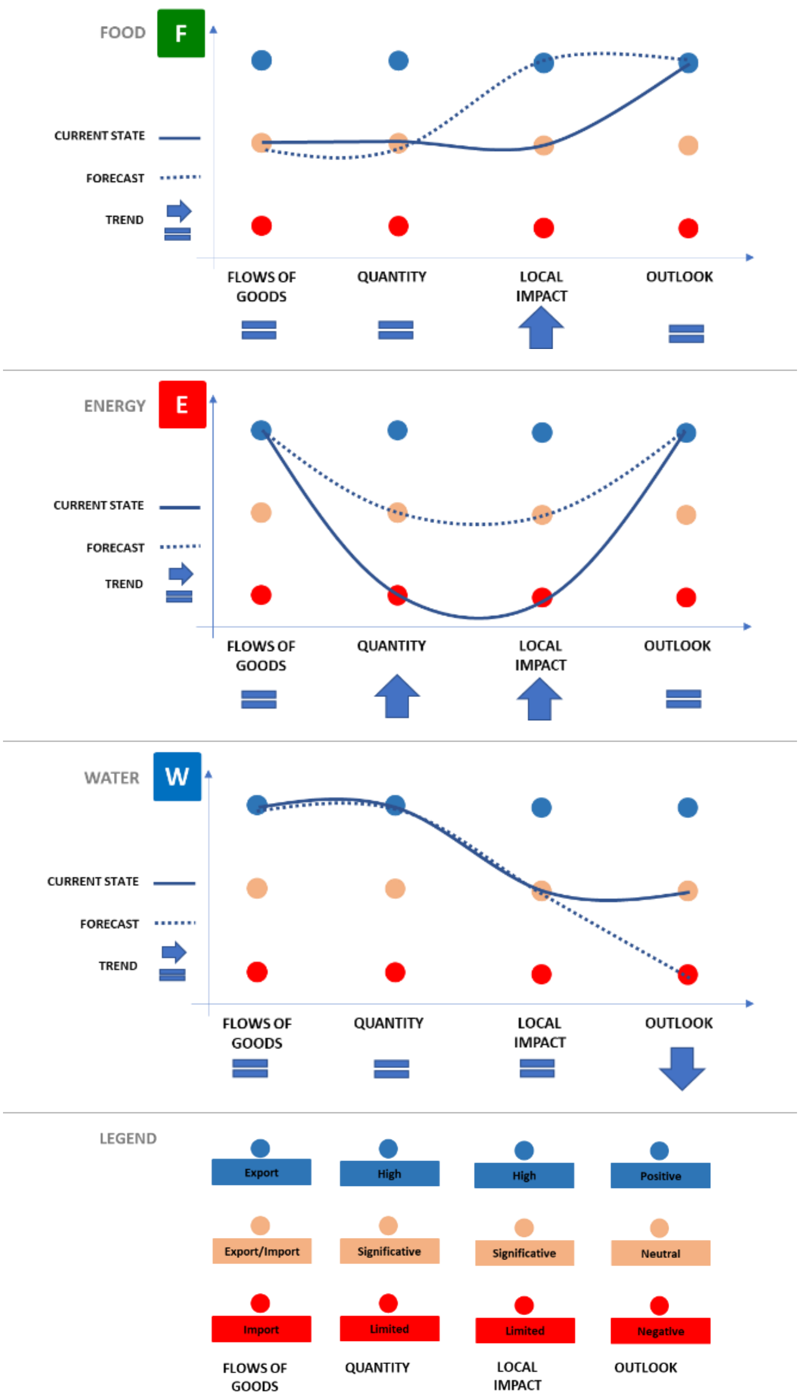

Fig.6 State and scenario qualitative indicators as applied to the case study of the FEW Nexus model

Finally, the water sector confirms the status of Avellino as an exporting province, even if there has been a reduction in spring flows in recent decades as a result of changing climatic conditions and lower rainfall. The resource will continue to have a significant local impact, which will grow if sustainable water use becomes the basis of economic development. In the case of this resource, the outlook can be considered negative and potentially critical because significant reductions in water supplies from springs due to climate change cannot be excluded. Hence the urgent need to draw up policies that are much more attentive to the use of the resource.

The scenario presented earlier is qualitative and should be considered as the initial step of a future research, aimed at deepening the data and at developing the scenario structure that is useful for applying territorial policies and plans.

4. Discussion. Towards new topics of the regional plan

4.1 The current regional plan for the province

Planning addresses the necessity of incorporating sustainability and resilience elements into the tools (Colucci, 2015). These elements must have an environmental focus, guiding urban and land-use systems toward active management of natural capital and ecological impact neutrality (Griggs et al., 2013). They should also encompass social aspects. In this context, a particular challenge affecting inland areas, such as the province of Avellino, is their livability. This extends beyond overall environmental quality (which is crucial) and includes the quality of services provided to the resident population, enabling them to lead their best possible lives.

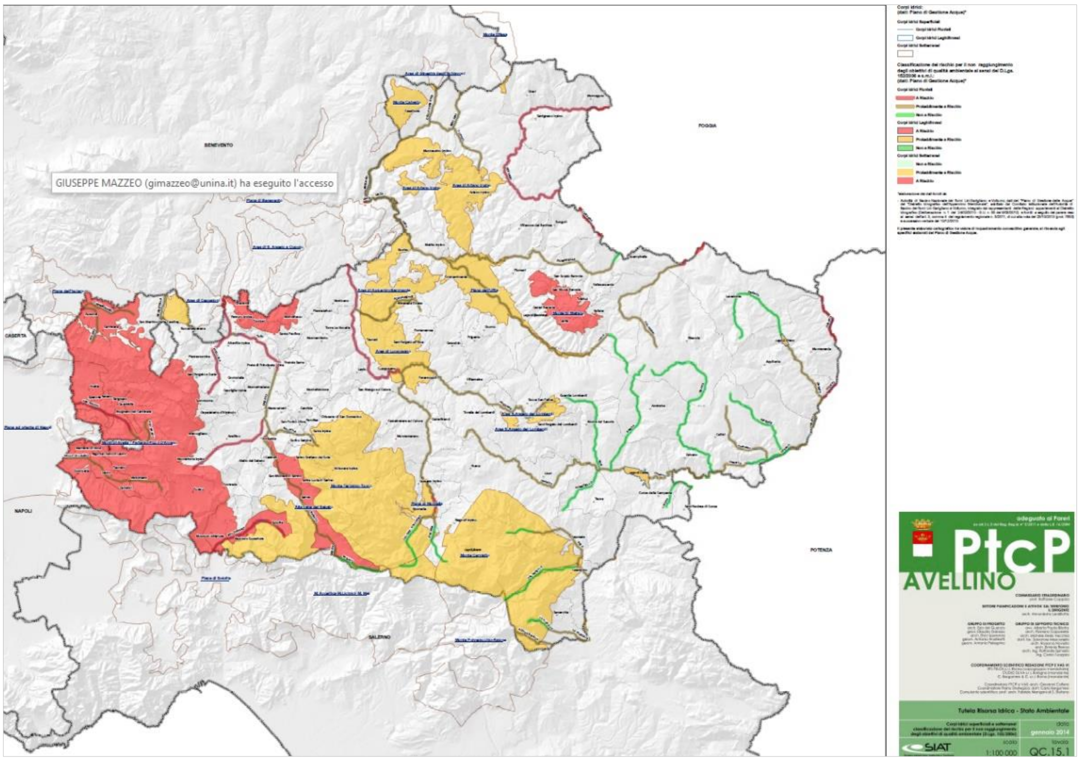

Fig.7 Regional Coordination Plan of the Province of Avellino. Table QC 15.1 "Protection of Water Resources, Environmental Situation". The table is based on data from the Water Management Plan of the Liri, Garigliano and Volturno River Basin Authority

These considerations are contained in the Territorial Coordination Plan (PTCP) of the Avellino Provincial Authority, approved in 2014. According to the Provincial Authority (2004), ensuring that people live better means offering them appropriate services, thereby avoiding depopulation of marginal lands and concentrations of population only in the largest urban areas.

The purpose of the plan is to organise the province so that the system of services and production activities operating within it can support the existing population and, if possible, lead it to increase in the future. To combat the demographic crisis pre-existing territorial strengths need to be enhanced and improved.

Interesting for the purposes of this paper are the PTCP guidelines in relation to the issues of energy, agricultural resources and water. Within the guidelines for compatible development of business and industry, one of the aims is energy saving to be implemented through three types of tools: integration in the plan of environmental improvement policies, and development of renewable sources; the development of guidelines to be implemented in municipal urban plans and building regulations (Gargiulo & Russo, 2017); identification of criteria and areas for implementation of energy districts.

The plan devotes specific attention to agricultural and agroforestry resources, sectors always considered by regional plans. In particular, the provincial plan serves to protect and enhance area resources (Mazzeo, 2021). In the case of the Avellino PTCP these objectives are the protection of the agricultural landscape and the development of responsible tourism.

The issue of water resources is less present in the plan (Fig.7). There is no mention of the strategic importance of such resources or of their representing the basis for the construction of policies to improve the environmental conditions of the population. When mentioned, the water issue is dealt with as a secondary theme, in support of other objectives. For example, when the plan suggests the creation of greenways it argues that ecological corridors to be conserved or strengthened are identified through a process of analysis of the hydrographic network. Furthermore, the plan states that "interventions can be designed by placing water, present in abundance along the entire network of the ecological corridors, at the centre of the choices and as a project variable. The characteristics of the area and the strong presence of water, in the form of waterfalls, springs, rivers, lakes, fountains, pools etc., creates the conditions for a 'environmentally sustainable' quality system. If water is life, waterways are the arteries of our province and of our landscapes" (Provincia di Avellino, 2014, 18).

The transition from description of resources to identification of projects to implement is further testimony of the scant consideration given to resources in the plan. Only two projects are concerned with the resources mentioned. The first are urban and energy redevelopment plans, which the Provincial Authority promotes for the benefit of municipalities. Starting from energy analysis of the urban fabric of the municipal area, the plans identify and encourage energy redevelopment of buildings and neighbourhoods (Provincia di Avellino, 2014, 105). The second group of projects concerns river redevelopment projects basically promoting tourism in the province, to be implemented with an action called "Irpinia: land of water".

4.2 New regional planning and the challenge of resources

Classical planning defines land use methods, urban loads, functions, and interrelationships between spaces and functions, with little attention to the impacts that such forecasts may have on primary area resources, such as water, food and soil. Such plans fail in these basic aspects: they lack a vision of the systemic impacts of sectoral policies, while a rigid system of actions and procedures persists, and they unfold along separate lines that do not intersect (Pahl-Wostl, 2017).

The need for a substantial change in pace is evident from the analysis of Avellino provincial planning (but the reasoning can probably be extended to many other plans). When preparing guidelines for management of a geographical area such as a province or region, effective evaluation of its own characteristics is of fundamental importance. Based on these, we structure the system of actions that is best suited to it. This is essential to avoid miscalculations that can lead to worse results than those we wish to rectify.

In an area such as Irpinia, the basic conditions require targeted actions able to achieve at least two important results. The first is to better preserve the system of existing resources, to be considered strategic because

they are used to obtain the necessary goods. To ensure that such resources continue to be used in the future, they must be taken into consideration in all land management policies and in all plans, from the regional level to the project level involving major environmental changes (Mazzeo & Polverino, 2023).
The second result would be to reverse the trend in depopulation and the reduction in existing services and in life quality (Friedman et al., 2023). In other words, it is necessary to interrupt the vicious circle of a declining population and the scrapping of services, which leads to the overall impoverishment of the province. To curb population loss, policies for inland areas need to be underpinned by a significant economic fabric. This means starting from the system of resources present in the province, to identify actions for resource conservation and enhancement, and to develop ongoing economic activities that can generate income, thereby reversing the processes of depopulation. At the same time, the limited usefulness of haphazard activities should be borne in mind: such action is able to concentrate attention on the environment for limited periods without translating into long-term benefits.
To this end, the FEW Nexus model can be useful thanks to its specific characteristics: systemic attention to three types of strategic resources; the highlighting of relationships between such resources; the ability to link resources and typical functions connected with regional planning, such as domestic and production sectors; finally, the ability to reveal how such resources may be connected with areas outside the province (Fig.8).

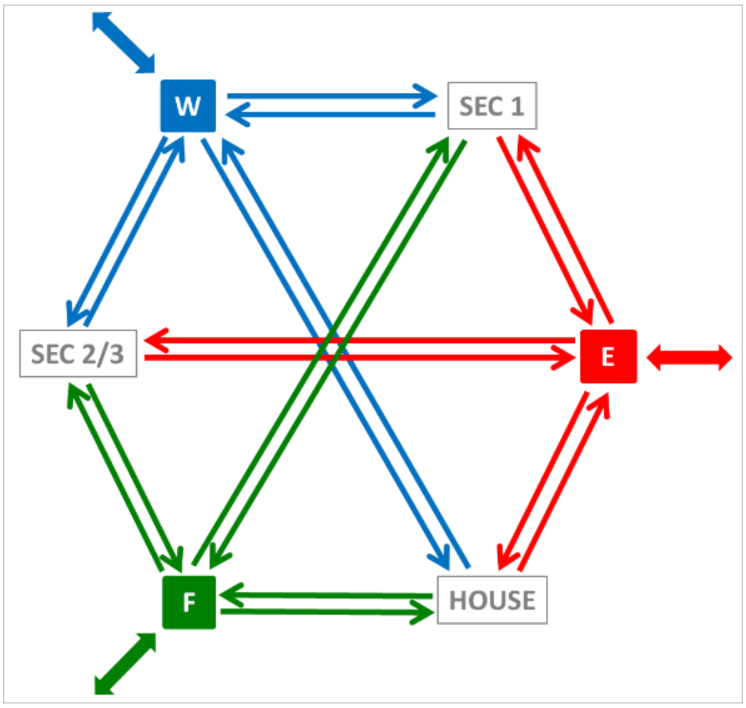

Fig.8 FEW Nexus model and relations with main planning sectors (house and economic sectors)

Redefining the connections between land use planning and natural resources entails giving new meanings to the plan (Fig.9). The latest generations of plans are distinguished by some specific characteristics such as landscape protection, soil consumption reduction or elimination, rewilding, urban regeneration, renewable energy production, and buildings with low carbon footprints.
All the above aspects are important for the plan to be able to confer greater sustainability. However, it is necessary to take a step forward and ascertain the possibility of the plan, with its general systemic vision, becoming the tool that sets the balance between consumption and natural resource use. If water, food and energy are three fundamental assets of an area, various situations can arise:

- the area exports all three resources;
- the area imports all three resources;

— the area is an importer of one or two resources; conversely, it is also an exporter of one or two resource types.

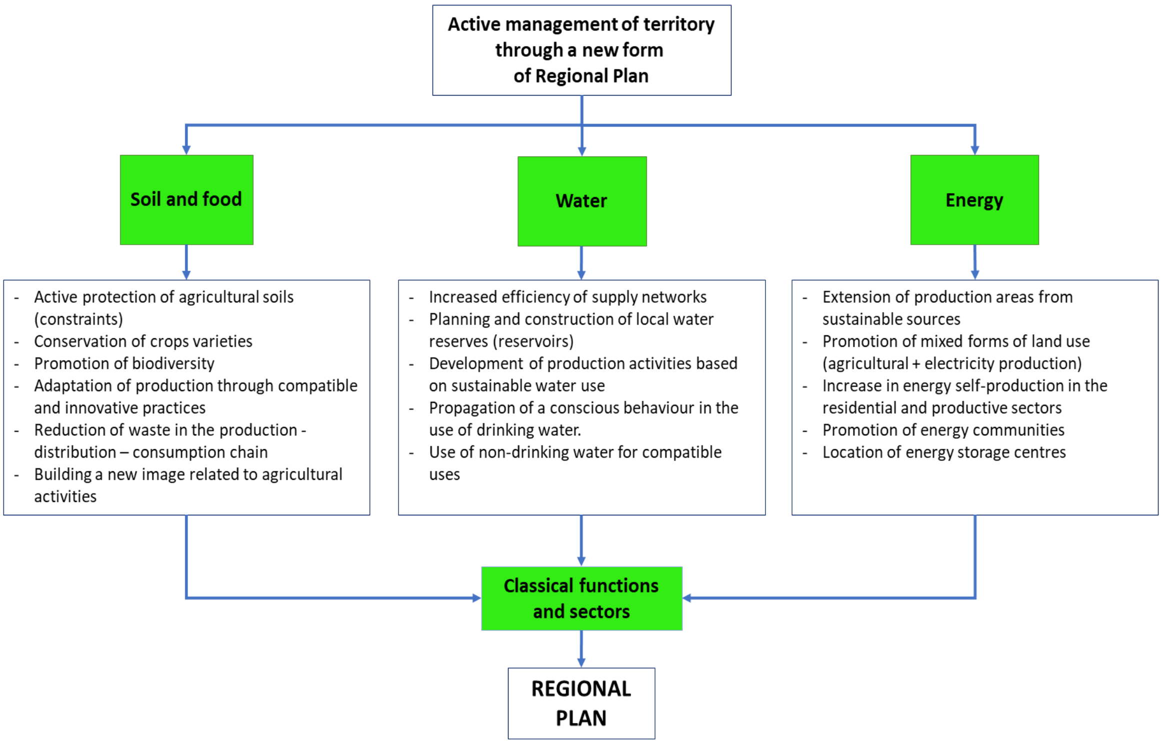

Fig.9 New strategic elements of the regional plan

In the various cases, the resources take on different values and affect land use differently. In any event, sound management of these resources becomes a strategic way to increase the area's resilience and reduce its overall carbon footprint.

Another aspect to consider is the need for the plan to envisage scenario analysis (Önkal et al., 2013; Meissner & Wulf, 2013). A plan devised today unfolds in the next decade; therefore, it needs to consider alternative development scenarios. Construction of such scenarios, based on the strategic resources present in the area, creates a new type of land use plan in which visions of the future are identified and worked towards through specific actions.

Active management of a region therefore means giving the right weight to new elements. They must be the backbone of land-use planning which will have to expand its range of action from the simple regulation of land use to the ways in which this use is brought about.

The new form of planning should be capable of achieving three objectives:

— increasing awareness of how the protection of natural capital can translate into an economic advantage and how it can affect settlement trends. Each of the components (water, soil, energy and others) has characteristics that can have a significant impact on the region and can lead to the construction of ecological districts that, in turn, can generate significant economic and settlement impacts;

— clarifying the meaning of natural resources, and modifying the perspective with which they are normally considered, especially highlighting the benefits resulting from usage patterns that contribute to resource enhancement and that have a positive impact on environmental sustainability, on the quality of the area in question and on liveability;

— drawing up guidelines to update land-use planning tools in terms of effective application of the principles of sustainability and neutrality of the local carbon footprint and as a contribution to the parallel process of decarbonisation (European Environment Agency, 2000; United Nations, 2015; Ulpiani et al., 2023).

5. Conclusions

The study represents an initial step in research intended to be developed in the near future. It requires theoretical and practical elaboration. The connection between food resources, energy, and water resources needs to be explored further with the aim of investigating the existing connections in relation to the following aspects: 1) the impact of climate change on these natural resources and 2) the ability to use climate change to modify behaviors, tools, and methodologies for sustainable resource utilization.

There is also a need to delve into the role of scenarios in constructing interrelationships. Scenarios, despite their inherent uncertainty, build knowledge that contributes to refining models for predicting changes. This knowledge can be directed towards the identification and test of a model of the relationship between resources that have so far been considered autonomous and analysed separately; the application of a systemic analysis, which involves exploring the relationships and intensity of flows generated due to these interconnections; and the investigation of the impacts of climate change on resources by determining the share of impact resulting from these interrelationships.

The optimal use of the natural resources of an area can represent the basis for building sustainable development strategies. Natural resources are strategic resources and will become increasingly vital over time. Their conservation, their careful use and their regeneration moves in the direction of EU policies for the enhancement of the natural heritage and decarbonization of the economy and urban areas.

Attention to such resources is highlighted on a scientific level by in-depth investigations performed by various fields of study such as the FEW Nexus model, analyses of natural capital and of ecosystem services. They testify to the growing importance of the link between the socio-economic structure and the physical basis for such resources, a link that allows land-use systems to continue evolving towards higher levels of sustainability.

Several insights may be drawn from the case study, based on in-depth analysis of the three systems considered by the FEW Nexus model. With regard to soil and agri-food production, the Irpinia case study shows a lower trend in soil consumption than that occurring in other areas of Campania. Yet the agricultural landscape needs to be preserved, as well as land not used for agriculture which is of fundamental importance for other resources (such as water). However, the Irpinia agri-food chain has further development potential, especially in eastern areas of the province. It is therefore necessary to investigate the characteristics and conditions for the development of new certified production areas, to be included in the national quality agricultural production system which represents a major part of the Italian economy (Basile et al., 2016).

The importance of water resources is evident, as is the need for them to be at the core of local and national policies. The water resources of the Irpinia basin should be subject to great care and attention. Yet they are still considered an infinite resource to be exploited in other areas, conferring few benefits on local communities and with little attention to distribution efficiency. Water is a resource used by millions of inhabitants in coastal Campania, as well as in Puglia and Basilicata, which represents natural capital that will become increasingly strategic with the exacerbation of climate change processes (Bates et al., 2008). Sustainable management of such resources means less water waste (both in extraction and in use), higher levels of safety and quality, and creation of innovative production systems in different sectors, from agriculture to tourism. It means using water where it flows, as well as where it is required. It is a strategic resource in terms of economic development and also of national geopolitics.

The management of water resources is closely linked to processes of climate change. The latter causes both direct effects (lowering of piezometric levels and decrease in flow rates) and indirect effects (infiltration of surface water and pollutants) upon groundwater resources. In addition, the rise in temperatures leads to an increase in consumption and hence greater extraction from aquifers. According to Ducci and Tranfaglia (2005), in this context, the management of drinking water resources in Italy and Campania (where in 2004 groundwater accounts for 86.4% and 99.7%, respectively, of drinking water) is a critical issue, since it must cope with increasing anthropogenic pressure, and hence with increasing drinking water demand, and with decreasing groundwater resources due to climate change.

Finally, energy production is to be considered a factor affecting development, like agriculture and water. Clean energy represents the future of this sector especially in consideration of the European policies to eliminate harmful emissions over the next few decades (European Commission, 2018). Clean energy already means new way to build communities (Gaglione, 2023) and energy autonomy for the province of Avellino. However, it could become a resource to be exported in ever greater quantities and to use for siting innovative production chains able to create a district economy in the area concerned.

Furthermore, international scenarios accentuate the strategic nature of the energy sector and the necessary national and European autonomy. Autonomy depends both on the reliability of suppliers and on the increase in production capacity from renewable sources. This second line of action is fundamental to reduce greenhouse gas emissions, hence to positively impact climate issues in the medium and long term, but it also plays a significant role in the freedom of action of a nation in moments of energy crisis.

Starting from in-depth knowledge of such systems and from the relationships existing between them and the area in which they act, new guidelines may be drawn up for regional planning, which must change to keep abreast of new attention to land use and to natural resources. Such planning for the near future must increasingly become strategic, changing from a static to a dynamic structure that accompanies evolving land use, employing tools for the various scenarios envisaged.

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Fig.1, 2: Author's elaboration;

Fig.3: Fiorillo & Ventafridda (2009);

Fig.4: Author's elaboration on data Campania Region, ATO-1 (2012);

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Circular and metabolic perspectives in urban contexts. Integrated flows analysis for an ecological transition

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Abstract

Recent European directives, including the "European Circular Economy Package" (2020), the "Farm to Fork" Strategy (2020), and the "Fit for 55" package (2022), focus attention on the issues of circular economy, security and sustainability of food production and reduction of emissions from anthropogenic activities. From this perspective, the study of urban metabolism is a useful approach to make local systems more resilient. In this regard, the intention is to emphasise the embedded commitment of territorial and urban planning to consider the current systemic components related to the flows that cross urban, peri-urban and rural territories, fostering the development of sustainable and circular supply chains capable of supporting an ecological, energetic and climatic transition. Therefore, this paper explores a methodology for the spatial analysis of urban contexts that take into account the main flows (water, energy, agri-food, and waste) that circulate and influence the transformation of the territory. In particular, thanks to the experience of the drafting process of the Territorial Plan of the Metropolitan Area (PTAV) of the Province of Rimini, it was possible to identify some methodological aspects useful for a trend shift towards effective actions aimed at the sustainable and circular management of local resources.

Keywords

Urban flows; Integrated flows analysis; Urban resilience; Ecological transition; Circular resources management.

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1. Introduction

Lifestyle and dynamics that characterise the current age require the adoption of a more efficient and sustainable use of natural resources, characterised by the minimization of waste production and environmental pollutants. Two complementary concepts stand among the main directions for sustainable territorial and city development: urban metabolism and circular economy.

Urban metabolism is an approach that compares urban agglomerations to organisms that, to live and support their functions, need resource flows as inputs, while producing, waste and pollutant emissions as outputs, in a typically linear logic and consistent with the principle of thermodynamics (Rocca, 2020; Lucertini et al., 2020). The analysis of the metabolism of urban systems enables decision-makers to manage the flows involved in a more responsible way to maximise benefits and minimise resource waste, thus promoting a transition from linear to circular and more sustainable systems.

At the same time, the circular economy model promotes a set of principles that guide companies, corporations and services, toward innovative development and business models according to which matter should be cyclically reused and regenerated, remaining within production cycles for as long as possible, minimising the outflows. The model not only generates tangible benefits and reduces raw material requirements and waste generation through eco-innovative solutions, synergies and symbiosis, new technologies and management agreements, but also encourages the recovery and reuse of new supply chains of secondary raw materials as an alternative to traditional ones (Amenta et al.; 2019; Ellen MacArthur Foundation, 2017).

The analysis and monitoring of cause-effect relationships between different urban flows has recently emerged as an innovative strategy for increasing synergy between urban cores and their surrounding areas, fostering processes of ecological transition and climate resilience (Colucci, 2015; Lucertini et al., 2022).

The need for urgent measures and actions to reduce emissions and face the effects of climate change, supporting the transition to circular approaches, is recognized and pursued at the community level, by tha main strategic plans and programs (Franco, 2023). The "Fit for 55" package, which aims to translate the ambitions of the Green Deal (EC - COM/2019/640) into legislation, proposes, in this regard, a series of climate, energy and transport measures. Meanwhile, the "European Action Plan for the Circular Economy" (CEAP - COM/2020/98) includes a wide range of initiatives to strengthen resource efficiency and long-term competitiveness, contributing significantly to achieving climate neutrality by 2050. It aims to modernise and make the EU economy suitable to support a green and inclusive future and protect the environment. It provides legislative and non-legislative measures for the entire product cycle, from design to recycling, to reduce the EU's overall production and consumption footprint and thereby contribute to the achievement of the Green Deal goals. The measures introduced under the Action Plan, in addition to aiming to improve the European regulatory part of sustainable products, aim to empower consumers and public stakeholders, enhance circularity and reduce waste in the sectors that use the most resources, such as electronics and ICT, batteries and vehicles, packaging, plastics, textiles, building and construction, in addition, the supply chains considered are also those of food, water and nutrients.

In this perspective, the research aims to identify a methodological process that can serve as a support to governments for future socio-economic and environmental development processes, through the integration of urban flow issues and the definition of innovative strategies aimed at pursuing the ecological transition and fostering circular approaches. This paper investigates a systematic approach to conducting spatial analysis of urban contexts that can be easily replicated and applied in urban planning. Such analysis takes into consideration key flows, such as water, energy, food, and waste, that circulate within urban areas and have a significant impact on the transformation of the territory (section 2), and then to move on to the experience conducted for the drafting of the Territorial Plan of the Metropolitan Area of the Province of Rimini (section 3). The last section provides an integrated reading of the main urban flows analysed to define a planning and management strategy that can evaluate and consider the entire cycle from a single metabolism perspective.

2. Materials and methods

The study of the interaction of urban flows, through the approach of urban metabolism and circular economy, helps the planning and development of strategies, plans and policies suitable to facilitate the ecological transition, thanks to a better knowledge of the processes in place and their negative externalities towards the environment (Longato et al., 2019; Bolger et al., 2019).

The main objective of both approaches is represented by the transition from a linear and unsustainable model, which generates waste according to the take-make-dispose logic, to a circular and regenerative model, capable of facilitating up-cycling processes and product life extension. In this system, biological flows should be reintroduced into the biosphere, while technical material flows should be valorized, reused, or recycled without causing environmental damage while minimising waste and increasing the efficient use of resources (Gusmerotti et al., 2020).

Requirements for urban metabolism studies, in fact, refer to inflows (water, construction materials, fossil fuels, electricity etc.) production (food, wood etc.), stocks (minerals, nutrients etc.) and outflows (air emissions, wastewater and solid waste) (Conke et al., 2015). The four major urban activities – to nourish and recover; to clean; to reside and work; and to transport and communicate – as identified by Baccini and Brunner (1991), are assessed in terms of four major components that are at core of urban metabolism: water, food (biomass), construction materials, and energy (Kennedy, 2010). This represents a basic accounting effort that can provide scientifically valid and representative data for urban planning.

The evaluation of these components shows the efficiency in resource use, its future need, the existence of any environmental burden, the contribution of recycling and the capacity of waste treatment, enabling a better awareness of how much impact human activity (social, economic and political) is causing in the natural environment (Brunner, 2007; Holmes & Pincetl, 2012). Furthermore, the scientific literature investigating these concepts at the spatial scale recognizes the importance of the WEF Nexus - Water, Energy & Food (Orimoloye, 2021), on which part of this research approach is based. The three sectors – water, energy, and food security nexus – are considered necessary to design inherent and interconnected future systems from the perspective of holistic spatial planning, which is also capable of considering potential synergies and critical conflicts to be addressed (Ahmadi et al., 2020; Varriale, 2018).

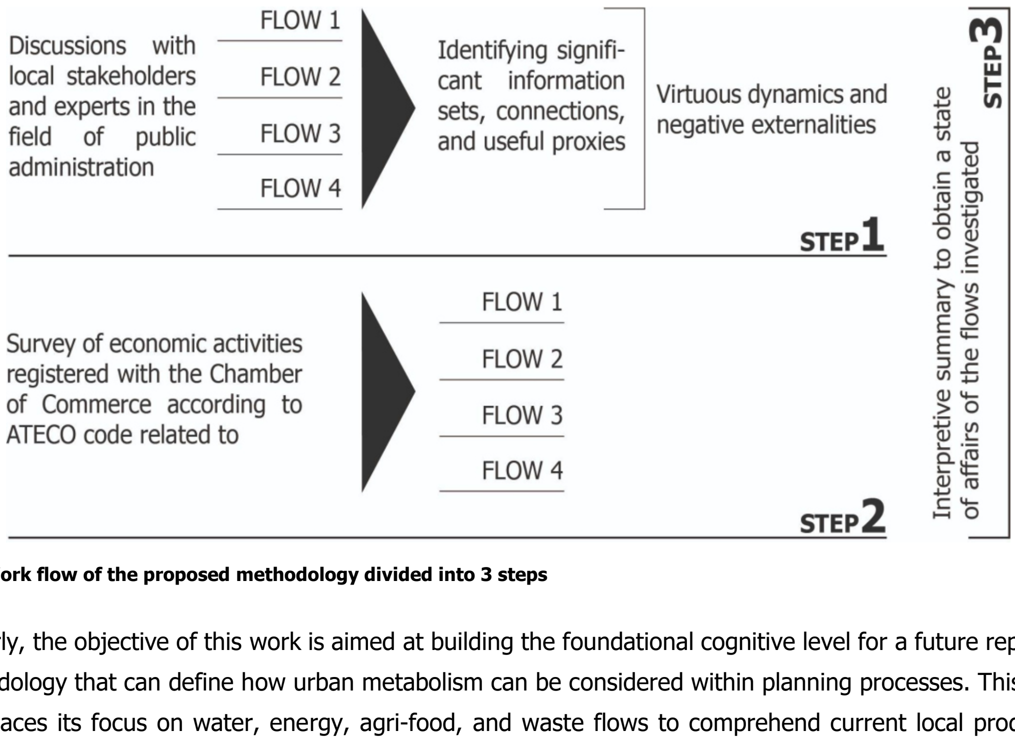

Fig.1 Work flow of the proposed methodology divided into 3 steps

Similarly, the objective of this work is aimed at building the foundational cognitive level for a future replicable methodology that can define how urban metabolism can be considered within planning processes. This study also places its focus on water, energy, agri-food, and waste flows to comprehend current local production processes and practices and to direct virtuous transition processes. The decision to restrict the analysis to these four primary flows was a direct request from the involved public administration, partly due to practical considerations related to managing data and information, thus ensuring a streamlined and reproducible process in analogous contexts. The study's execution is, therefore, structured into three steps designed to guide the process and ensure enhanced replicability.

2.1 Step 1

Discussions with local stakeholders and experts in the field of public administration involved allowed the initial study of usable spatial information to be contextualised, highlighting capitalizations and potential synergies with existing survey initiatives. For each flow, some significant sets of information are identified for connections and useful proxies to identify virtuous dynamics and negative externalities on the territory. Furthermore, the vector format of the spatial database chosen for evaluation is capable of collecting and processing different attributes useful for the spatial analyses under consideration.

Flows	Elements	Attributes
Water	Wells and springs	Withdrawals, extractions, ...
	Water consumption	Quantity by municipality, use, civil sector, ...
	Sewage treatment plants	Quantity/quality in terms of pollutants ...
	Distribution/disposal infrastructure network	Linear kilometres, white/grey/black network, ...
	Hydrographic network	Linear metres, monthly average level, ...
	Land-based water storage (reservoirs/natural reservoirs, dams, etc.)	Storage capacity, average monthly level, area, gross volume, ...
	(...)	(...)
Energy	Non-renewable energy systems	Type, amount of energy produced/year, plant emissions, ...
	Renewable energy systems	Type, amount of energy produced/year, ...
	Energy consumption	Quantity by municipality, use, sector, ...
	Non-renewable civil heating systems	Type, amount of energy/year, plant emissions, ...
	(...)	(...)
Agrifood	Livestock farming	Type, no. of cattle, ...
	Farmhouses, restaurants, bars	Type, no. beds, no. covers/day, services, ...
	Food and beverage processing, preservation and production industries	Economic activities, no. of employees, economic capital, ...
	Farms	Crop type, organic/non-organic, marketable production, ...
	(...)	(...)
Waste	Waste facilities	Type (EWC), quantity of waste treated, ...
	Waste production	Type, amount of waste (by municipality and/or per capita), ...
	Sorted/differentiated waste	Type, quantity of waste output by municipality, ...
	Local composting activities	Utilities, ...
	(...)	(...)

Tab.1 Potential components for each flow considered

2.2 Step 2

At the same time, a survey was conducted for the (4) urban flows of related economic activities registered with the Chamber of Commerce according to ATECO code. This step required a prior matching matrix with the grouping of consistent activity codes by flow.

Flows	ATECO code	ATECO Denomination
Water	36.00.00	- Water collection, treatment and supply
	37.00.00	- Wastewater collection and purification
Energy	35.11	- Electricity production
	35.12	- Electricity transmission
	35.13	- Electricity distribution
	35.14	- Electricity trading
	35.21	- Gas production
	35.22	- Distribution of gaseous fuels by pipeline
	35.23	- Gas distribution by pipeline
Agrifood	01.4	- Animal husbandry
	01.50	- Agricultural crops associated with animal husbandry: mixed activity
	10.1	- Processing, preservation and production of meat
	10.2	- Processing, preservation and production of fish, shellfish and molluscs
	10.3	- Processing, preservation and production of fruit and vegetables
	10.5	- Processing, preservation and production of dairy products
Waste	38.11.10	- Non-hazardous solid waste collection
	38.12.10	- Hazardous solid and non-solid waste collection
	38.21	- Non-hazardous waste treatment and disposal
	38.22	- Hazardous waste treatment and disposal
	38.32	- Material recovery and sorting
	39.00	- Remediation activities and other waste management services

Tab.2 Analysis of ATECO codes for the analysed flows

2.3 Step 3

The performance of the first steps lay the preconditions for an interpretative synthesis of the (4) cognitive frameworks to obtain a state of the art of the investigated flows.

The comparison and systematisation of the selection of usable spatial information allow a comprehensive picture of the analysed context as well as an interpretive synthesis framework for circular management. In this sense, the integrated reading of the main urban flows, which is useful for the evaluation of management strategies capable of considering the entire cycle from a single metabolism perspective, allows the construction of an interpretative and synthesis framework in which complexity can be translated into perspectives of change to direct and convey sustainable and circular management of the territory.

3. Results

The approach on which the experience conducted within the Province of Rimini is based, for the drafting of the Territorial Plan of Metropolitan Area (PTAV), involves different aspects of the life of cities and territories, to ensure a transversal and innovative contribution. In line with the regional law Emilia Romagna 24/2017, the process of identifying and analysing the (4) main urban flows – water, energy, agri-food and waste – contributes to initiating effective actions compatible with the preservation and recovery of urban and environmental heritage. More in detail, the approach pursued is based on an in-depth knowledge of the territory and the different components related to the 4 flows, closely related to the circular economy paradigm and urban metabolism, to support the definition of innovative and conscious spatial policies and strategic objectives.

For each flow chosen, as suggested by the methodology identified, significant sets of information were identified, capable of identifying the different attributes useful for the territorial analyses of Rimini Province (Tab. 3). In addition, the different economic activities registered with the Chamber of Commerce according to ATECO code referring to each urban flow analyzed were identified (Fig. 2).

Flows	Elements	Source	Attributes
Water	Wells (119)	ARPAE Emilia-Romagna	Localization
	Springs (44)	ARPAE Emilia-Romagna	Localization
	Sewage treatment plants	ARPAE Emilia-Romagna	Localization, type
	Hydrographic network	PTCP Rimini 2007, Variant 2012	Type
Energy	Energy installations (25)	ARPAE Emilia-Romagna	Location, type, manager
	Electricity consumption	ARPAE Emilia-Romagna	Civilian consumption, industrial consumption, transport sector consumption at municipal scale
Agrifood	Livestock farming (34)	Sustainable Agriculture Sector, Emilia-Romagna Region	Location, type, species raised, number of animals, amount of nitrogen emissions/storage
	Farmhouses (71)	Agritourism Sector, Emilia-Romagna Region	Location, type, number of rooms, number of beds, number of meals/year, type of courses/activities offered
	Food processing, preservation and production industries	ATECO – Chamber of Commerce	Location, type of business, number of employees, economic capital
	Farms (10)	ATECO – Chamber of Commerce	Location, type of business, number of employees, economic capital
Waste	Waste facilities (72)	ARPAE Emilia-Romagna	Localization, type
	Total waste generation	ARPAE Emilia-Romagna	Waste production by CER, quantity of separated, undifferentiated and total waste production at municipal scale

Tab.3 Components analysed for each flow considered

The analysis conducted for the water flow (Fig. 3) shows that the Rimini area has a consistent concentration of wells in the coastal strip (119). At the same time, the inland part is characterised by several springs (44). The lower number of springs is also due to the limited presence in Emilia-Romagna of karst formations, which represent just 1% of regional outcrops. Regarding the withdrawal of the water resource from water bodies, the data for civil use count for the year 2012, 4.32 mm^3/year (ATERSIR, 2018), while water consumption amounts to 31,875,602 m^3/year (ISTAT, 2020) with the prevailing sector being the domestic sector, which contributes more than half of the withdrawals, followed by the industrial, hotel and public establishments sectors.

Spatial planning for sewerage and water purification for the purpose of water protection is based on the agglomeration concept, which is under the responsibility of the Province, which exercises them in close collaboration with the municipalities concerned and ATERSIR. By resolution of the GR no. 201/2016, the Region redefined the delimitation of the agglomerations homogeneously over the territory, identifying in the Rimini area 131 agglomerations, for a total of 877,851 population equivalent served (p.e.), of which five main ones, with a consistency of more than 2,000 p.e. (Novafeltria; Bellaria - Igea Marina; Riccione; Cattolica - Misano -

Val Conca; Rimini - Val Marecchia - San Marino) with a service coverage of about 90%. It appears interesting to note that the remaining part of the resident population lives in isolated nuclei (0.9%) or in scattered houses (9.1%), not served by public sewerage, for a total of about 30,500 equivalent inhabitants.

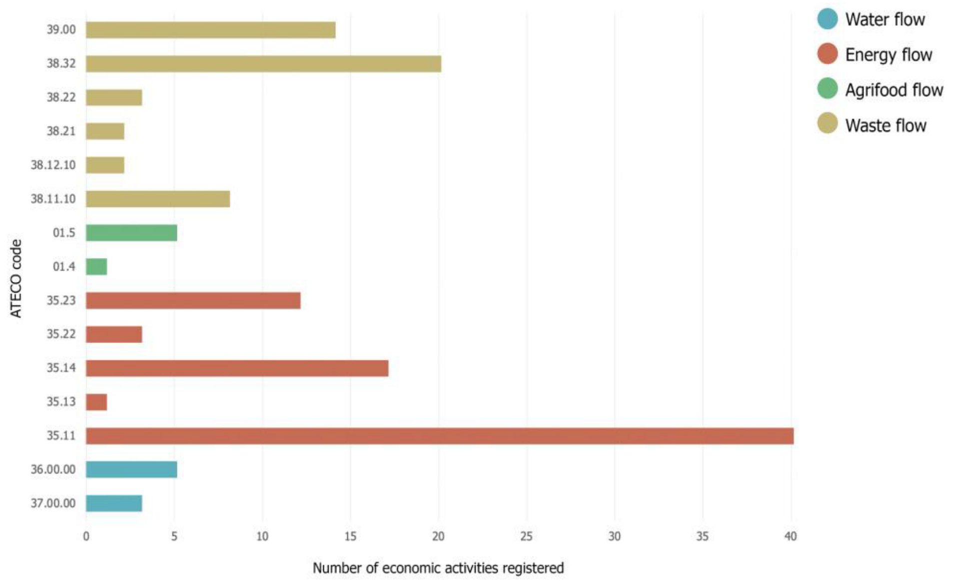

Fig.2 Histogram of economic activities registered with the Chamber of Commerce for the analysed flows. Identification of different economic activities registered with the Chamber of Commerce according to ATECO code referring to each urban stream analyzed. It emerges that the largest number of economic activities registered are those related to the energy and waste sector

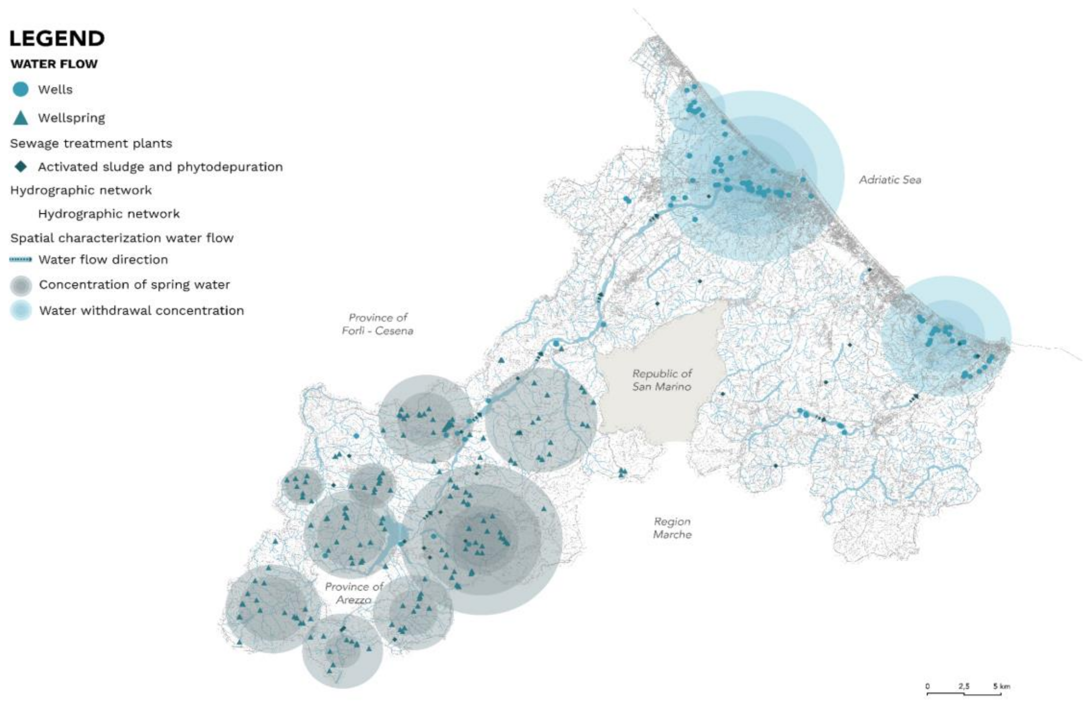

Fig.3 Metabolic flow of water system. In the figure there are point and linear elements and also interpretive elements, namely those falling under the category of "spatial flow characterization"

About the distribution of the collection network, the total extension of the sewerage network of the Rimini sub-area, in the year 2012, is about 2,324 km, divided into white network: 722 km, black network: 856 km, mixed network: 746 km. As for wastewater treatment systems, five main agglomerations are found to have more than 10,000 AE distributed along the coastal strip, while one is between 2,000 and 10,000 AE. There are also agglomerations below 2,000 AE, distributed mainly inland, which deliver urban wastewater to centralised sewage treatment plants equipped with Level 3 treatment. Almost all of the public sewage system conveys wastewater to such plants, while minimal fractions are served by small 2nd-level or phytoremediation plants. Level 1 treatments (Imhoff pits) also serve a marginal portion of the population (0.5%). Isolated cores and scattered houses outside agglomerations and served by individual sewage systems remain excluded from purification, with an incidence of about 30,500 inhabitants.

The territory under study has a good endowment of infrastructure in the area, which allows for the assumption of additions aimed at pursuing greater environmental sustainability (ATERSIR, 2018). In addition, the total number of economic activities registered with the Chamber of Commerce according to ATECO code for water flow amounts to 4 activities.

Regarding the energy issue, energy consumption related to the year 2021 was 295,702.9 GWh, split between industry (46% of total consumption), domestic sector (23%), services (29%) and agriculture (2%) (Fig.4a). The availability of energy sources is largely derived from imports: total energy production amounts to 291 GWh (Fig.4b), with about 191.9 GWh produced from renewable sources, including photovoltaics (56.8% of total provincial renewable production) and bioenergy (39.8%). In contrast, thermoelectric production amounted to 175.4 GWh, with 48.6% of the total from non-cogenerative plants, i.e., plants that do not jointly produce electricity and heat for technological uses or district heating.

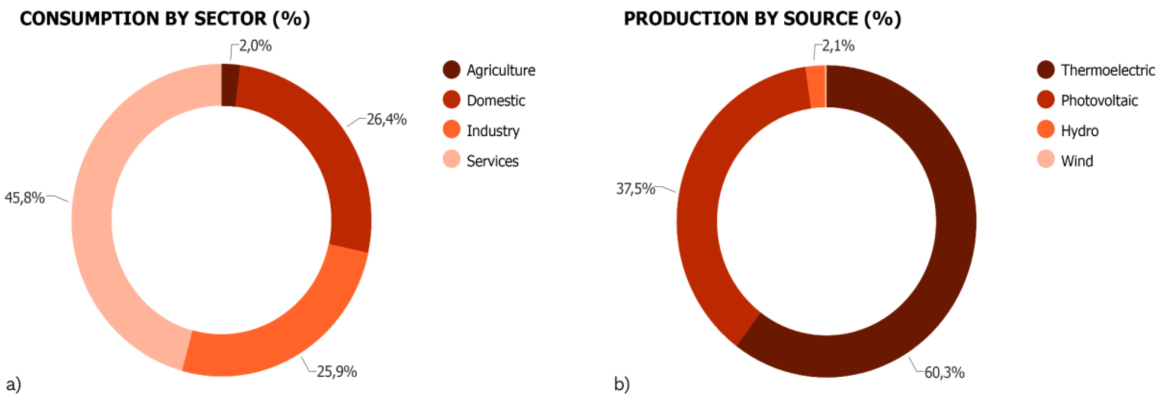

Fig.4 Electricity consumption by sector (a) and electricity production by source (b) of Rimini Province

Among thermoelectric power plants with cogeneration, as of 2021, there were 85.2 GWh produced by condensing plants, 61.8 GWh produced by internal combustion plants with cogeneration, and 28.5 GWh produced by gas turbines. In the province of Rimini, production from renewable sources (RES) relative to 2021 was 191.9 GWh; among these, production from bioenergy (76.3 GWh) and photovoltaic plants (109.0 GWh) stand out. In particular, for the gross output of installed photovoltaic systems, there is an increase in the two-year period 19-20 of 5.8%, which is higher than the regional average of 3.9% and equal to about 5 GWh. Regarding the number of systems present, as of 2020, there are 7,138 photovoltaic systems in the province (+7.8% compared to 2019) with a total installed capacity of 98.7 MW, (+4.3 MW) (TERNA, 2021). The provincial capital is the leading municipality in terms of total thermal and electrical energy consumption, followed by the municipalities of Riccione and Bellaria-Igea Marina. The municipal contexts of the coastal axis show higher total consumption than the inland areas, consistent with the different distribution of seasonal populations in the province. Regarding Rimini's energy infrastructure system, there are 25 power generation plants (ARPAE, 2021), discretely distributed throughout the territory (Fig. 5). In particular, (1) a wind power plant in the municipality of Casteldelci; (1) a geothermal plant in the municipality of Cattolica; (12) hydroelectric plants (>50 kW); (6) biomass thermoelectric plants; (4) fossil fuel thermoelectric plants; and (1) waste-to-energy plant in the municipality of Coriano.

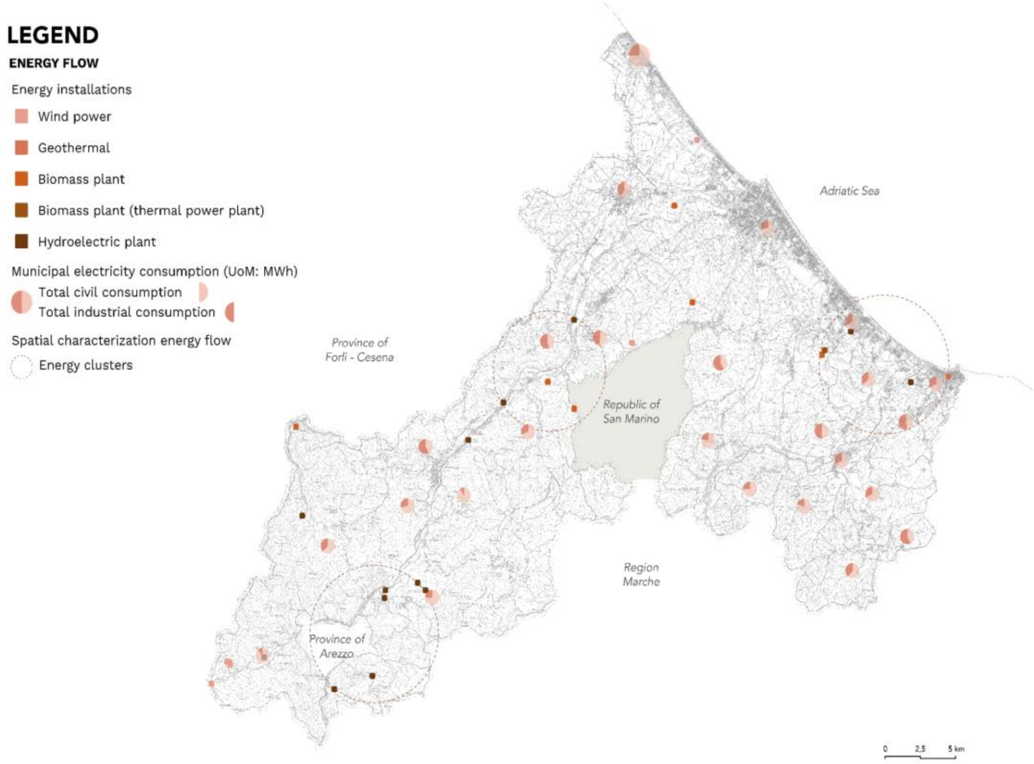

Fig.5 Metabolic flow of energy system. In the figure there are point and areal elements and also interpretive elements, namely those falling under the category of "spatial flow characterization"

The agri-food system is characterised by a balanced distribution over the territory (Fig.6), except for the coastal strip where economic and environmental dynamics strongly reduce the presence of agro-rural land uses. In a context characterised by a vocation for tourism, the presence of agri-tourism is distributed throughout the territory (71 total), with the greatest concentrations in the peri-urban areas, more accessible to the coastal system.

In general, the Rimini area is based mainly on several economic activities dedicated to livestock breeding (34) registered with the Chamber of Commerce according to ATECO code. Given the total number of livestock raised, poultry farms appear to be the most substantial (with about 342,627 heads), located especially in the belt in front of the hilly foothills, followed by pig farms (5,444 heads) and rabbit farms (4,500 heads). The few large farms (10) are mainly located in the belt facing the hilly first fifth while, near the coastal belt, a large presence of small farms characterises the area. Even in the mountainous area, the business categories are still similar, with a prevalence of small to medium-sized farms in the area, a positive feature of the entire territory that ensures a closer and more direct relationship between the rural and urban worlds. Moreover, regarding the agricultural context, it was noted that the back-coastal belt has predominantly traditional farming, while in the mountainous areas a much larger presence of organic farms.

This difference in production systems between the mountainous hinterland and the lowland agricultural territory can be explained taking into consideration two factors in particular: on one hand, a greater vulnerability of hilly areas to the phenomena of erosion and mineralization of soils related to the use of chemical synthetic fertilisers instead of the use of organic fertilisers capable of increasing the physical and mechanical properties of the soils; on the other hand, an insufficient conventional production in the most inaccessible areas to guarantee the income of farmers, who must necessarily opt for new management trajectories capable of guaranteeing a sustainable income for their activity.

Also very significant is the conversion of farmland to organic farming techniques, and the municipalities with a greater presence of organic practices are concentrated in inland areas, along valleys characterised by lower tourist attraction and strong agricultural vocation. The municipalities of the province tend to show processes of organic growth to the detriment of traditional practices that deplete local resources such as soil, except for urban contexts such as Cattolica, Bellaria – Igea Marina, Misano Adriatico and Morciano di Romagna, which are found to have a reduced presence of organic cultivation practices.

Fig.6 Metabolic flow of agri-food system. In the figure there are point elements and also interpretive elements, namely those falling under the category of "spatial flow characterization"

In the context of territorial policies aimed increasingly toward a circular and sustainable economy aimed at the more efficient use of resources, sustainable waste management plays a key role as it reintroduces resources into the local market. With this in mind, it becomes essential to respond to the needs emerging from sector planning, through an adequate infrastructure system based on recovery facilities capable not only of supporting the growing flow of separate waste collections but also of withstanding dependencies on foreign markets, with the support of local disposal facilities.

The province of Rimini has (72) waste management facilities, contributing in 5% to the regional system (ATERSIR, 2020a). The infrastructure system (Fig.7) consists of plants capable of meeting the treatment/disposal needs of undifferentiated waste and special waste, making the area self-sufficient (ATERSIR, 2020b).

Among the types of treatment plants present are treatment plants (70), divided into mechanical treatment (TM) plants, by which waste is screened to separate its different commodity fractions and/or conditioned to achieve process objectives, or, in the case of secondary solid fuel production, product performance; biological treatment (TB) plants, aimed at achieving mineralization of the most degradable organic components (stabilisation) and sanitization of the output waste; and mechanical biological treatment (TMB) plants. There is also a composting plant (1), for the management of the selected organic fraction, and a municipal solid waste incinerator (1) (WTE), operated by Hera S.p.A. In addition to being subjected to continuous supervision, the plant is included in the Region's environmental monitoring program named "*Moniter*".

The coastal zone shows a higher production of sorted municipal waste than the backcountry context, consistent with the higher population density and tourist attractiveness. The strong tourist attractiveness concentrated on the coast greatly accentuates the pressure on natural resources and waste generation, which is higher in the coastal zone than in the backcountry context. The study shows that waste is sorted more in the coastal areas than in the hilly areas, so much so that some inland municipalities (9) do not carry out separate collection services due to the fragmented management of the collection service, which implies different collection modes depending on economic feasibility. It can be seen that in such contexts the production of the undifferentiated fraction is significantly higher in absolute values, despite the clear disparity in resident population. On the contrary, it is evident that some urban waste flows, which have long been initiated to separate collection, such as paper, glass and wet waste, are more widespread and consolidated than others.

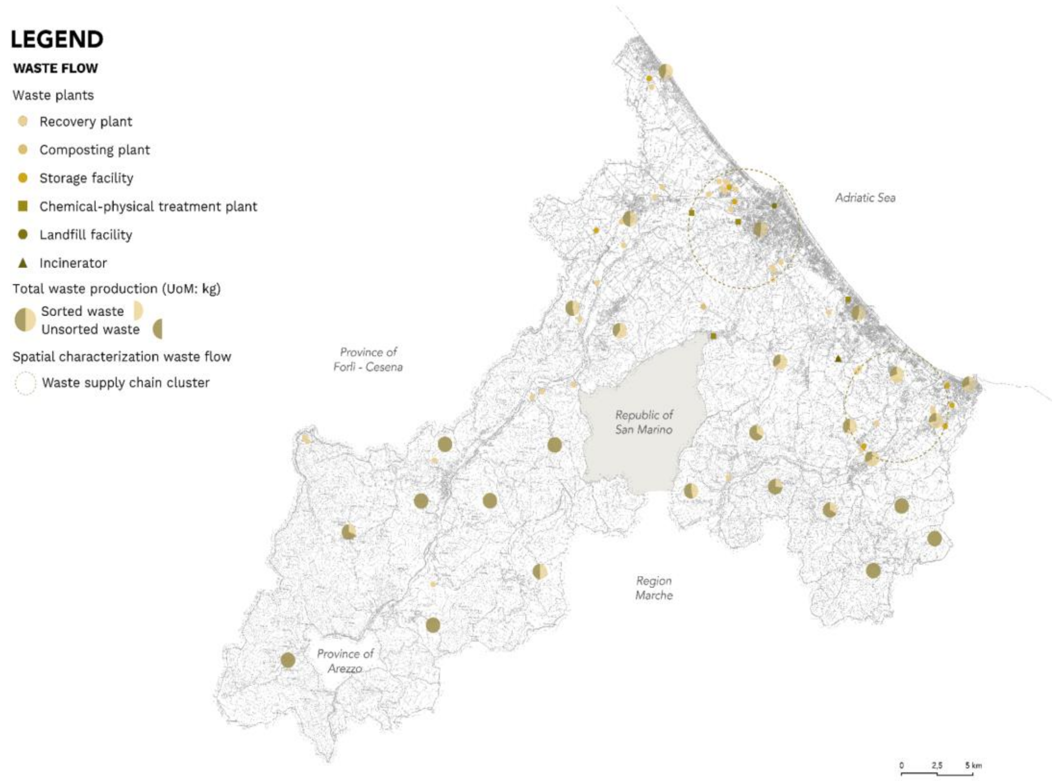

Fig.7 Metabolic flow of the waste system. In the figure there are point and areal elements and also interpretive elements, namely those falling under the category of "spatial flow characterization"

In general, the system is characterised by a network of flows sufficiently distributed throughout the Rimini area (Fig.8). In the coastal strip, where the economic dynamics are characterised by a high vocation for tourism, a higher concentration of water withdrawal is denoted, to the detriment of the concentration of spring water present in the hilly first-fifths. Concerning the spatial characterization of energy flow, civilian consumption is found to be greater than industrial consumption, while clusters related to the agribusiness chain are found to be distributed throughout the territory, with a greater presence in peri-urban areas. In addition, areas near the coast are characterised by higher waste production, consistent with higher population density and tourist influx.

4. Discussion and conclusions

The objective of this paper was to test a replicable methodology for spatial analysis of contexts that would take into account the investigated flows such as water, agri-food, energy and waste, which affect land transformation. The experimentation allowed the identification of the system and areas for flow management, preparing a cognitive framework useful for urban management strategies. The intention was to assess the local supply chain from a circular perspective capable of answering questions concerning "*how*," "*where*" and "*to what extent*" to act to enhance resources and undertake virtuous paths of sustainability, in the province of Rimini.

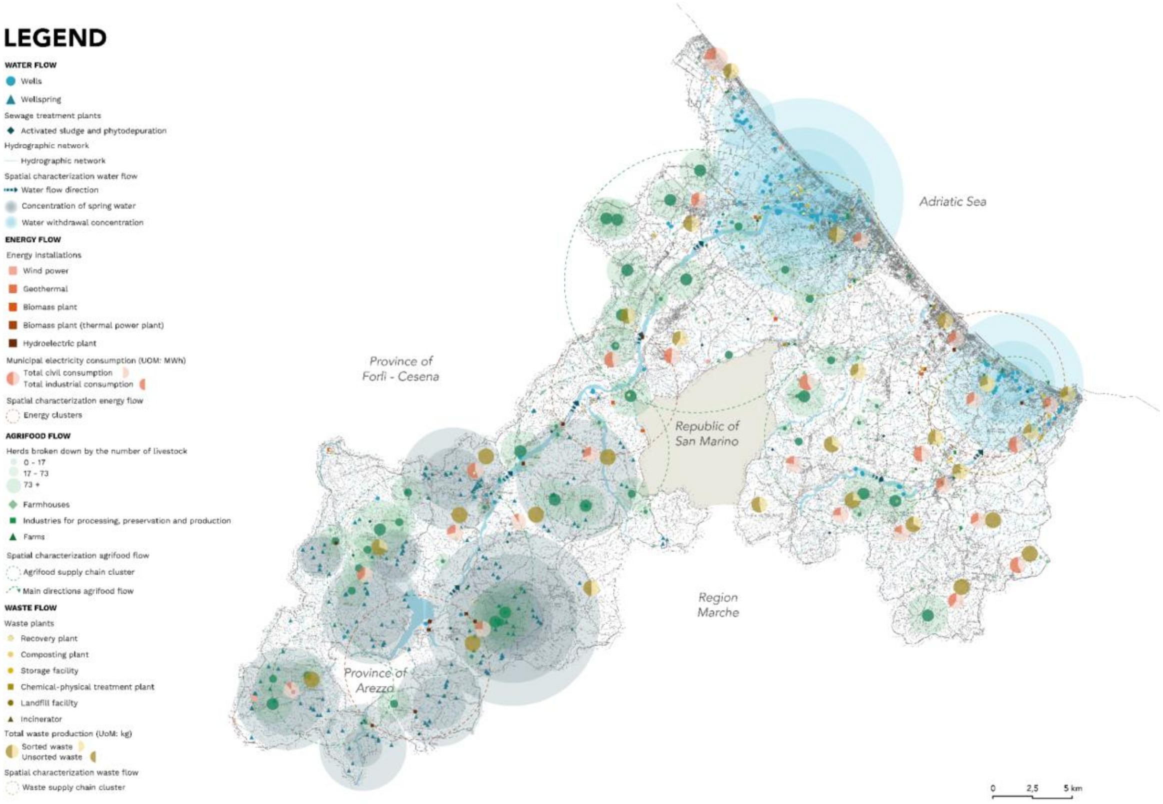

Fig.8 Overall analysis of urban metabolism related to the (4) flows analysed. The overall analysis of urban metabolism related to the four flows analyzed refers to a detailed examination of how a city functions in terms of the use and exchange of key resources, namely water, energy, food and waste. This type of analysis focuses on a comprehensive understanding and visualization of how these flows affect the urban environment as a whole

This contribution highlights some gaps and critical issues in the flows analysed, which are incomplete or partial and therefore do not allow an exhaustive and in-depth analysis. Despite the close collaboration with local government, the approach shows the need to provide itself with recent and detailed information data capable of rendering a static process into a dynamic system.

This contribution highlights some gaps and critical issues in the flows analysed, which are incomplete or partial and therefore do not allow an exhaustive and in-depth analysis. Despite the close collaboration with local government, the approach shows the need to provide itself with recent and detailed information data capable of rendering a static process into a dynamic system.

Consistent with this, the (4) flows investigated show data and information bases that could have more detail and be more useful in providing a circular approach, in terms of quality and quantity of extracted resources.

In a condition of uncertainty, there is an increasing need to prepare integrated management that provides for the active participation of stakeholders and ensures technical-specialist support for policy decisions, especially in critical emergencies resulting from climate change.

It seems interesting to note for the flow of water a fragmentation in the management of the service with repercussions in the balance between surface water and groundwater: the reclamation consortia manage the surface water withdrawal phases while the control and management of groundwater withdrawal is assigned to other entities. This subdivision causes conflicts to the qualitative and quantitative aspects, in view of climate change that sees a negative alteration of rainfall and the degree of groundwater recharge.

What has been illustrated helps to recognize the need for adaptive resource management, based on detailed knowledge of the availability and usability of local resources over time and space. Another aspect is being proactive and thus based on the ability to act consciously and responsibly with preventive actions in the presence of events that could affect availability and quality. This underscores the importance of proceeding with an integration of the metabolic approach into the decision-making and implementation tools in terms of policy and instruments, arriving earlier than decisions. Indeed, the collection of information, which underlies and is a prerogative aspect, requires that there be coordination in the form of both typological and temporal collection. This is to allow the complexity of studying metabolism, which involves the simultaneous integration of different information bases, to facilitate governance tools and local policies to act in a preventive and circular form. Especially in a scenario of ecological, climate and energy transition, it is important to be able to provide usable indications consistent with the principle of anticipation.

Very useful is the presence of a supra-local coordinating body capable of bringing together the collection of available data and information, much of it of a point type, then providing for their integration. In this sense, the PTAV is a favoured effort as it can hold together various data at the territorial level. In section 2 of our study, we emphasized that the choice to limit the analysis to the four main streams-water, energy, food, and waste-was made in response to an explicit request from the government involved. This choice was also motivated by practical considerations related to the management of the data and information needed for the analysis. The goal was to ensure a streamlined and replicable process that would also be suitable for use in similar contexts. Reducing the number of streams considered greatly simplifies data collection, processing and interpretation, enabling a more manageable approach to urban planning. This limitation has proven to be extremely useful in providing clear and easily interpretable results for public administration.

However, it is important to note that urban metabolism can involve a wide range of flows and sectors, in addition to those previously mentioned. Therefore, a future perspective might be to extend the proposed methodology to support the analysis of these other flows. This would provide a more comprehensive and detailed understanding of how the city functions and could be particularly valuable in situations where the complexity of the system requires a broader view. The flexibility of the methodology allows the interaction of the analysis with other flows, thus contributing to even more sophisticated and integrated urban planning.

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Image Sources

Fig.1: Author's elaboration;

Fig.2: Author's elaboration based on data provided by the Chamber of Commerce, 2022;

Fig.3: Author's elaboration for the Rimini Province PTAV drafting process;

Fig.4: Author's elaboraion based on data provided by TERNA Driving Energy, 2021;

Fig.5 to 8: Author's elaboration for the Rimini Province PTAV drafting process.

Table Sources

Tab.1: Author's elaboration for the Rimini Province PTAV drafting process;

Tab.2: Author's elaboration based on data provided by the Chamber of Commerce, 2022;

Tab.3: Author's elaboration for the Rimini Province PTAV drafting process.

Author's profile

Katia Federico

Katia Federico, Urban and spatial Planner. Research fellow at the Iuav University of Venice. From June 2021 she starts her research and urban planning support activities within the Planning and Climate Change LAB of the Iuav University of Venice, on issues related to climate change and circular economy. In particular, he carries out in-depth studies on the mapping of the vulnerability of rural territories to the impacts of climate change related to the Emilia-Romagna Region; technical support in the drafting of the Metropolitan Plan of the Province of Rimini, through the processing and metadata of spatial data, development of graphic designs and particular support in the drafting of contents and elaborations inherent to urban metabolism and circular economy, studying and planning the territory through the approach of the circularity of metabolic flows. She is currently carrying out research activities with a research grant developed in collaboration between Iuav and ENEA, entitled: "Circular economy and resource governance in the urban-periurban relationship," which aims to study how the circular economy approach can be translated and applied to the territory, to the flows of resources necessary for urban and peri-urban management.

Gianmarco Di Giustino

Gianmarco Di Giustino, Urban planner and PhD student in urban and territorial planning at the Iuav University of Venice and part of the Iuav Planning Climate Change LAB. Since 2019 he has been collaborating on different national and international research projects on spatial planning with a particular focus on the topics of circular economy, NbS and sustainable development with attention on socioeconomic impacts. In his current research activity, he is involved in projects and working groups, for which he deals with spatial planning and public policy programming about resilience challenges and environmental vulnerability. His PhD research project aims at deepening the knowledge relating to how planning and public policies can facilitate the process of ecological transition, and more generally the conservation of the ecosystem and biodiversity; the reduction of the impacts on the economic chains of climate change and the promotion of sustainable development.

Elena Ferraioli

Elena Ferraioli, Architect and PhD student in urban and territorial planning at Iuav University of Venice. Since January 2020 she has been collaborating in several Italian and European research projects on spatial planning with a particular focus on the topics of circular economy, urban metabolism and ecological transition. In her current research activity, she is involved in projects and working groups, for which she deals with urban and spatial design and planning in relation to issues of territorial resilience, regeneration and environmental fragility in relation to climate change. Her PhD research project aims at the regeneration of peri-urban and post-industrial areas through the implementation of Nature-based Solutions and the application of circular economy principles.

Giulia Lucertini

Giulia Lucertini, assistant professor in rural and agricultural appraisal, PhD in valuation and local economics (University of Padua) and in "aide à la decision" (Université Paris Dauphine). From 2021 she became an assistant professor at the Iuav University of Venice, at the Department of Architecture and Arts. In this period she deals mainly with evaluation and analysis of projects and public policies aimed at climate change adaptation, and resilient spatial planning between urban and rural environments. In recent years, she has also worked on the circular economy and urban metabolism linked to land use and rural activities for a more sustainable and regenerative exploitation and consumption of natural resources, with particular attention to local food policies and more generally local agriculture.

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Special Issue 2024

Urban Inequalities

(Floriana Zucaro)

(Under publication)

The unavoidable current and near-future challenges also contribute to widening the historically existing inequalities between different countries and, at the same time, generate additional ones even within the same state or city. At the urban level, these disparities are due also to the diversity of access to services, infrastructure, and urban places, as well as the origin from a specific territorial area. The reduction of socio-spatial inequalities constitutes the tenth Sustainable Development Goal (SDG) "Reduce inequality within and among countries" within the United Nations 2030 Agenda. The pursuit of this goal requires rethinking and redesigning territories and cities through transformative actions and interventions predicted by urban and spatial planning tools too. In this perspective, TeMA Journal aims at fostering the international scientific debate by welcoming interdisciplinary works about the topic of social inequalities. The TeMA Special Issue will collect papers aimed at answering the questions by providing new approaches, methods, tools, techniques and innovative practices to support policy- makers in preventing and reducing socio-spatial inequalities.