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Climate crisis and spatial planning

Green infrastructure and supply of ecosystem services

The climate crisis and its impacts are affecting, with ever greater pace and intensity, urban, peri-urban, and rural contexts, thus significantly impacting the environment, local development, and quality of life. Therefore, the identification and implementation of planning actions aimed at strengthening the resilience of spatial systems and at accelerating the ecological transition are highly desirable, mainly based on the effective and sustainable use of the functions of nature and natural resources.

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The cover image: The pedestrian route of Via Chiaia in the City of Naples by TeMA Editorial Staff

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EDITORIAL PREFACE

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Climate crisis and spatial planning
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1 Introduction

The climate crisis and its impacts are affecting, with ever greater pace and intensity, urban, peri-urban, and rural contexts, thus significantly impacting the environment, local development, and quality of life. Therefore, the identification and implementation of planning actions aimed at strengthening the resilience of spatial systems and at accelerating the ecological transition are highly desirable, mainly based on the effective and sustainable use of the functions of nature and natural resources. Within this conceptual framework, this Special Issue has the general objective of proposing and discussing methodological and operational approaches oriented toward the identification of territorial policies directed at the pursuit of climate neutrality and adaptation to the climate crisis.

In this perspective, two research profiles of particular relevance in scientific and technical terms are identified:

- for all spatial contexts, urban, peri-urban, and rural, the strengthening of a set of ESs related to the quality of human life, to be considered as fundamental factors for achieving climate neutrality, among which carbon capture and storage (CCS) is identified as a fundamental reference;
- for urban areas, the enhancement of a set of ecosystem services (ESs) significantly linked to the urban microclimate and its quality, especially in relation to the mitigation of the heat island effect and to energy saving.

For both profiles, the knowledge of the situation and the evolutionary dynamics of the supply of ESs constitute effective foundations for the assessment of the impacts of planning actions, also with reference to the location and installation of plants for the production of energy from renewable sources.

This Editorial Preface proposes some points for reflection to facilitate the reading of the articles of this Special Issue, as follows. First, the conceptual category of green infrastructure is analyzed with reference to territorial contexts characterized by widespread urbanization. Subsequently, the relationships between the supply of certain ESs and the inclusion of parts of the territory in the spatial systems of green infrastructure are discussed, in relation to the current literature. The last section briefly describes the articles of the Special Issue.

2. Green infrastructure and urbanized spatial contexts

The European Commission regards green infrastructures (GIs) as essential territorial frameworks that support biodiversity preservation, strengthen ecological linkages across natural systems, and foster the overall capacity for ecosystem services (ESs) provision (Directorate–General Environment, European Commission, 2012). In this context, the advancement of biodiversity conditions together with the expansion of ES supply represent primary objectives within spatial planning strategies designed to reinforce the operational efficiency of GIs (Liquete et al., 2015; European Environment Agency, 2014).

Within this perspective, the notion of green infrastructure located in urbanized spatial contexts (UGI) aligns with the conceptual orientation promoted by the Commission, while contemporary planning practices in cities have progressively integrated it as a critical interpretive lens for the organization of urban green systems (Tzoulas et al., 2007; Sandström, 2002). UGIs are conceived as interlinked networks of natural or semi-natural components, explicitly arranged to maximize ES delivery. They encompass green areas, open landscapes, and aquatic environments, situated both within densely built zones and in areas completely transformed by impermeable surfaces. The maintenance, development, and enlargement of these ecological networks, which vary widely in dimension, spatial position, and ownership, are understood as a shared duty of governmental institutions, private stakeholders, and civic society engaged in urban governance.

As instruments of sustainable and socially responsive city-making, UGIs are distinguished by several functional roles (Breuste, 2021):

- ensuring universal accessibility for urban populations;
- safeguarding health and enhancing the well-being of inhabitants;
- promoting the protection of biodiversity alongside the continuous and meaningful interaction with natural resources;
- contributing to the visual identity of cities while elevating overall quality of life, particularly in densely inhabited districts;
- expanding the availability of ESs for diverse categories of urban users, from residents to commuters, tourists, and temporary visitors.

Even environments dominated by artificial surfaces can be reintegrated into UGIs by replacing impermeable cover with vegetation, through processes such as greening initiatives or tree planting. The inclusive nature of UGIs, emphasized by Tzoulas et al. (2007), highlights their relevance not only to urban conurbations but also to multicentric territories, peri-urban and transitional areas, and rural contexts.

A decisive contribution of UGIs in urbanized landscapes lies in mitigating the fragmentation of green areas caused by sealed surfaces, structural barriers such as buildings, and transport infrastructures, all of which severely disrupt biodiversity. While UGIs cannot always prevent such fragmentation, they provide additional ecosystem benefits not strictly dependent on spatial continuity, for instance, cleaner air derived from the presence of vegetated surfaces, a function particularly strengthened when trees are present in considerable numbers (Echevarria Icaza et al., 2016; Salata et al., 2016). Similarly, vertical greening systems such as living walls and rooftops mitigate excessive heat accumulation, reducing the impact of phenomena like the urban heat island effect (Eggermont, 2015).

The guiding principles for the stewardship and future development of UGIs can be summarized as follows (Breuste, 2021):

- adjust the provision of urban ESs to the differentiated needs of users through targeted spatial planning policies;
- foster multifunctionality and versatile uses of UGI assets;
- ensure continuity and efficiency of ESs provision by optimizing maintenance activities;
- reintegrate UGIs into highly sealed urban contexts via partial soil re-permeabilization and the adoption of nature-based solutions;

- design participatory urban planning policies aimed at maximizing UGI effectiveness, including the active involvement of profit and non-profit organizations, civic associations, labor representatives, environmental groups, and public administrations with responsibility for city management.

The adoption of inclusive, collaborative, and forward-looking urban strategies intended to consolidate UGIs embodies a holistic framework of spatial governance, merging sustainable growth with principles of social fairness at the local scale (Zoppi, 2012; Walmsley, 2006; Schrijnen, 2000; van der Ryn & Cowan, 1996). The compact city model integrated within ecological networks underpins Dresden's planning vision, which aspires to establish itself as a green city (Breuste, 2021). The city's approach is to embed dense urban settlements within a wider ecological matrix, with its river systems, comprising nearly 400 watercourses and the Elbe basin, serving as the backbone. This ecological system is envisioned to expand progressively while enhancing access to public green spaces. Its assigned functions include (Breuste, 2021):

- promoting air quality improvements and climate resilience;
- recharging groundwater reservoirs effectively;
- reducing flood risks and controlling runoff;
- providing more recreational spaces for outdoor activities;
- ensuring ecological connectivity through functional corridors for fauna and flora, thereby preserving habitat quality;
- maintaining and improving the aesthetic character of both built and natural urban environments.

In Dresden, UGI is shaped by interconnected hubs and corridors. Policies are directed toward enhancing the ecological standards of these nodes and links, while simultaneously regulating urban expansion to avoid further encroachment on open landscapes. The underlying intent of this planning model is to instill in the community a perception of urban ESs as a coherent and complex GI framework, in which open spaces are regarded not as residual land but as fundamental structural components of the city's ecological infrastructure (Buijs et al., 2019; Fors et al., 2015)

3. Green infrastructure and supply of ecosystem services: CCS, habitat quality and natural outdoor recreational spaces

CCS constitute an ecosystem service closely linked to the persistence of green areas within urban environments, and thus to the efficiency and resilience of urban structures in UECs (urban ecological corridors). This relationship is analyzed and discussed by Valente et al. (2022), with reference to the spatial arrangement of green spaces and the urban ecological network, using the Landscape Service Index spatial framework applied to the city of Lecce, Southern Italy. A notable aspect pertains to the functional relationship between carbon sequestration services provided by UECs, where the primary feature of these corridors is the provision of well-maintained urban green spaces containing high-quality vegetation, which results in substantial carbon dioxide absorption. This phenomenon is explored in several studies, including those by Lv et al. (2023) and Zhang et al. (2015), focusing on ecological restoration in Southwest China, particularly in karst landscapes.

Supporting these observations, Floris and Zoppi (2020) report, first, a negative correlation between temporal changes in land consumption and carbon storage potential, indicating a strong link between urban expansion and increased land use (Stachura et al., 2015). Second, they note that the reduction in carbon storage capacity caused by land consumption is quantitatively significant. Their study emphasises how the presence and extent of protected areas, represented in this analysis as the heads of UECs, can restrict urban sprawl and land take, thereby playing a crucial role in maintaining and potentially enhancing carbon sequestration (Martínez-Fernández et al., 2015; Mücher et al., 2009).

Concerning the association between habitat quality spatial classification and the suitability of spatial contexts to be considered part of UECs, Lai et al. (2018) highlight two key factors. Firstly, the mitigation of environmental pressures, including the renaturalization of sealed soils due to urbanization, removal of legal or illegal waste sites, restoration of urban understory, monitoring of fallow lands, and relocation of industrial installations. Secondly, processes of soil loss and land cover transitions associated with qualitative degradation are of limited importance (Vassilev; 2011; Ruiz Benito, 2010), as habitat quality depends primarily on the condition of land cover. These findings are corroborated by other research. He et al. (2017) propose a predictive tool for assessing the impact of land cover changes on habitat quality, integrating scenario simulations with cellular automata and the InVEST habitat quality model. Their results suggest two strategies to enhance habitat quality: controlling urban sprawl via managed growth of urbanized areas, and implementing agricultural policies to reduce dispersed rural settlements, which negatively affect surrounding habitat quality. Sallustio et al. (2017) present a methodology to assist decision-makers in identifying conservation priority areas and evaluating habitat quality and degradation within the current Italian protected areas framework. Their results indicate that habitat quality declines with proximity to densely populated or intensively farmed areas and where weaker conservation measures apply.

The issue of the inclusion of outdoor recreational spaces into UGIs align with Song & Liu (2024), who show that the network of movement patterns for leisure activities is influenced by the availability of accessible, equipped urban green spaces, ideally reachable without transportation. The study notes that the association between public green spaces and UECs as neighbourhood connectors has intensified during the pandemic, when perceived safety against contagion was higher in open green areas that enable multiple recreational activities while allowing for safe distances. The importance of outdoor recreation spaces, considered nodes and branches of UGI-related networks, for urban life quality and their reinforcement as a strategy to enhance it, is highlighted by Park (2017) in the Phoenix metropolitan area. Park emphasizes how community perceptions are shaped by public sensitivity to the protection and proper use of urban open spaces, a sensitivity particularly heightened in communities engaged in hiking and wildlife interaction. Richards et al. (2024), through virtual landscape simulations, underscore the role of ecological connectivity in enhancing attractiveness for outdoor recreational activities, especially those related to sports and relaxation, particularly in areas with high-value land covers, such as forests and native vegetation, especially near waterways or wetlands.

In urban settings, UECs play a critical role in connecting outdoor recreational areas, mitigating landscape fragmentation caused by impermeable surfaces and built infrastructure. Even if UECs do not provide fully continuous recreational corridors, they still supply significant ecosystem services, including air quality improvement due to the presence of trees and vegetated areas. This positive effect is amplified when patches are closely situated, if not fully continuous. Relevant studies include Lee et al. (2014) for Gwacheon, South Korea, and Samways et al. (2010), concerning Southern forestry production.

4. Renewable energy sources

Renewable Energy Sources (RES) are widely recognized as a key component of the global strategy to mitigate climate change and reduce carbon emissions. Their contribution to decarbonization and the transition toward a low-carbon economy is undeniable. However, a crucial issue that requires deeper examination is that RES, despite their environmental benefits, are not intrinsically sustainable. Their deployment inevitably generates environmental, social, and spatial impacts that must be carefully assessed.

Policies and programs at international, national, and regional levels increasingly encourage the development of new RES farms, often under ambitious targets for energy transition. While these initiatives are essential for achieving climate goals, they simultaneously create complex challenges for regional planners and administrators. The central question becomes: how can we effectively manage landscape transformation and territorial fragmentation in order to integrate these technologies in a manner that is both efficient and sustainable? (Opdam & Wascher, 2004; Akella et al., 2009; Saidur et al., 2011; De Montis et al., 2017).

The impacts of RES installations extend far beyond energy production alone. Land-use changes and land take may alter traditional agricultural systems, fragment ecosystems, and reduce biodiversity. The placement of

large solar or wind farms can also diminish aesthetic and cultural values associated with landscapes, thereby affecting local communities and heritage sites. Habitat quality often deteriorates as natural areas are disrupted by infrastructure such as access roads, transmission lines, and service facilities (Möller, 2006; Broto, 2017).
Significantly, the magnitude and nature of these effects are strongly influenced by spatial factors, including the specific location of plants, their density and spatial arrangement, the scale of the projects, and the technical design of the installations. Secondary infrastructure, often overlooked in early planning phases, can compound the negative effects by increasing fragmentation and altering natural dynamics (Saganeiti et al., 2018; Saganeiti et al., 2020). Consequently, evaluating the trade-offs between clean energy production and environmental protection requires not only technical assessments but also multidisciplinary approaches that integrate ecological, social, and cultural dimensions.
In this sense, RES development must be understood as part of a broader territorial strategy rather than as isolated technological interventions. Effective planning involves balancing climate mitigation objectives with long-term sustainability, ensuring that renewable energy systems contribute to a just energy transition while preserving landscape integrity, ecosystem services, and community well-being.
There are numerous implications, in several cases, that have not been thoroughly investigated. The water-related ecosystem services are used to holistically assess the hydrological impact of land-use transformations driven by renewable energy deployment. This approach examines how RES infrastructure modifies fundamental water regulation processes through three interconnected dimensions: the alteration of natural infiltration capacities and runoff generation patterns, the consequent effects on landscape-scale flood mitigation potential, and the fragmentation impacts on watershed connectivity. These analytical products collectively identify critical intervention areas where energy development interfaces with sensitive hydrological systems, providing a science-based foundation for sustainable resource management strategies that harmonize climate mitigation objectives with the preservation of water ecosystems.
The increasing focus on Renewable Energy Sources (RES) exemplifies the broader lack of structured management of technological innovations within spatial and urban planning systems. The diffusion of new technologies, and particularly RES, is characterized by a rapid and often uncoordinated spatial expansion, which tends to outpace the adaptive capacity of regulatory and planning frameworks. This misalignment generates a situation in which the territorial footprint of RES develops largely in the absence of comprehensive spatial strategies, producing unintended environmental, social, and economic consequences (Scorza et al., 2020; Romano et al., 2018).

5. Overview of collected contributions

This Special Issue comprises eight papers that concentrate on the intersection of the climate crisis and spatial planning, utilising various methodologies and scales. It is possible to categorise the papers into two main groups based on territorial scale: urban and rural. The first group consists of five papers, while the second comprises three papers.
The first paper, titled "Carbon sequestration and ecosystem services. Evidence from the functional urban area of Cagliari, Italy" by Sabrina Lai and Corrado Zoppi (University of Cagliari in Italy), proposes a methodological approach that combines ecosystem services modelling and mapping with inferential models to identify and evaluate the relationships between carbon sequestration, storage, and other ecosystem services. The approach was applied to the context of the Functional Urban Area of Cagliari (Italy).
The second paper, titled "Adaptation and energy saving through urban green spaces in climate action plans: the experiences of 20 global cities" by Laura Ascione, Carmela Gargiulo and Carmen Guida (University of Naples Federico II in Italy), proposes a systematic analysis of the Climate Action Plans of a sample of twenty cities recognised globally for their commitment to climate action. The objective is to identify significant relationships between the adaptation strategies implemented by the different cities and their urban, climatic,

physical, social, and environmental characteristics. Special attention is given to understanding the role of green spaces in mitigating the effects of global warming.
The third paper, titled "Divergent stakeholder valuations of ecosystem services in Batticaloa Lagoon, Sri Lanka: implications for payment for ecosystem services frameworks for sustainable management" by Partheepan Kulasegaram, Muneeb M. Musthafa, Thangamani Bhavan and. Beniamino Murgante (United Nations Development Programme in Sri Lanka and University of Basilicata in Italy), examined stakeholder perspectives on preservation versus degradation scenarios employing a choice experiment methodology. The survey targeted stakeholders through stratified sampling and successfully engaged 405 participants within the Batticaloa Lagoon Watershed (BLW). The findings provide empirical evidence that underscores the diversity of preferences among lagoon users.
The fourth paper, titled "Reducing UHI in historical centres: the greening transformation of open small spaces in San Lorenzo district in the city of Naples (Italy)" by Carmela Gargiulo, Tonia Stiuso and Floriana Zucaro (University of Naples Federico II in Italy), investigates the urban heat island effects that exacerbate thermal discomfort and energy consumption in densely built areas, particularly within historical city centres characterised by compact and stratified urban fabric. The focus is on the San Lorenzo district in Naples (Italy), a representative Mediterranean historic city where limited open spaces coexist with stringent heritage conservation regulations.
The last paper of the first group, titled "Analysis of factors affecting urban land use changes (1993-2023): a case study of Urmia City, Iran" by Keramatollah Ziari, Ahmad Pourahmad, Mohamad Molaei Qelichi and Shahriar Hamidi Kay (University of Tehran in Iran), analyses land-use transformations (1993–2023) to identify key drivers and to propose sustainable management strategies. Utilising satellite imagery from four distinct time points, land use was classified with high accuracy through the employment of ENVI, ArcGIS, and Google Earth platforms, applying supervised classification methods such as Maximum Likelihood and Neural Network.
The first paper of the second group, titled "Global climate crisis and regional contexts. A study on ecosystem services related to Sardinia, Italy" by Federica Isola, Bilge Kobak, Francesca Leccis, Federica Leone and Corrado Zoppi (University of Cagliari in Italy), aims to propose and implement a methodological approach for achieving climate neutrality through spatial planning policies. The methodologies used focus on evaluating and visually representing the five ecosystem services within the Sardinia region.
The second paper, titled "Predicting the aesthetic impact of wind turbines and their influence on landscape value" by Shiva Rahmani, Vito Pierri, Luigi Zuccaro and Beniamino Murgante (University of Basilicata in Italy), focuses specifically on wind turbines and their aesthetic impact on the landscape. Using the 'Scenic Quality' model from the InVEST software suite, the study evaluates the visual effects of wind energy infrastructure under both current conditions and a projected future scenario that includes turbines currently in the authorisation phase.
The last paper, titled "Identifying regional green infrastructure hotspots. A comparison between the Basilicata and Campania regions, Italy" by Federica Isola, Sabrina Lai, Francesca Leccis and Federica Leone (University of Cagliari in Italy), proposes a methodological approach for the identification of ecosystem services hotspots, defined as key areas that supply high levels of ecosystem services, to support more sustainable spatial planning. The developed approach was applied to the Italian regions of Campania and Basilicata.
As Guest Editors of this volume, we wish to express our gratitude to the members of the editorial staff of TeMA Journal (in particular, to prof. Gerardo Carpentieri) who, with passion and great professionalism, dedicate themselves to a challenging scientific undertaking, such as the publication of TeMA Journal, now in its eighteenth year of life (2007-2025).

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