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Sustainable Spatial Planning Based on Ecosystem Services, Green Infrastructure and Nature-Based Solutions

Edited by
Sabrina Lai and Corrado Zoppi

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Cover image courtesy of Sabrina Lai

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About the Editors

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Preface

The conceptual category of ecosystem service was pioneered in the 1970s by articles that identified connections between the life quality of human settlements and the social and economic positive effects of ecosystems. Thenceforward, several studies have identified ecosystem services as important public goods and, as a consequence, the concept of ecosystem service has progressively gained relevance with regard to the ecological, economic, and spatial planning scientific and technical profiles.

A significant general research question is to consider ecosystem services as value-generating resources and to assess their use within the implementation of public policies. From this standpoint, ecosystem services can be associated with the benefits that human settlements, either directly or indirectly, enjoy from nature, and to the support offered by the natural environment to the enhancement of the life quality of human societies. At the outset of the 21st Century, the Millennium Ecosystem Assessment defined a relevant taxonomy of ecosystem services. Thereafter, a number of classifications have been proposed by several international bodies and discussed in many studies. Outstanding comprehensive scientific and technical issues in the spatial planning debate can be identified by the analysis and assessment of trade-offs between the protection of nature and economic growth and between the provisions of different kinds of ecosystem services.

The conceptual category of green infrastructure is strictly related to ecosystem services, according to the European Commission definition. This entails that, according to the European Commission, environmental conservation and improvement are closely connected to the quality of green infrastructure as a provider of ecosystem services, and that public policies should give priority to management, enhancement, and monitoring of green infrastructure as an ecological network that not only supplies multiple ecosystem services but also implements their spatial connectivity.

The conceptual category of nature-based solutions is also strictly linked to ecosystem services. Nature-based solutions are policy measures, which build on nature and natural resources, designed and implemented to recover and improve ecosystems' quality, and to support human societies in order to increase their resilience to climate change. Nature-based solutions are generally aimed at decreasing water run-offs, land surface, and air temperature in highly urbanized areas, and at generating positive impacts on environmental, economic, and social spatial contexts. Nature-based solutions identify a conceptual framework which embeds a number of methodologies addressing many spatial issues. Important among these are the approaches based on selection and management of ecosystem services and green infrastructure, planning and governance of spatial processes aimed at supplying ecosystem services, measures to increase water holding capacity and purification in natural environments, and policies related to afforestation, reforestation, and sustainable management of forests and woodland. Nature-based solutions are increasingly being embedded into the international, national, and local policies that address the negative impacts of climate change and related environmental hazards thereof, although these issues imply relevant technical expertise and insights in order to make nature-based solutions fully operational with regard to the thematic questions and spatial contexts at stake.

This Special Issue focuses on ecosystem services, green infrastructure, and nature-based solutions as important reference points for spatial planning, related to urban and rural contexts, with particular reference to the definition and implementation of planning policies aimed at protecting nature and natural resources.

Sabrina Lai and Corrado Zoppi
Editors

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Editorial

Sustainable Spatial Planning Based on Ecosystem Services, Green Infrastructure and Nature-Based Solutions

Sabrina Lai and Corrado Zoppi *

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In the last decade, ecosystem services, that is, the goods and benefits provided by ecosystems to people, have gained significant importance in the planning domain, as a consequence of the growing scholarly awareness about, and interest in, the complex relationship between human well-being and nature. On the one hand, human life is sustained by, and depends upon, healthy ecosystems; on the other hand, spatial plans struggle to keep up with the needs and demands of ever-increasing urban populations and to allocate land uses in such a way to prevent biodiversity loss and ecosystem degradation. It is therefore not surprising that the integration of ecosystem services into spatial planning, and especially into planning practices, has been advocated as a means to strike a balance between these two contrasting issues and to deliver urban environments that are more sustainable and fairer to all kinds of living things, not just human beings.

In this vein, several researchers have been investigating how the spatially explicit assessment of ecosystem services can be put to good use to ground spatial plans and policies, what types of contribution they can bring in the different stages of plan-making processes, or which ecosystem service indicators would better fit and integrate into consolidated spatial planning practices and decision-making processes. Worth mentioning are also newer streams of research concerning the spatial mismatches between ecosystem service providing and demanding areas, the implications of synergies and tradeoffs in ecosystem service provision on the choice between alternative planning scenarios, or the interdependence between climate change effects and ecosystem service provision.

This fast and impressive research growth has, so far, not been accompanied by an equal growth in planning practices, although there is evidence of pioneer urban and regional plans that explicitly assess and integrate nature's contributions. Such limited consideration in planning practice calls for addressing those hurdles that limit ecosystem service integration in real plan-making processes, such as planners' unfamiliarity with the concept and lack of technical skills required to run assessment models and understand assumptions and limitations, availability of data having an appropriate spatial and temporal resolution, and broad mistrust in assessment methods and, consequently, in their outcomes. To address these gaps, more applied science and reflection on the effectiveness of ongoing spatial planning strategies that integrate ecosystem service consideration would be required, but also, improved exchange and collaboration between researchers, practitioners, and policymakers is needed.

Intrinsically polysemic, the concept of green infrastructure can take different meanings, encompassing not only networks of green areas that are purposefully designed, planned and managed to deliver multiple ecosystem services [1], but also those green technologies and artificial vegetative systems that provide benefits especially in urban environments [2] and which are next referred to as nature-based solutions.

The first, and wider, meaning proposed by the European Commission provides a conceptual framework whereby a green infrastructure is used as a strategic tool allowing for the integration of ecosystem services in spatial planning at various scales, and for developing a unitary discourse around public and private green areas, natural protected areas, water bodies, and even agricultural land. In urban areas, the focus is especially on the delivery of cultural ecosystem services, such as recreation or health benefits (both physical and psychological), and on regulation of negative or extreme phenomena, such as heat waves, flood, geological instability, air pollution, or soil contamination. However, when planning for wider spaces and landscapes, issues of climate regulation, habitats for wildlife, water supply and purification, or even provisioning ecosystem services become extremely relevant. The green infrastructure concept, when integrated into spatial planning, is therefore instrumental in addressing social, economic, and environmental issues and in strengthening ecological resilience and supporting climate adaptation.

Against the numerous pros, some debated issues and questions arise, of which only three are next mentioned, calling for further research on the integration of green infrastructures in planning practice. A prominent one, particularly relevant in densely populated areas, concerns the tension between, on the one hand, greener cities and, on the other hand, urban spaces that can meet the demands of urbanization, which, in turn, raises the issue of green gentrification and inequitable accessibility to green infrastructures for diverse urban populations. A second one, which especially applies to densely built-up urban areas showing vast predominance of sealed soils, is associated with how to conceptualize and implement the physical and functional connection between green areas that, besides translating the "network" idea conveyed in the definition provided by the European Commission, also provide urban ecological corridors (paralleling the study in this Special Issue carried out by Isola, Lai, Leone, Zoppi at the regional scale), hence enabling animal species to better move around, hunt for food, and ultimately survive in urban areas. Finally, a third one relates to the need for deeper quantitative and evidence-based understanding of green infrastructures' long-term effectiveness in fostering climate adaptation.

Nature-based solutions are infrastructures, artifacts, and works that make effective use of ecosystem services to address and resolve negative situations encountered in the spatial organization of environments [3], especially in relation to adaptation to climate change and the reduction of associated environmental risk [4].

Climate-related hazard conditions are generally mitigated by increased resilience generated by reduced exposure and economic and social sensitivity to the negative impacts of climate-related events, and improved adaptive capacity [5]. Decreased exposure can, for example, result from the ability of ecosystems to act as a shield against extreme events. In this context, increased flood resilience can be fostered through nature-based solutions aimed at reducing flood damage through maintenance of riverbanks and riverbeds. Increasing green areas in urban areas reduces heat island damage [6]. The sensitivity of the quality of life of local communities to the negative impacts of climate change can be improved through appropriate diversification of land use, which allows them to manage, effectively, the unpredictability of climate-related phenomena [3]. For example, it is more cost-effective to use tree species and crops that are more resistant to water scarcity, both in forest and agricultural production, to diversify income streams. This implies a growth of local communities' skills in production management, geared toward the integration and development of practices based on climate change adaptation and mitigation of negative climate-related impacts [7].

There are multiple approaches to implementing nature-based solutions aimed at reducing exposure and sensitivity to climate-related hazards. To increase adaptive capacity to such situations, some approaches can be adopted, such as conservation and restoration of natural ecosystems in places of particular relevance to climate change adaptation, or management geared toward resilience to climate impacts of ecosystems that provide different services, such as agricultural areas and forests, if managed appropriately to diversify these services. In addition, it is possible to create from scratch natural ecosystems that provide services related to climate change adaptation, such as green roofs and walls and hybrid solutions for coastal zone management [8].

Within this conceptual, cultural, scientific, and technical framework, the studies published in this Special Issue relate to three main issues, which can be highlighted as follows. A first issue focuses on the relationships between the definition and development of spatial planning processes, both local and supra-local and regional, and ecosystem services, both with reference to their spatial organization and in relation to the recognition of the supply dimension and opportunities for improvement, both qualitative and quantitative. Fistola's study emphasizes the general terms of the inclusion of ecosystem services issues in urban planning, as this implies the integrated reading and interpretation of two complex systems, nature and the city, whose field of interactions and interdependencies highlights open issues that are difficult to address, both from a theoretical and technical and application perspective. In this perspective, the Special Issue opens up some significant avenues to follow, basically based on proposals for the implementation of plan processes based on the exploitation of services offered by ecosystems. This is the case of the study by Cattani, Montaldi, Di Pietro and Zullo, which describes and discusses the role of habitat quality and carbon capture and storage as ecosystem services to be leveraged in the urban planning of the municipalities of the earthquake crater of Umbria, in the post-earthquake time. In this perspective is, also, the article by La Riccia, Assumma, Bottero, Dell'Anna, and Voghera, which explores the issue of the use of the ecosystem services paradigm for the management of cork oak forests in the regional context of Sardinia, proposing an economic evaluation through a methodological approach based on contingent valuation. The issues of ecosystem services related to water resource management in spatial planning are addressed, in the study, with a strong theoretical connotation, by Patano and Camarda, who propose a knowledge organization and management system to be implemented in a multiagent context.

A second thematic order of the Special Issue is represented by some studies aimed at defining the spatial structure of green infrastructures, and the conditions to be put in place for them to operate effectively as spatial networks aimed at the qualified provision of ecosystem services. Within this conceptual framework is the article by Ladu, Battino, Balletto, and Amaro Garcia, which proposes a methodological approach for assessing the feasibility of a project aimed at the implementation of slow mobility of pedestrians and bikers in the context of a bridleway, as an enhancement of the ecosystem services offered by a green infrastructure located in the Sulcis-Iglesiente-Guspinese Bioregion, in the regional context of Sardinia. The study by Pristeri, Di Martino, Ronchi, Salata, Mazza, Benedini, and Arcidiacono defines a green infrastructure in the territorial context of the Alpine Subregion of Media Valtellina, in which the cognitive elements structuring the spatial network are identified in the Landscape Plan, from which prescriptive and guiding contents are also derived. Isola, Lai, Leone, and Zoppi define and implement a methodological approach for mapping a regional green infrastructure, referring to Sardinia, based on the assessment of the spatial organization of multiple ecosystem services, including habitat quality, outdoor recreation, and agricultural production, and a network of ecological corridors identified through the taxonomy of species movement resistance. The article by Isola, Leone, and Zoppi discusses the relationship between ecological corridors and the spatial taxonomy of landscape components, as identified by the Regional Landscape Plan of Sardinia, to assess whether, and to what extent, current regional land use zoning can be used as a basis for implementing regulations aimed at protecting ecological corridors.

Finally, the third thematic order of the Special Issue focuses on green infrastructure aimed at climate change adaptation. With this in mind, Gargiulo and Zucaro identify, as foundational elements of a green infrastructure in the urban area of Naples, the restoration, enhancement, and maintenance of an integrated network of green and open spaces, which constitute a valuable asset in which the definition of nature-based solutions to address the local impacts of climate change is integrated. La Rosa and Junxiang Li analyze the various factors and constraints, related to the urban morphology and the social and economic characteristics of the urban environment, that influence the location of new greening scenarios, generating significant benefits related to decreasing atmospheric temperature. In the last article of the Special Issue, Ledda, Kubacka, Calia, Bródka, Serra, and De Montis propose a comparative analysis of the spatial planning practice of Italy and Poland, in relation to the use of green infrastructure in the context of climate change adaptation policies, with reference to the regional contexts of Sardinia and Wielkopolska.

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References

1. European Commission. Green Infrastructure. Available online: https://environment.ec.europa.eu/topics/nature-and-biodiversity/green-infrastructure_en (accessed on 12 March 2024).
2. EPA United States Environmental Protection Agency. What is Green Infrastructure? Available online: https://www.epa.gov/green-infrastructure/what-green-infrastructure (accessed on 12 March 2024).
3. EEA (European Environment Agency). *Nature-Based Solutions in Europe: Policy, Knowledge and Practice for Climate Change Adaptation and Disaster Risk Reduction*; EEA Report no. 1/2021; Publications Office of the European Union: Luxembourg, 2021. [CrossRef]
4. Debele, S.E.; Leo, L.S.; Kumar, P.; Sahani, J.; Ommer, J.; Bucchignani, E.; Vranić, S.; Kalas, M.; Amirzada, Z.; Pavlova, I.; et al. Nature-based solutions can help reduce the impact of natural hazards: A global analysis of NBS case studies. *Sci. Total Environ.* **2023**, *902*, 165824. [CrossRef] [PubMed]
5. Ingaramo, R.; Negrello, M.; Khachatourian Saradehi, L.; Khachatourian Saradehi, A. Transcalar project of nature-based solutions for the 2030 Agenda. Innovations and interconnections. *AGATHÓN—Int. J. Archit. Art Des.* **2023**, *13*, 97–108. [CrossRef]
6. Seddon, N.; Daniels, E.; Davis, R.; Chausson, A.; Harris, R.; Hou-Jones, X.; Huq, S.; Kapos, V.; Mace, G.M.; Rizvi, A.R.; et al. Global recognition of the importance of nature-based solutions to the impacts of climate change. *Glob. Sustain.* **2020**, *3*, e15. [CrossRef]
7. Baills, A.; Garcin, M.; Bernardie, S. Platform dedicated to nature-based solutions for risk reduction and environmental issues in hilly and mountainous lands. *Sustainability* **2021**, *13*, 1094. [CrossRef]
8. Liu, H.-Y.; Jay, M.; Chen, X. The role of nature-based solutions for improving environmental quality, health and well-being. *Sustainability* **2021**, *13*, 10950. [CrossRef]

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Article

Ecosystem Services for the City as a Complex System: A Methodological Proposal

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Abstract: Originating from the main theories on the interpretation of the city as a system, this paper calls attention to the need to build a new theoretical framework. This framework would be able to support actions related to the consideration of ecosystem services in the activities governing urban and territorial transformations. By adopting the systemic interpretation of the city, it may be possible to more readily identify the ecosystem services related to each of the urban subsystems, and promote a new and different consideration of them when defining urban policies on the sustainable management of urban and territorial systems. This reflection describes a new approach to the problem, by indicating mainly the theoretical references and methodological connections to be considered in the development of a new dimension of territorial government. This dimension would be, by necessity, built upon issues that characterize the current historical phase, such as ecological transition, and the new potential of technological innovation that, if properly reconsidered, could contribute to substantially redefining the field of traditional urban planning.

Keywords: ecosystem services; city as a system; spatial planning

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1. Introduction

The research on the theme of ecosystem services (ESs) and the relationships among them has now reached a mature extent, such that one can find a consistent number of studies in the international literature [1]. For over thirty years, the consideration of ESs as an essential support for the survival of the human species within anthropic contexts has generated numerous reflections, in various fields of scientific research. Significant insights have been developed regarding the role of ESs in biological, economic, natural resource management, and biodiversity contexts [2]. As early as the late 1990s, there were studies in the field of urban planning and land management which examined ESs in relation to the regeneration of abandoned and disused areas. In this context, we adopt the definition provided by the Millennium Ecosystem Assessment in 2005, which classifies ESs into the following categories: supply, which includes products obtained from ecosystems such as food, clean water, fibers, fuel, and medicines; regulation, where benefits are derived from the regulation of ecosystem processes, such as climate, water regimes, and the control of pathogens; cultural, which refers to non-material benefits obtained from ecosystems, such as spiritual, ethical, recreational, aesthetic values, and social relationships; and support, which encompasses the services necessary for the production of all the other ESs, such as soil formation, nutrient cycling, and primary biomass production [3]. The relevance of this field of research is further substantiated by the particular moment of global crisis that the planet is experiencing. This crisis can be traced back to universal phenomena such as climate change, taking into consideration all of the side effects that such upheaval entails, and area phenomena, circumscribable in specific territorial contexts, and generally referring to the presence and action of humans.

There is no doubt that the new sustainable development perspective implied by ecosystem services requires a substantial change in approach, even toward those activities that suggest spatial arrangements which can be traced back to the management of territorial transformation. In light of the above, it appears useful to fully define the theoretical–methodological and interpretive approach that can allow us innovative insights into the evaluation of ecosystem services, and their transfer flow from the natural to the anthropic context. In order to provide a first hypothesis to frame the methodological background, it appears necessary to consider the nature of ecosystem services as complex systems, regarding which it is appropriate to refer to specific interpretive approaches [4]. Considering ESs through a systemic approach allows the establishment of a common ground between these services and the city, which is interpreted as a dynamically complex system [5].

Ecosystems are incredibly complex and dynamic systems that are constantly changing and adapting in response to various internal and external factors. Due to this complexity, it is often necessary to develop multiple classification systems, to help us better understand and manage these ecosystems [6].

Starting from this concept, it appears appropriate to attempt to propose a new vision, useful in the process of urban planning, which relates ecosystem services to the city interpreted as a system, and to the urban subsystems [7].

In other words, in the development of future urban planning policies/actions, we should consider which ecosystem services urban subsystems need (at a minimum) to activate a metabolic process capable of ensuring the survival and correct evolution of the urban system. Such components will need to be identified and quantified as a priority, without which erroneous predictions are likely to generate high levels of urban entropy. We aim to attempt a theoretical homogenization between the systemic approach to the study of urban phenomena, and the reflection on ecosystem services that are, in any case, part of this approach.

Finally, one of the most important objectives is to redefine, within the tools for territorial governance, the urban planning rules that regulate the definition of land use, by considering the ESs associated with each urban zone, while also taking into account the trend toward *mixité fonctionnelle*, and the overcoming of single-land-use designation. Further in-depth analysis is required for such a classification, but it appears that this could be a path to be explored.

The ultimate goal is to reach a new perspective on urban planning which, considering the rapid changes underway, must innovate, to define new, effective policies for sustainable territorial governance.

2. Materials and Methods: The Need for a New Approach

The dynamic and complex nature of cities poses significant challenges for traditional town-planning methods, which often rely on static and closed forecasts of future urban layouts. These methods may fail to take into account the unpredictability and adaptability of urban systems, leading to inefficient or unsustainable outcomes. To address these challenges, new theories of town planning are needed, that embrace the systemic nature of cities, and consider their evolution over time. This requires a shift toward more adaptive and flexible planning approaches that can respond to changing circumstances and uncertainties.

Overall, the adoption of a systemic paradigm for urban planning is essential to addressing the challenges posed by the complexity, and dynamic evolution, of cities. By embracing a more adaptive and flexible approach to town and country planning, we can help create more sustainable, livable, and resilient urban environments that meet the needs of present and future generations. The interpretation of the city as a dynamically complex system is now widely shared. This started with the first studies conducted in this field by J.B. McLoughlin, J. Regulsky, and others [8,9].

Considering the city as a dynamic and complex system, articulated into interrelated subsystems [10], represents the most useful model for establishing a direct relationship with ES. If the city is interpreted as a complex system, it is consequently possible to identify a certain number of subsystems that ensure urban survival, and to prioritize them over others. From a large number of urban subsystems, we can identify five main ones that can be considered the most significant.

As proposed in other studies [11], the urban system can be seen as a complex and dynamic interplay of these five subsystems, each of which contributes to the evolution and transformation of the city over time.

Understanding the interactions between these subsystems is essential for effective urban planning and management. These are the five main urban subsystems that have been identified: the geo-morphological, the anthropic/human, the physical/spatial, the functional, and the psycho-perceptive. These subsystems interact with each other, but are interdependent, meaning that changes in one subsystem can have an impact on the others. Therefore, a holistic approach is necessary for urban planning and design, taking into account the complex dynamics of these subsystems and their interrelationships (Figure 1).

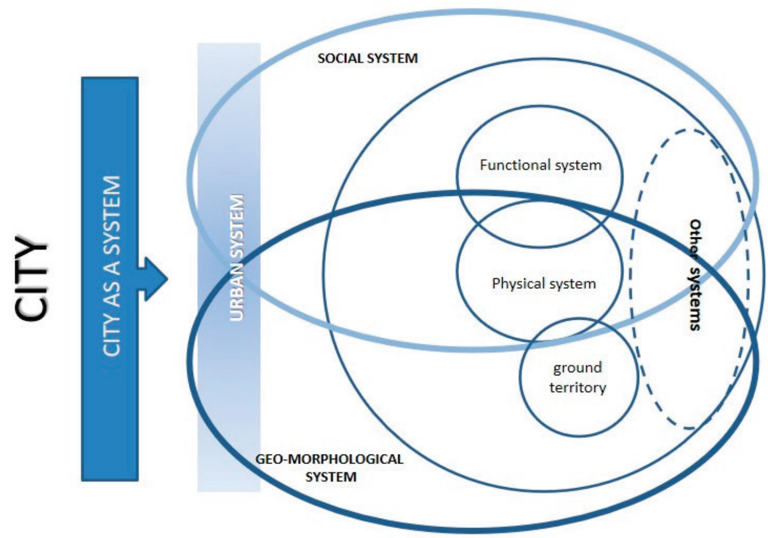

Figure 1. A conceptual scheme of the urban system and its different subsystems. The geo-morphological system and the anthropic/human one (social system) are to be considered "generative" subsystems, because they allow the generation of the urban system as a whole. Furthermore, the functional system and the physical system, as well as the perceptive one, must be considered "generated" systems.

The physical system provides the physical support for the functional system, which in turn represents the activities occurring in the urban space, or running through the area. The functional system includes various elements, such as transportation, commerce, housing, and services, which interact and influence each other in complex ways.

The functional system of the city includes all the human activities that take place within the physical spaces of the urban environment, as well as the relationships and interactions that occur between these activities. This system is responsible for the flow of goods, services, and information throughout the city, and is a critical component of the urban infrastructure. It is often studied in the field of urban planning and design, as well as in related disciplines such as transportation engineering, and public policy.

The psycho-perceptive system, on the other hand, represents the subjective experience of the city by its inhabitants. This system includes elements such as urban image, sense of belonging, and emotional attachment to the urban environment. It is shaped by a variety of factors, such as culture, history, and personal experience.

The physical system and the functional system can be regarded as "generated" systems that arise from the presence of, or interaction between, generative systems. As previously mentioned, each system consists of elements that constitute its systemic architecture: the elements and the relationships. The relationships among elements, as a whole, represent the "structure" of the system. In the case of the physical system, the components are the constructed spaces of the city, such as buildings, squares, infrastructure, and urban sites. The relationships, on the other hand, are the physical channels that connect these spaces, facilitating the flow of functional activities. These channels can be seen as the supportive framework for functional flows.

The psycho-perceptive system is important in the evolution of urban systems, because it influences how individuals perceive and interact with the city. This system is closely related to the physical and functional systems, as the material spaces and human activities within the city contribute to shaping the image and perception of the city [12]. The concept of "memory of places" refers to the emotional and cultural connections that individuals have with specific locations within the city, which can have a significant impact on urban planning and development. This system is included within the other subsystems that make up the urban system, but will not be addressed specifically here.

The geo-morphological system consists of the territorial and environmental substrate of the ecosystem, for which the parts can be identified in territorial areas, however defined (continents, nations, hydrographic basins, macro-regions, municipal territories, etc.), and the relationships in the infrastructure of physical connection between them (roads, railways, canals, energy networks, etc.).

The anthropic/human system, also known as the "social system", encompasses the "biocenotic" aspect of the city, referring to the community that gives meaning to the space. Within this system, the elements consist of human aggregations that operate within urban spaces. These aggregations include individuals and groups who interact with one another, working toward the development and progress of the city. The actors (citizens) and their relationships form the core elements of this social system, driving the dynamics of the urban environment [13].

Ecosystem Services and Urban Sub-Systems

Following a classification [14], it is possible to assert that the studies carried out on ecosystem services have mainly concerned three major thematic areas. The first one considers the articulation of ESs according to the specific field of study, and the different measurement methods. The second area focuses on the study of the flows (ESFs) through which ESs are transferred through the territorial base.

The last thematic area is strongly related to the adoption of ESs in order to achieve sustainable development of the city and territory. The first-mentioned thematic area finds its main reference in the classification and the need to quantify these resources, in order to subsequently calculate their balance in the metabolism processes of human settlements.

The second topic area has been developed in many interesting studies, from which it appears that consistent and standardized definitions and measurement methods for ESFs are essential for effective policy-making and decision-making.

Regarding the demand for ecosystem services, some studies define ESFs based on the actual use or delivery of ecosystem services to people, while others focus on the potential demand for ecosystem services based on the characteristics of the beneficiaries. Spatially, ESFs can be measured by the distance or accessibility between ecosystem services' supply and demand, or by the spatial pattern of ecosystem services' supply and demand in a certain area. In terms of the flow process, ESFs can be measured by the amount, direction and speed of ES flow between ecosystems and people. Without a clear and consistent understanding of ESFs, it is difficult to accurately measure, monitor, and manage ecosystem services. This could lead to ineffective policies, and decisions that do not fully consider the importance of ecosystem services for human wellbeing and the environment.

There is still a need for more standardized and widely accepted definitions and measurement methods for ESF. The last thematic area is the one closest to the debate on new forms of urban planning, and how urban-development planning cannot ignore the consideration and formalization of available resources. As highlighted in the diagram reproduced in Figure 2, in order for ecosystem services to produce positive effects, the presence of sets of capital is necessary: social, built, human, all included in natural capital, which can easily refer to the subsystems of the urban system.

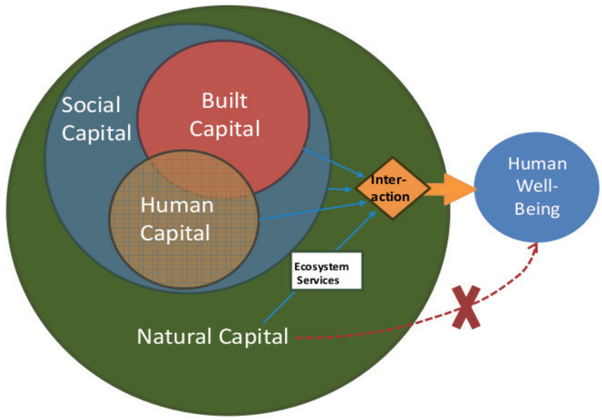

Figure 2. The interaction between built, social, human, and natural capital required to produce human wellbeing (source: Costanza et al., "Changes in the global value of ecosystem services" [15]).

In this sense, it is possible to state that there is a relationship between the subsystems of the city and the ecosystem services, and that the ecosystem services can be connected to the urban subsystems in defining a sustainable future for the city (Figure 3).

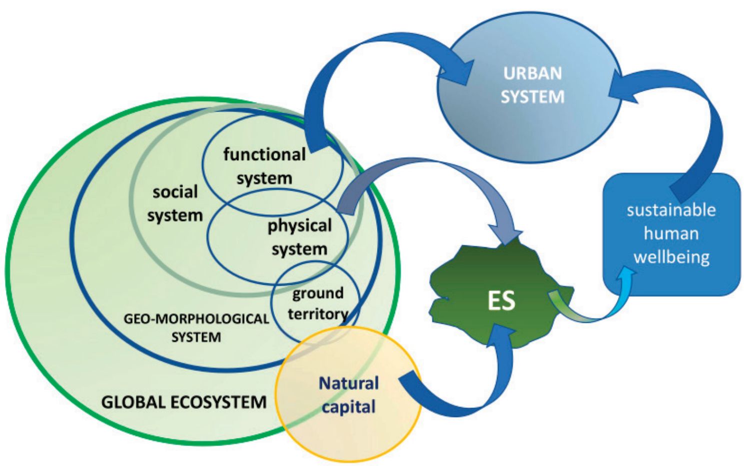

Figure 3. A reinterpretation of the Costanza diagram, considering urban subsystems.

In other words, the appropriate identification of such relationships allows for the minimization of entropic production [16] attributable to systemic evolution that uses energy for its progression over time and space. This energy can be referred to as the production of energy fluid produced by ecosystem services.

Where ESs are identified and properly considered in the planning process, urban entropy is fully metabolized by the urban system, and the "ecosystemic fluid" becomes available within the range of variation of the urban system, determining its sustainable development.

The diagram in (Figure 4) aims to describe this concept by considering the path of the urban system that has to be maintained inside the range of evolution, where possible, to assure sustainable development for it. On the X axis is the time for the system's evolution, and on the Y axis are the resources useful for its sustainable development. If the resources are not able to produce sufficient ecosystemic fluid, the system can fall into the entropic zones, which are very dangerous areas for its development. To return from these zones, it is necessary to use many more resources than before. In other words, the figure aims to represent, in a conceptual way, the nature of the development of the urban system in time and space, and aims to underline the way that this development is strongly related to the amount of ecosystem fluid available inside the range of urban evolution.

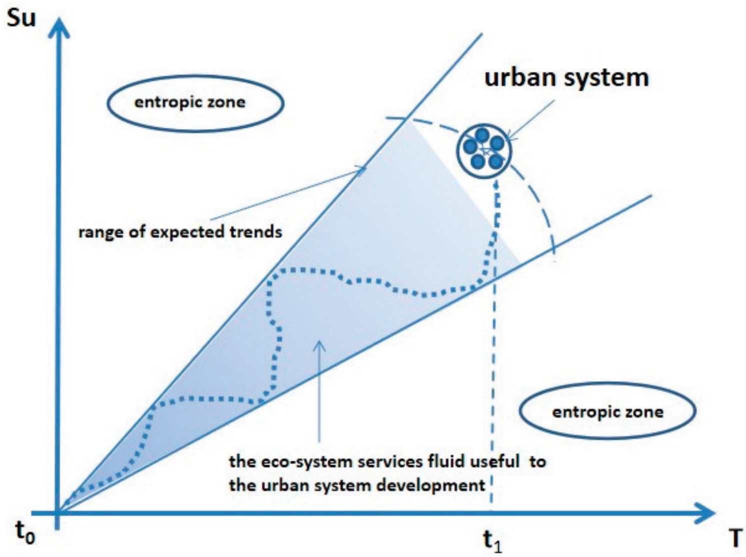

Figure 4. The urban system evolution, in the range of sustainable development filled with the ES fluid.

Another idea that brings out a relevant analogy between the urban system and ecosystem services (which is briefly mentioned here for future research), is complex systems' property of containing subsystems, and of being contained in meta-systems [17].

In a way, it is possible to say that the meta-systems of the two compared systems correspond. In fact, by going up a level with respect to the urban system, it is possible to identify the territorial meta-system, and then the environmental meta-system, and then the planetary meta-system, and so on. On the other hand, going down in level, one observes how the two systems are characterized differently, as cities and ecosystems, but retain mutual relations that are of great importance for the development of spatial governance policies, and that will be described in the following section.

3. Systemic Analogies and Sub-Systemic Relationships

It is true that in recent years, there has been an increase in knowledge about mainstream approaches to spatial planning that incorporate ecosystem services. However, many of these proposals remain limited in scope, and do not fully integrate ecosystem services into the planning process. While tools and technical procedures are essential for improving the knowledge system, they alone cannot effectively impact the planning process. Instead, operational frameworks that fully integrate ecosystem services into the planning process are needed. Unfortunately, such frameworks are still in their infancy, and the full inclusion of ecosystem services in spatial planning has been precluded as a result. To address this issue, further research into, and development of, operational frameworks that can integrate ecosystem services into the planning process are necessary. This will require collaboration between planners, policymakers, and scientists, as well as engagement with local communities and stakeholders to ensure the effective implementation of such frameworks. Reflection on ecosystem services, their taxonomy, their fundamental role in the survival of human contexts, and also the need for management activities in territorial transformations to consider them as a founding element of the planning process [18], has certainly reached a consistent level of maturity, through many contributions present in the various scientific literature related to the study of territorial phenomena [19].

Along with this assumption, the extreme instability of human behavior with respect to the consideration of environmental resources must be considered, particularly that which is determined by geopolitical arrangements and imbalances. In this sense, one can think of the Russian–Ukrainian conflict, which has determined, in a short time, an unacceptable loss of human life, and a global energy crisis, and the reconsideration of the restoration of energy sources, such as coal, which is well known for its environmental impact, and a compromise in the natural assets that generate ecosystem services.

Furthermore, if the conflict aims at the direct destruction of urban contexts and, consequently, physical, functional, and other subsystems, any discussion about the need to identify and preserve environments that generate ESs appears futile. However, studies aimed at building a new perspective, that also sees ESs as being at the center of consideration for urban decision-makers, should not be abandoned.

Referring to the definitions of the Millennium Ecosystem Assessment, mentioned before, and subsequent reflections [20], it can be stated that soil, as a fundamental part of the geomorphological system, is of particular importance in generating ecosystem services and, as such, represents a component directly affected by territorial-transformation processes, and the entropic side effects attributable to consumption (and waste), pollution, impermeabilization, etc. It has been shown that the possibility of linking ecosystem services to urban subsystems also derives from the ability to model the energy flows capable of powering the systems themselves. In this sense, it appears useful to recall the studies of Odum, and his conceptual diagrams related to a system capable of using renewable resources [21].

In particular, we refer to the diagram in Figure 5, which describes a renewable resource whose source is indicated by the letter S. The arrow from the source indicates the energy flow J, toward the system with a part Jr that is dissipated. The arrow R indicates the part of the energy actually converted, to form a stock Q_R. All the quantities in the system depend on interactions with Q_R. In more detail, it is possible to state that the system X polarizes the energy and processes it, before transfer to the meta-system Q_R. The arrow E indicates the part of the resource leaving the stock as entropic output. By reinterpreting this diagram, it is possible to identify S as an ecosystem service that transfers its energy flow (resource), which is processed by the urban subsystem X, which, in turn, transfers the elaborated resource to the urban system Q_R. Q_R uses the resource for its own survival and development, dispersing a part of it in evolutionary entropy.

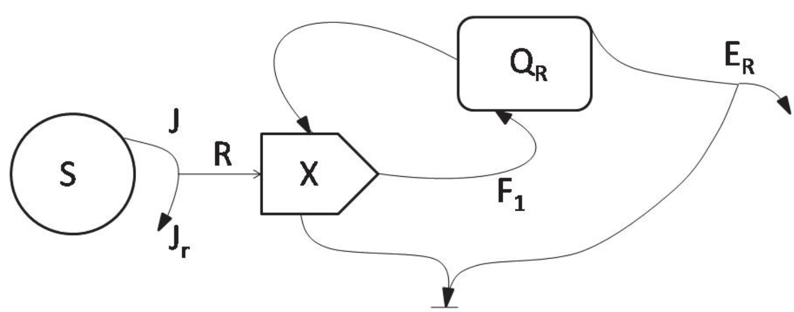

Figure 5. A reinterpretation of Odum's diagram on the use of a renewable resource (source: Pulselli R., and Tiezzi E., "Città fuori dal caos", p. 62 [22]).

Through this reinterpretation, we can connect ecosystem services to urban subsystems.

4. Results: The Relationships among ESs and Urban Subsystems

Following the reasoning developed so far, and recalling the diagram in Figure 1, it is possible to propose a conceptual framework that directly relates ESs to urban subsystems (Figure 6). This diagram highlights the different phases in the process of managing territorial and urban transformation by adopting the systemic approach.

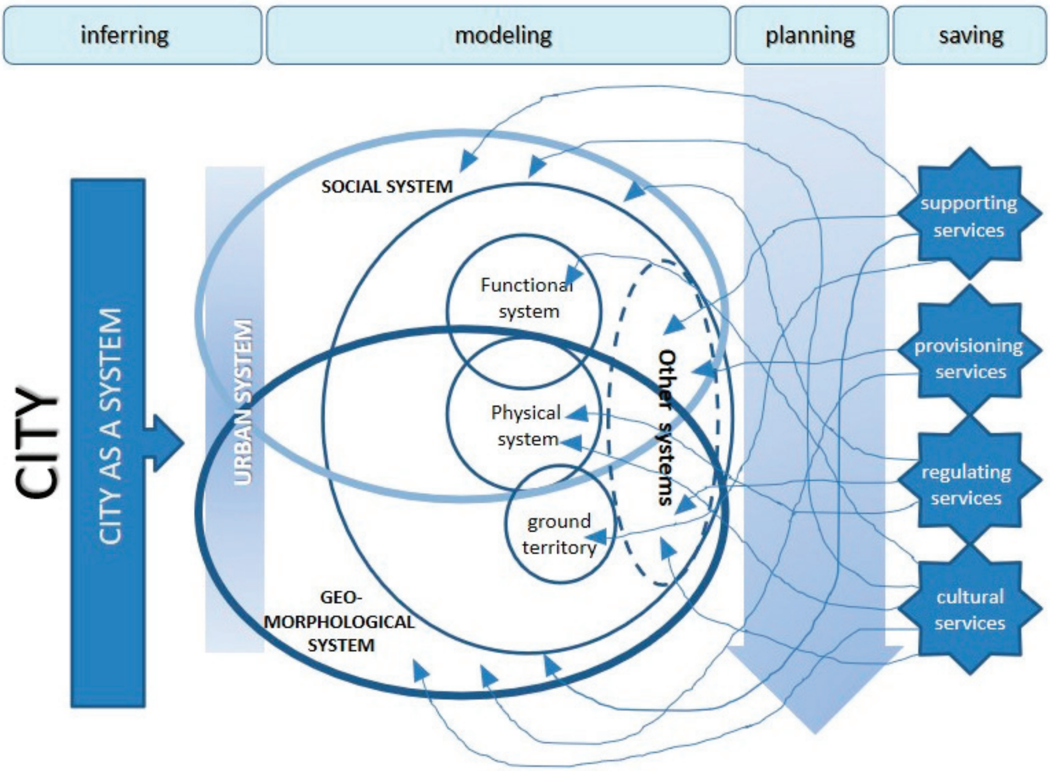

Figure 6. A conceptual scheme demonstrating the relationships among ESs and the urban subsystems.

This process, starting from the systemic modeling of the city, identifies the relevant urban subsystems, mentioned earlier, and the ESs connected to them that need to be prioritized for conservation.

This set of relationships could inform the urban planning of cities, allowing a new vision for the management of territorial transformations.

This new perspective could represent a useful element in the theoretical definition of the relationship between ecosystem services and urban planning, managing to determine which elements must be taken into consideration when defining the organization of territorial transformations. In particular, it is therefore possible to directly identify which ecosystem services need to be safeguarded in the systemic approach to city planning (Figure 7). Depending on the subsystems intended to guide the new urban arrangement, the ecosystem service to be considered and prioritized can be identified, along with all others that are crucial to the survival of the urban system.

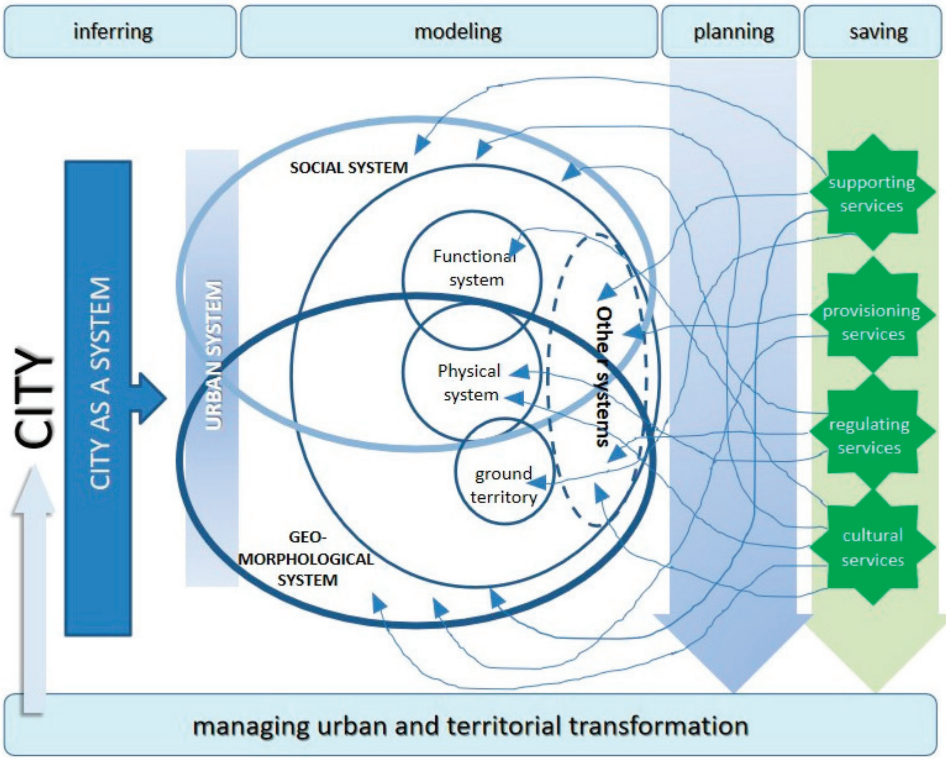

Figure 7. The conceptual scheme demonstrating the relationships among ESs and the urban subsystems, highlighting the contribution (expressed through the arrows) to the government of territorial transformations (GTT).

5. Discussion

Attempting to build a theoretical background for the vast subject of ecosystem services may seem ambitious, and lacking in real usefulness. However, it should be noted that much of today's debate on the topic is focused on the formalization and monetization of ecosystem services, with the aim of obtaining a quantification to consider in territorial policy evaluations and urban planning.

As mentioned earlier, by the late 1990s, a focus on the role of ecosystem services within urban systems had already produced interesting studies. Specifically, attention was given to the capacity of "urban ecosystems" (green and blue infrastructure) within the city to generate ecosystem services for the community in an endogenous manner. More recently, starting from the observation of the entropic impacts caused by increasing urbanization, the effects on the degradation of ecosystem services within spatial contexts have been evaluated [23]. However, referring to the systemic nature, and bringing it back to the modeling of the city as a dynamically complex system, can lead to new research contributions that can complete the treatment of the topic, and provide a concrete disciplinary dimension. The proposal of a new methodological approach requires the generation of a discussion among scholars and, consequently, a specific literature on the subject. In essence, the proposed reflection aims to stimulate discussion among scholars, and foster the exchange of ideas. As is often the case in scientific research, it is sometimes necessary to pause and consider the conceptual and methodological framework that can be applied to a specific practice or action. In the case of ecosystem services and their actual consideration in the governance processes of urban system transformations, it is useful to begin outlining a background methodological landscape that, despite limited literature presence, can contribute to shaping new areas of knowledge. The need for a theoretical reference is recognized by scholars of urban phenomena who pay particular attention to the necessity of defining shared procedures for the adoption of ecosystem services in urban planning processes, with the aim of promoting the governance and sustainable evolution of the urban system [24]. This is probably the most interesting working hypothesis that can be catalyzed by reflection, leading to future in-depth studies that could go beyond the technical dimension that is prevalent in the literature.

6. Conclusions

Undoubtedly, this is only the beginning of defining this possible theoretical construction, to be considered prior to operational actions toward ecosystem services that are involved in urban planning processes. In other words, this conceptual definition represents an initial step toward a complete theoretical–methodological advancement, which requires further reflection to frame a real reference theory.

This consideration, placed at the beginning of the conclusions, is useful in highlighting the main limitation of this paper, but emphasizing, at the same time, its specific contribution in indicating the need for a change in perspective. Another limitation lies in the inability to conduct a comparative analysis of the literature on the topic, mainly because the adoption of a systemic approach, aiming to create a common field of reflection, and naturally identify connections between systems, is still relatively unexplored. A final limitation is the inability to provide specific guidelines and operational actions for professionals involved in territorial transformations. Nonetheless, the objective is to eventually define guidelines, possibly even regulations, within Italian urban planning, that can align with the approach described.

However, highlighting the systemic common denominator, and the connections that can be identified between ecosystem services and urban subsystems, can be particularly useful in urban planning, as it can configure a new dimension of territorial transformation governance, originating from the need to safeguard resource generators and minimize anthropic entropy. This type of consideration appears particularly relevant today, in relation to the scarcity of available resources, the sudden and increasingly impactful changes that are occurring, and in particular, the increasing anthropic entropy that causes increasing degradation, and a high level of uninhabitability, within urban systems.

The thinking that has been proposed in this paper could also be a further contribution to the transition process from Smart City to Eco City, and could contribute to the field of sustainable urbanism [25]. The development of approaches, methods, and procedures that support this evolution should be a common commitment of researchers of urban phenomena.

This reflection fits into the broader consideration that should characterize scientific research activities and, more generally, the task of scholars in every discipline: to share perspectives toward the progress of humanity, in order to overcome the climatic crisis and the self-destructive inversion of the human species. Scientific research must envision and formalize methods and procedures to define a new balance between humans and the environment. The human species constitutes only 2% of the living organisms on planet Earth, yet it is the only species that pollutes its own habitat, and employs a significant portion of its intelligence—which is unique among living beings—in developing technologies of destruction for use in war events oriented toward mutual elimination. Currently, there are over 13,000 nuclear weapons and warheads in the world, and an annual production expense of about two trillion dollars on devices to be employed in conflict. Engaging in defining theories and methods useful to generating a new consideration of the values of nature, and the services it provides to humankind to ensure its survival, such as ES, represents an attempt to contribute to constructing a new awareness of "respectful development". This awareness, in some ways, even goes beyond the concept of sustainable development.

The future of humanity will be decided in cities. We can no longer ignore the necessity to develop policies and actions to ensure that cities can develop in balance with available resources.

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References

1. Ndong, O.O.; Therond, O.; Cousin, I. Analysis of relationships between ecosystem services: A generic classification and review of the literature. *Ecosyst. Serv.* **2020**, *43*, 101120. [CrossRef]
2. Cordella, M.; Gonzalez-Redin, J.; Lodeiro, R.U.; Garcia, D.A. Assessing impacts to biodiversity and ecosystems: Understanding and exploiting synergies between Life Cycle Assessment and Natural Capital Accounting. *Procedia CIRP* **2022**, *105*, 134–139. [CrossRef]
3. Millennium Ecosystem Assessment 2005. Available online: https://www.millenniumassessment.org/documents/document.356.aspx.pdf (accessed on 1 May 2022).
4. von Bertalanffy, L. *General System Theory*; Penguin Books: Harmondsworth, UK, 1972.
5. Papa, R.; Battarra, R.; Fistola, R.; Gargiulo, C. The city as a complex system in structural crisis. *TeMA J. Land Use Mobil. Environ.* **2021**, *14*, 455–491.
6. Costanza, R. Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. *Ecosyst. Serv.* **2020**, *43*, 101096. [CrossRef]
7. Fistola, R. *ME-Tropolis-Funzioni Innovazioni Trasformazioni Della Città*; I.Pi.G.E.T. CNR, Giannini: Napoli, Italy, 2001.
8. Mc Loughlin, J.B. *La Pianificazione Urbana e Regionale*; Marsilio: Padova, Italy, 1973.
9. Regulsky, J. *La Pianificazione Della Città: Un Approccio Sistemico*; Officina Edizioni: Rome, Italy, 1981.
10. Condon, P.M. Rule one: See the city as a system. In *Five Rules for Tomorrow's Cities: Design in an Age of Urban Migration, Demographic Change, and a Disappearing*; Island Press: Washington, DC, USA, 2019.
11. Fistola, R. La città come sistema. In *Per il XXI Secolo Una Enciclopedia. Città Cablata e Nuova Architettura*; Beguinot, C., Cardarelli, U., Eds.; Università degli Studi di Napoli "Federico II" (Di.Pi.S.T.), Consiglio Nazionale delle Ricerche (I.Pi.Ge.T.): Napoli, Italy, 1992; Volume II, Chapter 2.
12. Lynch, K. *The Image of the City*; MIT Press: Cambridge, MA, USA, 1960.
13. Fistola, R. Ecourbanistica: Toward a new sustainable town planning. In *The Sustainable City VI. Urban Regeneration and Sustainability, the Sustainable City VI*; Brebbia, C.A., Hernandez, S., Tiezzi, E., Eds.; WIT press, WIT Transactions on Ecology and The Environment, Vol. 129, Section 1: Planning, development and management; WIT Press: Southempton, UK, 2010.
14. Wallace, K. Ecosystem services: Multiple classifications or confusion? *Biol. Conserv.* **2008**, *141*, 353–354. [CrossRef]
15. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.R.; Turner, R.K. Changes in the global value of ecosystem services. *Glob. Environ. Chang.* **2014**, *26*, 152–158. [CrossRef]
16. Rifkin, J. *Entropy: Into the Greenhouse World*; Bentam: New York, NY, USA, 1989; Rev Rei edition.
17. Miller, H.; Page, S. *Complex Adaptive Systems, an Introduction to Computational Models of Social Life*; Princeton University Press: Princeton, NJ, USA, 2007.
18. Zoppi, C. Ecosystem Services, Green Infrastructure and Spatial Planning. *Sustainabilty* **2020**, *12*, 4396. [CrossRef]
19. Ronchi, S. *Ecosystem Services for Spatial Planning. Innovative Approaches and Challenges for Practical Applications*; Springer Nature: Cham, Switzerland, 2018.
20. Tondelli, S.; Arcidiacono, A. Suolo e servizi ecosistemici nella pianificazione urbanistica. *Urban. Inf.* **2022**, *305*, 46–48.
21. Odum, H.T. *Ecological and General Systems: An Introduction to Systems Ecology*; Colorado University Press: Niwot, CO, USA, 1994.
22. Pulselli, R.M.; Tiezzi, E. *Città Fuori Dal Caos. La Sostenibilità Dei Sistemi Urbani*; Donzelli Editore: Rome, Italy, 2008.
23. Zhang, Z.; Shen, Z.; Liu, L.; Zhang, Y.; Yu, C.; Cui, L.; Gao, Y. Integrating ecosystem services conservation into the optimization of urban planning policies in eco-fragile areas: A scenario-based case study. *Cities* **2023**, *134*, 104200. [CrossRef]
24. Bolund, P.; Hunhammar, S. Ecosystem services in urban areas. *Ecol. Econ.* **1999**, *29*, 293–301. [CrossRef]
25. Bibri, S.E.; Krogstie, J. Smart Eco-City Strategies and Solutions for Sustainability: The Cases of Royal Seaport, Stockholm, and Western Harbor, Malmö, Sweden. *Urban Sci.* **2020**, *4*, 11. [CrossRef]

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Effects of Urban Planning on Ecosystem Services: The Umbria Region Seismic Crater

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Abstract: The earthquake in central Italy in 2016 led to a profound urban and natural landscape transformation. The role of territorial planning in this kind of situation is extremely important because it allows the orientation of future settlement choices through appropriate interpretative keys of the existing territorial dynamics. This work aims to analyze the effects of the planning choices made in the post-earthquake period in the seismic crater municipalities of the Umbria region. Using the InVEST models, these studies regard the comparison of the effects of in-force plans on ecosystem services such as habitat quality and carbon storage. The data about the mosaic of the municipal urban planning tools are derived from specific actions produced under two LIFE projects (SUNLIFE and IMAGINE). The comparison makes it possible to identify how and to what extent the transformative scenarios, linked to the new condition, change the spatial planning compared to the previous one and the effects on the provision of ecosystem services. The knowledge of the latter aspect allows optimization of the methods of urban transformation that will be implemented. Moreover, this process of optimizing the provision of essential ecosystem services could certainly play a key role in the enhancement and economic recovery of these areas.

Keywords: ecosystem services; spatial planning; performance-based planning

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1. Introduction

Among the most seismically dangerous areas in Europe, the Italian Apennines have, in recent years, been affected by numerous seismic events of significant intensity [1,2]. The seismic events caused significant damage to the historical centers, and consequently, a reorganization of urban structures [3,4]. This reorganization was highly dependent on the demographic and urban dimensions of the municipalities involved. It has had an internal structural component (aimed at rebuilding the damaged heritage) and a functional external one (both assigning new roles to the centers and recreating relationships). Both processes are still ongoing and have led to a new urban geography of the inner areas of central Italy. The earthquakes that occurred from 2009 to 2016 affected several important urban centers (L'Aquila 2009; Amatrice 2016; Norcia 2017) located in four different Italian regions (Umbria, Abruzzo, Lazio, and Marche) [5]. Following each earthquake, several regulative measures were issued with the aim of defining the municipalities concerned within which the reconstruction processes were defined. The effects of the earthquake directly affected economic activities, housing stock, and local communities, and also, the indirect effects on the environmental system were not negligible. There were effects such as: landscape fragmentation, the loss of crops and food resources, deteriorating water quality and water availability, soil erosion that led to the future reduction in agricultural production, the loss or deterioration of natural habitat, and threatened or reduced biodiversity [6–9]. The regulations issued in the various seismic craters have generated an important consumption of soil related to the construction in different areas of "temporary" housing, much of which today needs indispensable support from recovery operations (e.g., project C.A.S.E.

(Sustainable and Eco-friendly Seismic Complexes) and the S.A.E. (Housing Solutions in Emergency)), and also for the possibility of providing their own accommodation [10]. Many of these achievements largely escaped the control of spatial planning and contributed to an increase in the pre-existing dispersed configuration that characterized these areas [11]. Often many of these buildings were built in areas at risk (landslides, floods) and without considering the environmental component. For example, little attention has been paid to the effects on the environmental system in terms of the loss of ecosystem services, environmental fragmentation, habitat degradation, and habitat loss [12–14]. Figure 1 shows that the central Apennines represents an extremely important reservoir of biodiversity in the national and European context. There are in fact several National Parks and Natura 2000 network sites. As for the Umbria region, the protected territory corresponds to 19% of the entire regional area, which consists of a National Park, seven Regional Parks, and numerous areas of the Natura 2000 network. This paper focuses on the urban transformations that have affected the municipalities of the 2016 earthquake crater in the Umbria region with the aim of evaluating the effects of these changes on the ecosystem services (carbon storage and sequestration and habitat quality) while analyzing whether, in the municipalities that have updated their urban plan, the important aspect of the ecological value of these territories has been considered.

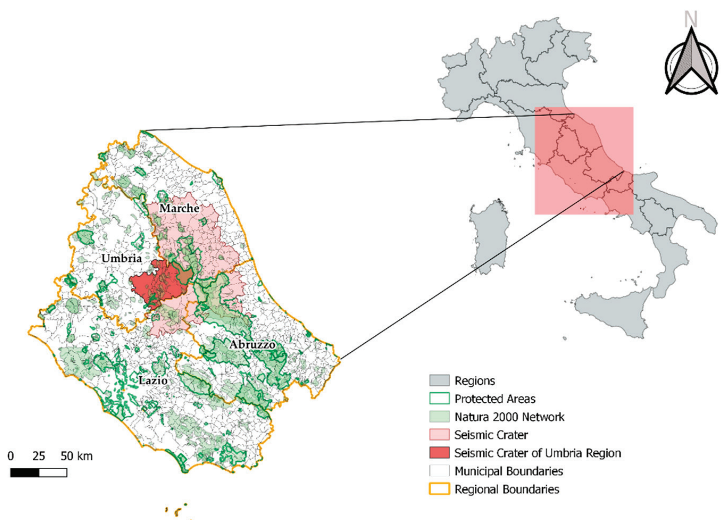


Figure 1. Geographical view of the seismic crater with areas under environmental protection.

2. Study Area

The study area concerns the 15 municipalities of the Umbria region included in the seismic crater of 2016 (Figure 1). A first list was compiled with the Decree-Law No. 189 of 17 October 2016 inserting 62 centers distributed over 4 regions. This list was then updated with Decree-Law No. 205 of 11 November 2016 following the earthquake of 30 October 2016, before arriving at the final list of the 69 municipalities included in the seismic crater described in Annex 2 of Law No. 229 of 15 December 2016. In summary, the 2016 earthquake involved 4 regions, 10 provinces, and 138 municipalities [15]. The studied area covers an area of 1400 km^2 (17% of the regional area). In these municipalities, the population in 2021 was about 55,000 inhabitants (6.4% of the regional population). This value is lower than the 2016 population which was 57,560 inhabitants, equal to 6.5% of the regional population [16]. From an environmental point of view, 5% of the study area is covered by protected areas and some of the municipalities involved fall within the boundaries of the Monti Sibillini National Park (Preci and Norcia) and the Nera River Regional Park (Arrone, Ferentillo, Montefranco, Polino). There are several Natura 2000 sites and protected areas; for this reason, this area is important in the environmental context of central Italy, for the system of connections between areas with different degrees of protection.

3. Materials and Methods

The analysis was conducted using data from different sources. First, a survey of municipal urban plans was carried out considering the 2015–2021 timeframe. The main reason for this research was to verify which municipalities had updated their urban plans following the earthquake in 2016. In this way, it was possible to reconstruct the framework of the transformations planned by the municipalities before and after the earthquake. This allowed verification of the behavior adopted by individual municipalities to respond to the seismic emergency. As already described in previous works [17–19], the synoptic descriptions associated with the allowed transformative types are extremely different between the various entities. To analyze the regulatory framework of new urbanization, the mosaic of municipal plans (Planning Tool Mosaic, PTM) was created for the study area (Figure 2). The PTM required the retrieval of plans at the institutional portals of the individual municipalities, a pre-elaboration (georeferencing, digitization, elaboration of the union framework) and the reclassification according to the homogeneous territorial zones defined by Ministerial Decree 2 April 1968, No. 1444. This process involves a certain discretion in the zonal attribution; however, this is a reversible process because the original description of the area is always preserved in the database. The territorial zones are thus defined as:

- (A) parts of the territory concerned by urban agglomerations that have a historical, artistic character and of particular environmental value or portions of them, including surrounding areas, which may be considered to be an integral part, for those characteristics, of the agglomerations themselves;
- (B) parts of the territory that have been totally or partially built up, other than (A) zones: partially built up are those areas in which the covered area of existing buildings is not less than 12.5% of the buildable area and in which the territorial density exceeds 1.5 m^3/m^2;
- (C) parts of the territory intended for new settlement complexes, which are unbuilt or in which the pre-existing building does not reach the limits of surface area and density referred to in point (B);
- (D) parts of the territory intended for new settlements for industrial installations or similar;
- (F) parts of the territory intended for equipment and installation of general interest, public spaces, or spaces reserved for collective activities, public green, or parking, with the exclusion of spaces intended for road locations.

The ecosystem services analysis was conducted through the open-source software InVEST (Integrated Assessment of Ecosystem Services and Tradeoffs) version: "InVEST 3.11.0 Workbench", which is a suite of models, including that of Carbon Storage and Sequestration (CSS) and that of Habitat Quality (HQ). These two models were used in this study. The methodologies used for the evaluation of models follow the flowchart already tested in other geographical areas [20], and were customized for this work as shown in Figure 3.

The ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) data on land use were used for the assessment of these ecosystem services. The data used can be found at the following link https://www.isprambiente.gov.it/it/banche-dati/banche-dati-folder/suolo-e-territorio/uso-del-suolo (accessed on 15 September 2022). Two years were considered: 2012 (the one closest to the date of the earthquake) and 2021. The geometric resolution of the data is 10 m/pixel. The analysis of the amount of carbon stored was carried out using the Carbon Storage and Sequestration model. The model (based on the IPCC guidelines [21]) requires four types of carbon pools: epigeal biomass, hypogeal biomass, soil and dead organic matter. Input data for land use were derived from the SimulSoil database using the different sources [22–24] and adjusting the legend to the one in the ISPRA land cover data. SimulSoil is a computer application that allows to perform balances of ecosystem functions of the territory. The tool allows downloading a land use data package at the national level [25].

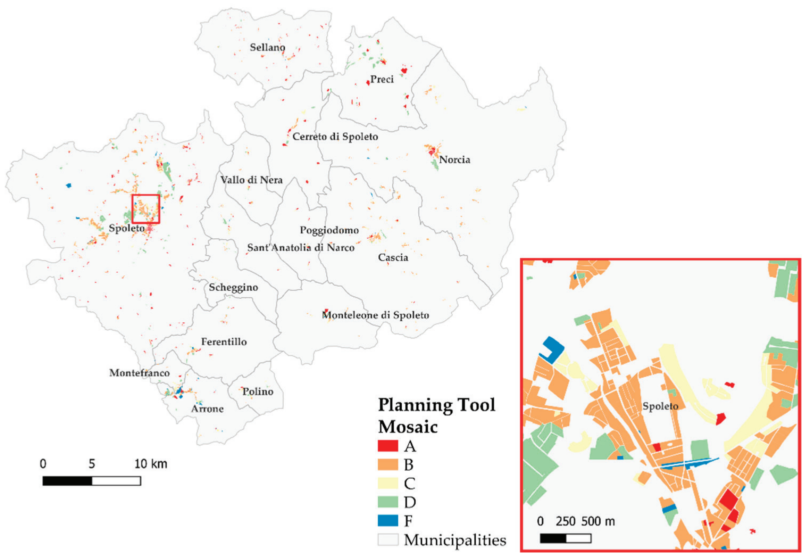


Figure 2. Geographical view of the study area with Planning Tool Mosaic. Detail of PTM on the right.

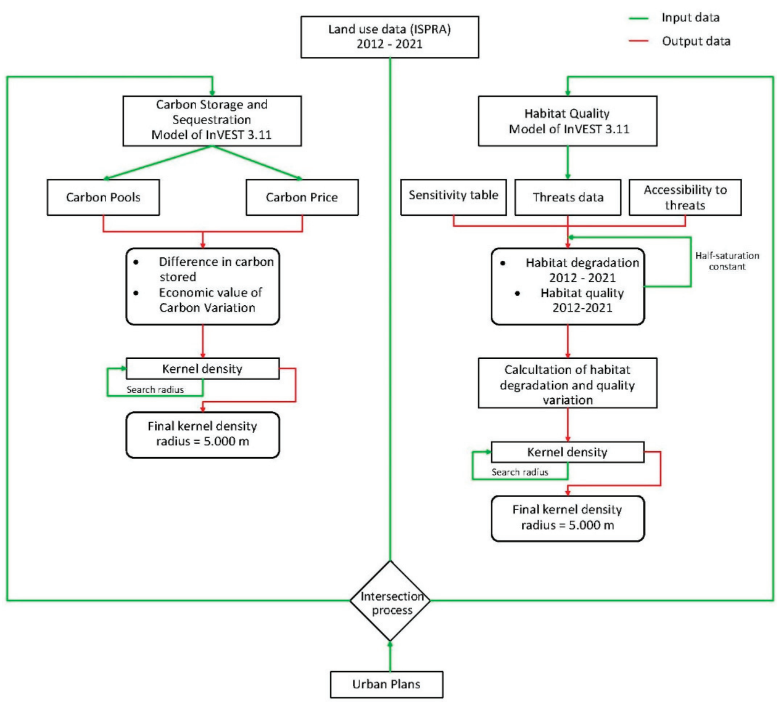


Figure 3. Flowchart of used analysis methodology.

The economic value of the seized carbon (expressed in EUR/ton) was derived from Trading Economics (carbon price from the ETS (Emission Trading Systems) market on 15 September 2022 https://tradingeconomics.com/commodity/carbon (accessed on 15 September 2022). Moreover, the assessment of habitat quality input data refers to the same two chrono sections as previously indicated, using the SimulSoil database for the adaptation of the legends for inclusion in the relevant InVEST model. Parameters relating to habitat suitability and threats present in the investigated territory were also included in the input [20].

The sensitivity of the habitat to the threats considers the interferences of the anthropized system and the agricultural areas, and therefore is classified as follows:

Urban: codes 3 and 4 of the ISPRA legend (Table 1), both for the 2012 scenario and for the 2021 scenario;

Table 1. Legend of ISPRA land uses for the study area.

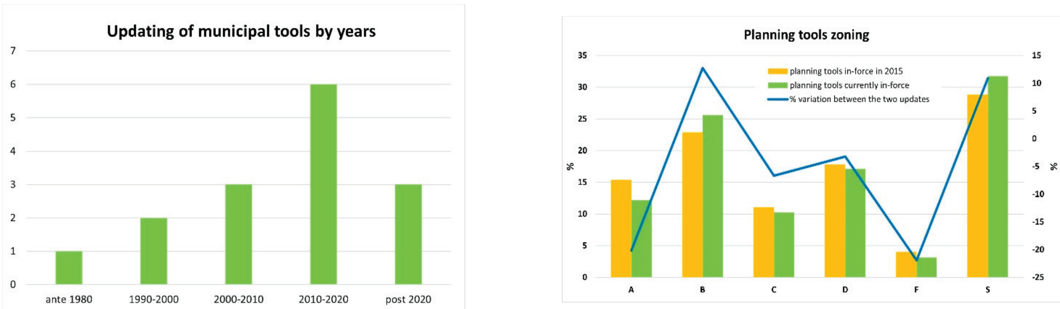
ISPRA Legend	
CODE	**Description**
2	Forest use
3	Quarries and mines
4	Urban and similar areas
5	Water uses
11	Arable crops
12	Forage
13	Permanent crops
14	Agro-forestry areas
16	Other agricultural uses
61	Wetland areas
62	Other non-economic uses

Agricultural: codes 11, 12, 13, 14, 16 ISPRA legend (Table 1), both for the 2012 scenario and for the 2021 scenario.

For this type of model, a buffer of 1 km was made on the boundary of the study area; in this way, it is possible to consider the edge effect caused by Habitat Quality in the model of InVEST. Edge effects refer to changes in the biological and physical conditions that occur at a patch boundary and within adjacent patches. The identification of the hotspots and coldspots related to the losses of ecosystem services investigated in output to the InVEST model was evaluated through the Kernel analysis with a bandwidth of 5000 m. This distance results from an iterative process aimed at identifying the distance at which such concentrations emerge clearly. We used the QGIS v.3.16 tool "Kernel Density Estimation" choosing as Kernel shape "Epanechnikov".

4. Results

As shown in Figure 4a, 9 of the 15 municipalities analyzed have an urban plan that was updated after 2010, of which 7 updated their instrument after the earthquake of 2016. The analysis was carried out by studying changes in urban plans and their effects on the territory in terms of the loss of ability to provide the ecosystem services previously mentioned. The updated plans, when compared with the previous ones, show an increase in areas destined for urban completion, together with those destined for services (Figure 4b). For the same period, the demographic trend analysis reveals a demographic decline for all the municipalities. This phenomenon is typical of the Italian inland areas and it is now accentuated by the recent earthquakes. On the other hand, the excessive oversize of the transformative forecasts of the plans emerges. In fact, despite the demographic decline, the sizing of the plans is widened. Their full implementation would have significant effects on the environmental system.



(**a**) (**b**)

Figure 4. Information about municipal urban plans in force in the study area: (**a**) Updating period of municipal planning tools. (**b**) Comparison of the territorial zones between municipal urban plans in force before 2015 and currently in force.

Moreover, many of these predictions are still out of date. As shown in Figure 5, planned but not yet urbanized areas of most municipalities are very high. Residential areas (zones B and C) in most of the analyzed territories do not exceed 50% of the implemented areas. Lower percentages are found both for production areas (D zones) and for areas intended for services (S zones).

Regarding the assessment of the ecosystem services, the first analysis carried out concerned changes linked to land use changes between 2012 and 2021. This allows both evaluation of the geographical location of the variations (positive and negative) and to understand which were the drivers that led to this new arrangement. The lack of carbon sink amounts to about 950 Mg, and is more concentrated in the municipality of Norcia, and in the municipality of Monteleone di Spoleto (Figure 6). In the latter case, these are losses linked to changes in land use that are not particularly linked to the urbanization processes resulting from the earthquake but rather to different types of use. In the case of the municipality of Norcia, as shown in Figure 7 the aspects related to the first response to the housing emergency have played a major role in the loss of the ability of the soils to store carbon. Moreover, in the municipality of Norcia, and in particular in the territory bordering the Marche and Lazio Regions, the abandonment of some agricultural areas has led to an increase in the capacity of these soils to store carbon (in green in Figure 6). The same condition was found in the territories between the municipalities of Montefranco and Spoleto. In economic terms, the total loss of these changes amounts to around 8000 EUR/y.

As previously mentioned, in this work, the effects of plan choices on two ecosystem services are highlighted. Specifically, the scenarios obtained from the urban forecasts of the pre- and post-earthquake plans are compared. Using InVEST models shows that the capacity to store carbon in 2021 was over 16 million Mg of carbon. The hypothetical scenario derived from the implementation of the settlement forecasts, contained in the plans, was constructed through the overlap of the PTM to land uses of 2021. In other words, it was assumed that the current uses were entirely replaced by urban ones as provided by the plans. The data output of this process was used as data input into InVEST to verify the loss of capacity to store carbon of the soil involved. There was a difference of about 132,000 Mg of carbon equivalent to an economic loss of about EUR 10 million. The municipalities in which the loss of carbon storage is greatest are Spoleto (67,122 Mg), Norcia (14,900 Mg), and Cascia (12,980 Mg). For the municipalities that updated their plans, the 2016 urban forecasts were compared with the ones of 2021. Significant negative variations in carbon storage capacity were detected in the municipalities of Norcia and Poggiodomo. For the municipality of Cascia, the removal of several residential and productive areas has had a positive impact in terms of soil storage capacity.

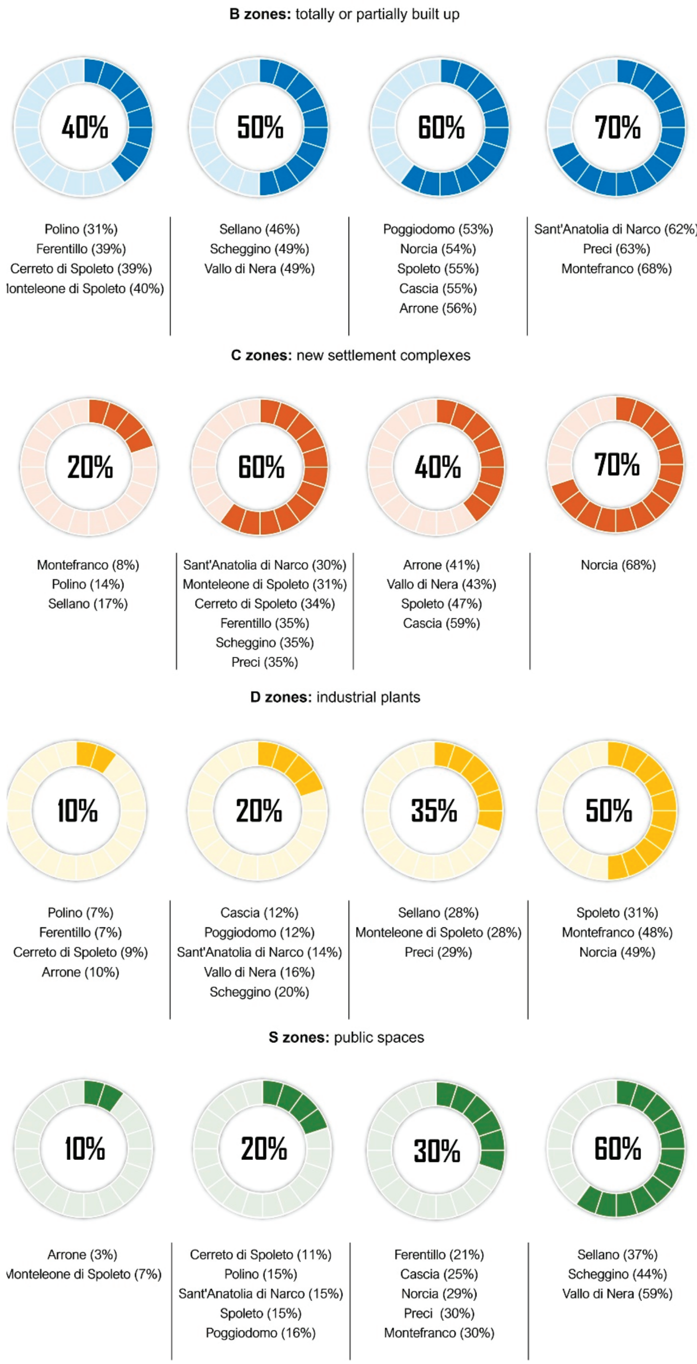


Figure 5. Geographical view of the study area with Planning Tool Mosaic. Detail of PTM on the right.

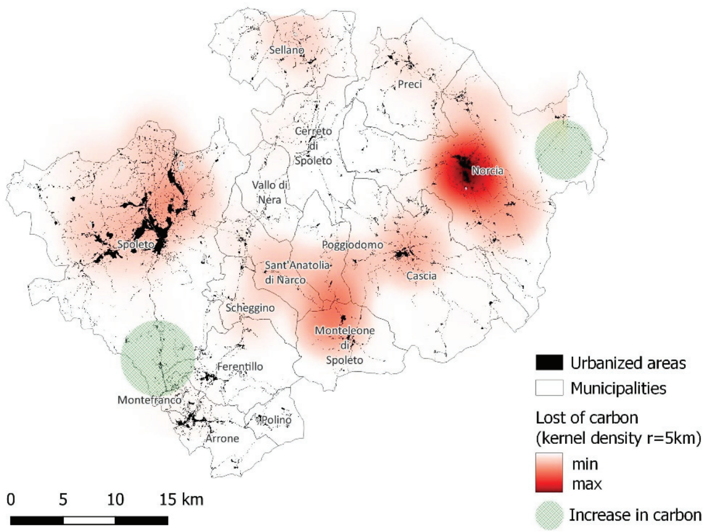


Figure 6. Variation in carbon sequestration between 2012 and 2021 in plans of municipalities that updated the urban plans.

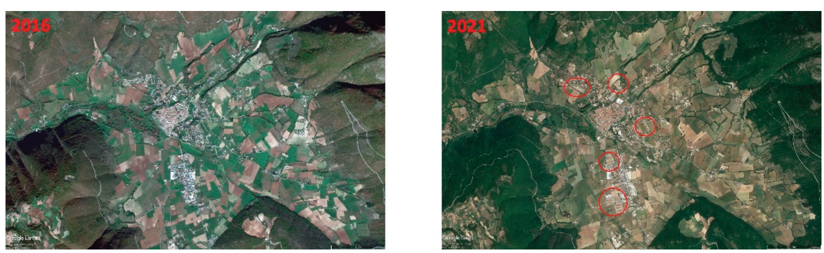


Figure 7. Comparison between the pre-earthquake and post-earthquake geography of the main urban area of the municipality of Norcia.

The effects of land use variations on the quality of habitats are shown in Figure 8. Additionally, in this case, a kernel analysis was carried out using a 5000 m bandwidth. A significant increase in degradation of the habitat quality was found in the municipality of Spoleto, specifically in the hamlet of San Giovanni di Baiano and San Martino in Trignano. This phenomenon is mainly due to the increase in agricultural activity with the loss of forest areas. Additionally, in Norcia, the situation was similar but linked to the construction of new urban areas resulting from the earthquake. Conversely, increases in the habitat quality were found in the municipality of Spoleto (hamlets of Cortaccione and Eggi). The reasons for this occurrence are linked to both the increase in forest areas and to changes in crop typologies.

Moreover, this ecosystem service was carried out as an analysis to evaluate the effect of the implementation of the plans' forecasts. The image in Figure 9 and Table 2 show the results obtained. Currently, more than 22 km^2 of the transformative forecasts of the plans remain to be implemented, most of which are intended for services (9.8 km^2) and residential use (9.1 km^2). The greatest impact in terms of habitat degradation would be in the municipality of Spoleto, which alone concentrates 45% of the areas for residential use not yet implemented and about 60% of those intended for services. The area between the municipalities of Norcia and Cascia, as already highlighted above, could potentially suffer further negative effects linked to the implementation of the forecasts, which, as shown in Table 2, still have outdated percentages higher than 50% of the zonal destinations considered.

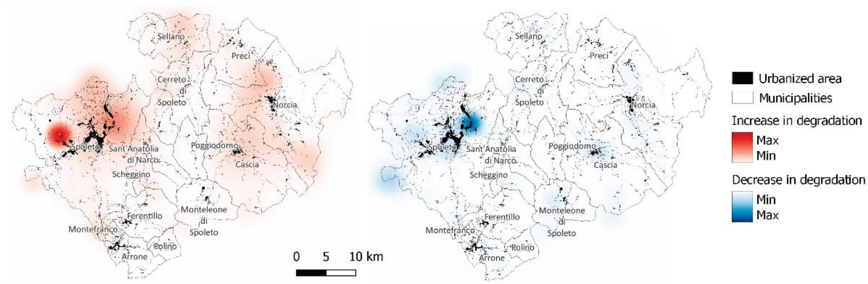


Figure 8. Increasing and decreasing changes in habitat quality in the area surveyed between 2012 and 2021. The variations are a function of land use changes.

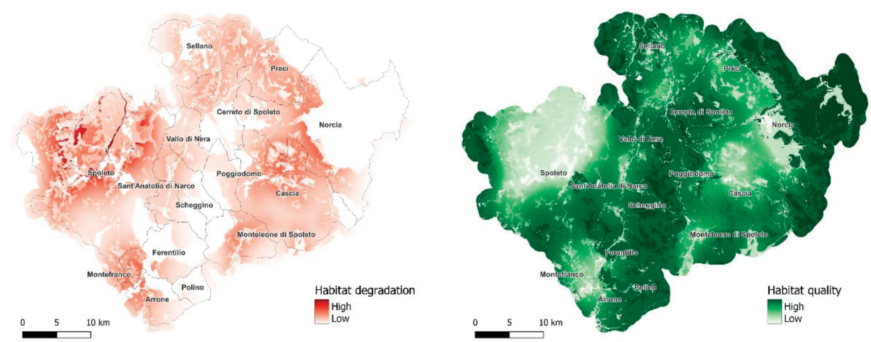


Figure 9. Effects on the quality of the habitats linked to the possible implementation of all the settlement forecasts contained in existing municipal urban plans.

Table 2. Total and percentage planning forecasts not yet implemented for each zone type in the municipalities investigated.

Municipalities	B + C Zones		D Zones		S Zones	
	Surface (ha)	Planned but Not Urbanized Areas (%)	Surface (ha)	Planned but Not Urbanized Areas (%)	Surface (ha)	Planned but Not Urbanized Areas (%)
Arrone	75.0	52.4	26.8	52.9	48.9	77.3
Cascia	182.8	56.7	10.1	43.0	85.3	75.0
Cerreto di Spoleto	65.3	68.4	10.7	67.4	41.9	88.7
Ferentillo	50.8	63.7	11.9	69.1	10.5	70.5
Montefranco	24.2	42.5	6.7	94.0	5.2	68.1
Monteleone di Spoleto	42.5	61.4	2.0	78.4	13.4	90.6
Norcia	200.9	44.1	43.2	32.4	173.7	72.8
Poggiodomo	15.3	53.6	0.0	0.0	7.9	84.4
Polino	19.0	76.1	5.3	89.3	2.4	88.4
Preci	110.0	67.8	100.2	77.1	1.6	72.0
Sant'Anatolia di Narco	20.9	57.1	12.0	72.8	31.1	84.8
Scheggino	10.6	64.4	5.0	64.8	11.9	57.1
Sellano	66.9	47.6	6.0	83.1	44.3	62.5
Spoleto	795.6	51.4	363.6	53.9	754.4	83.2
Vallo di Nera	22.0	60.6	3.0	54.6	3.0	48.9
Total	1701.8	53.8	606.5	58.1	1235.7	80.0

Even in the municipality of Preci, there is over 150 ha of land with urban destinations not yet implemented, and that would lead to a depletion in the quality of habitats in an area of high ecological value affected by the Sibillini Mountains National Park. The rugged morphology that marks the border between Umbria and the Marche that affects the municipalities of Norcia and Preci, together with the presence of the National Park, represent the reasons for the high quality of the habitats found in this area.

5. Discussion

This work is part of a research project that analyses the effects of urban change and land use on ecosystem services. Specifically, there are several works that analyze these issues. Nowadays, ecosystem services (ES) mapping is attracting growing interest from landscape and urban planning, but its operationalization in actual decision making is still limited. The mapping of ES capacity, flow, and demand can contribute to the successful integration of the ES approach in landscape and urban planning because it provides a comprehensive picture of the ES delivery process, considering both ecological and social underlying factors [26,27]. The theme of ecosystem services (SE) in support of urban planning practices becomes fundamental for the preliminary assessment of environmental effects and the consequent economic and social consequences of urbanization [28]. The environmental approach to land use planning is mainly referred to in the bureaucratic procedure of plans' approval rather than the construction of a knowledge system embedded within the strategic environmental assessment procedure. Notably, a great number of skills are required to improve the technical framework for land use sustainability considering its practical application [29]. Urban planning practices should integrate soil quality evaluation procedures to achieve rational urban planning with regard to soil consumption and to ensure less destructive methods with regard to the capacity of the soil to perform its environmental functions. The methods should facilitate effective soil evaluation, and enable planners to recognise the environmental quality of soil, its properties, spatial location, and extent in urban and suburban areas. The outputs of the methods should be developed to the level where they can be easily integrated into existing planning procedures and used in local communities with little adaptation by local experts [27,30].

In this specific case study, the highest limit is linked to the territorial scale. In fact, the study area is small to correctly evaluate some ecosystem services, but, at the same time, it is necessary to work at this scale to fully understand the changes in land use induced by the earthquake. These transformations occurred in a very short time compared to non-emergency periods.

The results of the work clearly show the effects in terms of the loss of the ability of soils to store carbon and those related to changes in habitat quality. The study also quantified the economic damage due to the possible implementation of all the urban planning forecasts, a loss that amounts to about EUR 10 million /y. The consumption of land that occurred in the considered period is linked in large part to the construction of both the S.A.E. concentrated mainly in the municipalities of Norcia, Preci, and Cascia and of private interventions to respond to the housing emergency caused by the earthquake [31]. The laws refer to temporary structures but not to the restoration of the original soil condition at the end of the emergency. This happened also in L'Aquila, after the 2009 earthquake.

As proof of the above, the municipalities that have updated the urban plan after the earthquake of 2016 indicated these areas in the plan as "Aree per la gestione dell'emergenza Sisma 2016" (Regional Law No.8/2018 of the Umbria region), which are areas for the management of the emergency after the earthquake. For these areas, after the emergency, this is preventing the maintenance and recovery of existing buildings, equipment, technological systems, and open spaces during the emergency period. At the end of this phase, however, restoration of the previous conditions is not foreseen, but the predictions of urban reuse are in accordance with what is stated in Art. 26 of the Regional Law No.8/2018 of the Umbria region. In essence, for these areas, the legislation attributes a large panel of possibilities for reuse. These areas could therefore be used for: areas equipped or to be equipped for recreational–tourist–sports use, public facilities, civil protection functions, residential settlements, settlements for activities and services—tourism, sport, leisure, hospitality, reuse of reception equipment—tourism, settlement for activities and services, and areas for any relocation of functions and services. If on the one hand, the pre-existing ecosystem services will barely be recovered, it is true that their geographical position is felt to integrate the existing building fabric. In fact, the S.A.E. are in areas adjacent to the already urbanized territory and this has contained land consumption (e.g.: construction of new ancillary and connecting roads) and made these areas, as mentioned, potentially integrable in the pre-existing urban context.

On the contrary, the criteria used for the localization choices of the interventions in the earthquake of L'Aquila in 2009 did not foresee this possibility at all [32,33] as these are mainly aimed at limiting hydrogeological risk. Moreover, it should be stressed that none of the residential areas (B and C) of the old urban plan (1975) of the capital of the Abruzzo region have been affected by the emergency interventions of public initiatives (project C.A.S.E. and M.A.P. (temporary housing modules)) [34] with the result of creating, in fact, new parts of the cities in areas mainly for agricultural use, without consequent planning of the necessary services. The recovery for many of these areas and their re-functionalization in the urban context, already heavily dispersed, seems extremely difficult and complex [35].

6. Conclusions

This work on the one hand highlights the effects on the environmental system (ecosystem services) linked to the 2016 earthquake emergency, and on the other shows the differences with the L'Aquila earthquake (2009) in terms of urban transformation management. As underlined in this work, these differences require different approaches in view of the restoration/improvement of both the ecosystem services provision and the urban dynamics management. In this sense, the assessment of the ecosystem services before and after the earthquake provides a clear framework of the losses generated by the urban transformations induced by the emergency. In addition, this analysis provides a view of the environmental potential of these territories. An important novelty of the work is that relating to the assessment of the change in the provision of ecosystem services in an area affected by a large-scale calamitous event that triggered a series of social, environmental, and urban changes that in normal conditions would have involved a certainly wider time interval.

Indeed, the earthquake of 2016 that affected the central Italian Apennines profoundly upset the social, urban, and environmental dynamics of the centers involved. The processes of demographical desertification [36,37], already underway in some of the areas investigated, were further intensified, in particular in the hamlets, some of which suffered profound structural damage to the housing stock. Often they were houses used only in particular periods of the year, and for this reason, it is highly unlikely that they will be rebuilt in the near future, mainly because of legislative restrictions.

In these areas, the transformative energies that were in sharp decline left room for the resumption of natural processes and ecosystem services associated with a consequent increase in ecological value. The earthquake of 2016, as often happens in these cases, marked a point break in the existing equilibrium in the area. In the larger municipalities such as Cascia and Norcia, the realization of the S.A.E. has generated new land consumption in the immediate area from before where it was used for agricultural purposes or where the vegetational aspect prevailed.

As mentioned, these areas represent new parts of the future city settlement, which will be strongly integrated into the existing fabric. In the new plan of Norcia, the issue of the containment of land consumption has been one of the objectives and the actions taken move in this direction, favoring the recomposition of the urban margins and limiting the settlement's dispersion. Moreover, for the municipality of Cascia, the positive effects of both carbon sinks and habitat quality are attributable to the new zoning plan that has essentially removed many of the areas with urban destinations not implemented in the previous instrument.

The same act approved by the Umbria region, with which a specific measure of the Decree-law for the earthquake is implemented (Art. 14 D.L. No. 8 of 9 February 2017, published in the Official Gazette No. 33 of 9 February 2017), provided that the regional authority could buy housing as an alternative measure to the S.A.E., thus encouraging the reuse of existing housing assets not damaged by the earthquake. These buildings then became part of the public housing stock and were used for the public response to the housing emergency. While this issue has nevertheless been addressed in the urban plans approved after 2015 and in the regional measures, none of these focus on ecosystem services. An attempt has been made to provide an immediate response to the housing emergency without considering at the same time the potential loss of eco-systemic services. This work, however, highlights both the effects of the territorial dynamics induced by the earthquake on ecosystem services and the possible loss resulting from the implementation of the transformative predictions present today in the plans. If in the first case, it is not possible to go back, much can be carried out in the second. Many of these plans are oversized in the forecasts and not related to the real demographic dynamics of the territories to which they refer. Re-linking the urban forecast with demographic trends would allow a secure land saving as well as it being in line with target 11.3 of the Agenda 2030 (by 2030 enhance inclusive and sustainable urbanization and capacities for participatory, integrated, and sustainable human settlement planning and management in all countries) [38]. Knowledge of the ecosystem services provided by the soil, together with the current urban planning would allow planners to geographically position the new parts of the built area so as to maximize performance in terms of services and minimize the environmental impacts. It is clear that a limit is linked to the reduced territorial scale of investigation, which could lead to non-exhaustive assessments of the ecosystem services. The future research lines, as also indicated in the LIFE IMAGINE project, intend to extend these assessments to the entire regional territory to provide an overall framework of the environmental potential. This could allow orientation of the future urban plan in an ecosystem, safeguarding the potential of the territories and also in anticipation of future emergencies.

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References

1. Zullo, F.; Marucci, A.; Fiorini, L.; Romano, B. The Italian Apennines between earthquakes, high naturalness and urban growth. *Environ. Plan. B Urban Anal. City Sci.* **2020**, *47*, 716–731. [CrossRef]
2. Console, R.; Vannoli, P.; Falcone, G. Magnitude distribution and clustering properties of the 3-D seismicity in Central Apennines (Italy). *Geophys. J. Int.* **2023**, *233*, 2004–2020. [CrossRef]
3. Romano, B.; Zullo, F.; Fiorini, L.; Ciabò, S.; Marucci, A. Sprinkling: An Approach to Describe Urbanization Dynamics in Italy. *Sustainability* **2017**, *9*, 97. [CrossRef]
4. Domenella, L.; Galasso, M.; Marinelli, G.; Rotondo, F. Planning seismic Inner Areas in Central Italy. Experimental application for the infrastructural project, lifeline and resilient public space in the shrinking territory. *Transp. Res. Procedia* **2022**, *60*, 140–147. [CrossRef]
5. Brando, G.; Pagliaroli, A.; Cocco, G.; Di Buccio, F. Site effects and damage scenarios: The case study of two historic centers following the 2016 Central Italy earthquake. *Eng. Geol.* **2020**, *272*, 105647. [CrossRef]
6. Duan, Y.; Di, B.; Ustin, S.L.; Xu, C.; Xie, Q.; Wu, S.; Li, J.; Zhang, R. Changes in ecosystem services in a montane landscape impacted by major earthquakes: A case study in Wenchuan earthquake-affected area, China. *Ecol. Indic.* **2021**, *126*, 107683. [CrossRef]

7. Cui, P.; Chen, X.-Q.; Zhu, Y.-Y.; Su, F.-H.; Wei, F.-Q.; Han, Y.-S.; Liu, H.-J.; Zhuang, J.-Q. The Wenchuan Earthquake (12 May 2008), Sichuan Province, China, and resulting geohazards. *Nat. Hazards* **2011**, *56*, 19–36. [CrossRef]
8. Zhang, J.; Hull, V.; Xu, W.; Liu, J.; Ouyang, Z.; Huang, J.; Wang, X.; Li, R. Impact of the 2008 Wenchuan earthquake on biodiversity and giant panda habitat in Wolong Nature Reserve, China. *Ecol. Res.* **2011**, *26*, 523–531. [CrossRef]
9. Wang, Y.K.; Fu, B.; Xu, P. Evaluation the impact of earthquake on ecosystem services. *Procedia Environ. Sci.* **2012**, *13*, 954–966. [CrossRef]
10. Contreras, D.; Blaschke, T.; Kienberger, S.; Zeil, P. Spatial connectivity as a recovery process indicator: The L'Aquila earthquake. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 1782–1803. [CrossRef]
11. Contreras, D.; Forino, G.; Blaschke, T. Measuring the progress of a recovery process after an earthquake: The case of L'Aquila, Italy. *Int. J. Disaster Risk Reduct.* **2018**, *28*, 450–464. [CrossRef]
12. Iannella, M.; Liberatore, L.; Biondi, M. The effects of a sudden urbanization on micromammal communities: A case study of post-earthquake L'Aquila (Abruzzi Region, Italy). *Ital. J. Zool.* **2016**, *83*, 255–262. [CrossRef]
13. Gargiulo, C.; Zoppi, C. *Planning, Nature and Ecosystem Services*; FedOA-Federico II University Press: Naples, Italy, 2019.
14. Zoppi, C.; Lai, S. Land-taking processes: An interpretive study concerning an Italian region. *Land Use Policy* **2014**, *36*, 369–380. [CrossRef]
15. Commissario Straordinario Ricostruzione SISMA 2016. Flash Rep" Sisma 2016 3° trim 2019. 2019, p. 340. Available online: https://sisma2016data.it/report/FlashRep_Restyling_A4_full_30_settembre-2.pdf (accessed on 31 October 2022).
16. Istat. Statistiche Demografiche. Available online: https://www.istat.it/ (accessed on 31 October 2022).
17. Fiorini, L.; Zullo, F.; Marucci, A.; Di Dato, C.; Romano, B. Planning Tool Mosaic (PTM): A Platform for Italy, a Country Without a Strategic Framework. *Land* **2021**, *10*, 279. [CrossRef]
18. Francesco, Z.; Cristina, M.; Chiara, C.; Bernardino, R. Ecological connectivity efficiency: A study for Maiella National Park and Abruzzo, Lazio and Molise National Park. In *SUPTM 2022: 1st Conference on Future Challenges in Sustainable Urban Planning & Territorial Management*; Universidad Politécnica de Cartagena: Cartagena, Spain, 2022. [CrossRef]
19. Montaldi, C.; Zullo, F.; Cattani, C.; Di Pietro, G. Effects of urban planning on ecosystem services. The Umbria Region Seismic Crater. In Proceedings of the 4th ESP Ecosystem Services Partnership Europe Regional Conference, Heraklion, Greece, 12 October 2022.
20. Zullo, F.; Montaldi, C.; Di Pietro, G.; Cattani, C. Land Use Changes and Ecosystem Services: The Case Study of the Abruzzo Region Coastal Strip. *ISPRS Int. J. Geo-Inf.* **2022**, *11*, 588. [CrossRef]
21. Eggleston, H.S. (Ed.) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; Institute for Global Environmental Strategies: Hayama, Japan, 2006.
22. Di Cosmo, L.; Gasparini, P.; Tabacchi, G. A national-scale, stand-level model to predict total above-ground tree biomass from growing stock volume. *For. Ecol. Manag.* **2016**, *361*, 269–276. [CrossRef]
23. Sallustio, L.; De Toni, A.; Strollo, A.; Di Febbraro, M.; Gissi, E.; Casella, L.; Geneletti, D.; Munafò, M.; Vizzarri, M.; Marchetti, M. Assessing habitat quality in relation to the spatial distribution of protected areas in Italy. *J. Environ. Manag.* **2017**, *201*, 129–137. [CrossRef]
24. Di Fabbio, A.; Di Leginio, M.; Fumanti, F.; Rischia, I. *Progetto SIAS—Sviluppo Di Indicatori Ambientali Sul Suolo in Italia*; APAT. Available online: https://www.isprambiente.gov.it/files/doc-suoli/14dileginio.pdf (accessed on 22 March 2023).
25. Simulsoil. User Guide. Available online: http://www.sam4cp.eu/wp-content/uploads/2018/06/SimulSoil_UserGuide-it.pdf (accessed on 15 February 2023).
26. Baró, F.; Palomo, I.; Zulian, G.; Vizcaino, P.; Haase, D.; Gómez-Baggethun, E. Mapping ecosystem service capacity, flow and demand for landscape and urban planning: A case study in the Barcelona metropolitan region. *Land Use Policy* **2016**, *57*, 405–417. [CrossRef]
27. Salata, S.; Giaimo, C. Nuovi paradigmi per la pianificazione urbanistica: I servizi ecosistemici per il buon uso del suolo. In *Un Nuovo Ciclo Della Pianificazione Urbanistica Tra Tattica e Strategia*; Planum-Publisher: Rome, Italy; Milan, Italy, 2016; pp. 197–202.
28. Helian, L.; Shilong, W.; Guanglei, J.; Ling, Z. Changes in land use and ecosystem service values in Jinan, China. *Energy Procedia* **2011**, *5*, 1109–1115. [CrossRef]
29. Joint Research Centre, Institute for Energy and Transport; Bertoldi, P. *9th International Conference on Energy Efficiency in Commercial Buildings and Smart Communities*; Bertoldi, P., Ed.; Publications Office: Luxembourg, 2016. Available online: https://data.europa.eu/doi/10.2790/290244 (accessed on 22 March 2023).
30. Vrščaj, B.; Poggio, L.; Marsan, F.A. A method for soil environmental quality evaluation for management and planning in urban areas. *Landsc. Urban Plan.* **2008**, *88*, 81–94. [CrossRef]
31. Trombadore, A.; Paolini, M. ReCycle Norcia—The metamorphosis of temporary housing solutions via permanence and innovation. *TECHNE-J. Technol. Archit. Environ.* **2020**, *20*, 222–235. [CrossRef]
32. Zullo, F.; Rusci, S. Lo shock sismico al servizio della speculazione: Dinamiche immobiliari e rendita urbana nella città dell'Aquila. *Arch. Studi Urbani E Reg.* **2021**, *129*, 137–159. [CrossRef]
33. Marucci, A.; Fiorini, L.; Zullo, F. *L'effetto Delle Politiche Emergeniali Sull'odierno Assetto Della Città Dell'aquila*; Franco Angeli: Milan, Italy, 2019.
34. Sette, C.; Montaldi, C. Riqualificazione urbana e coesione territoriale nelle aree interne italiane. *Urban Inf. Plan.* 2022, *online*.
35. Forino, G. Riflessioni geografiche sul disaster management a L'Aquila. *Semest. Studi E Ric. Geogr.* **2012**, *1*. [CrossRef]

36. Morettini, G. All'ombra dei mille campanili. Dinamiche demografiche di lungo periodo nell'area del cratere sismico del 2016 e 2017. *Pop. E Storia* **2019**, *1*, 19–41. [CrossRef]
37. Ugolini, A.; Conforti, A. A quando ritorneremo e l'orologio sopra la porta ricomincerà a pulsare». Strategie e problemi della ricostruzione nei centri abbandonati delle Marche dopo il sisma del 2016. *ArcHistoR* **2020**, 846–869. [CrossRef]
38. Calka, B.; Orych, A.; Bielecka, E.; Mozuriunaite, S. The Ratio of the Land Consumption Rate to the Population Growth Rate: A Framework for the Achievement of the Spatiotemporal Pattern in Poland and Lithuania. *Remote Sens.* **2022**, *14*, 1074. [CrossRef]

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A Contingent Valuation-Based Method to Valuate Ecosystem Services for a Proactive Planning and Management of Cork Oak Forests in Sardinia (Italy)

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Abstract: The paper develops a model through a contingent valuation approach to support public authorities in the exploration and assessment of ecosystem services (ESs) generated by forest and woodlands (FOWLs). This approach is employed to the cork oak forests of the Sardinia region (Italy) due to their ability in the provision and regulation of cultural and recreational values to society. The paper describes the economic valuation of cultural ESs through the contingent valuation method (CVM) with the purpose to explore residents and tourists' willingness to pay (WTP) preferences towards conservation, valorisation, and the management of Goceano's cork oak forests in Sardinia. The approach may help retain suitable support for DMs, planners, technicians, and operators for a better understanding of the ESs' role in policy decisions, leading FOWLs towards a learning process between the environment, human beings, and landscape to promote and develop a proactive landscape and forest planning and management within the region.

Keywords: stated preferences; willingness to pay (WTP); ecosystem services (ESs); forest and woodlands (FOWLs); landscape assessment

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1. Introduction

Over the last several decades, the environment and its components have become ever more transversal in policy decisions, especially those dealing with urban and territorial transformations. The increasing uncertainty and ambiguity due, on the one hand, to climate change (e.g., droughts, or run-off alterations) and, on the other hand, to man-made factors (e.g., unmanaged fires, lack of forest management, or abandonment of rural and inner areas) require a radical action for a trend reversal from recent worrying predictions [1]. The latest United Nations Conference on Climate Change held in Glasgow [2] stressed the urgency to reduce emissions to nought by 2050, limit the increase in temperatures, and also reduce deforestation by protecting and recovering ecosystems.

The forest and woodlands (FOWLs) are the keepers of habitats and microhabitats where autochthonous flora and fauna species live in. These produce biological energy through the ecological connectivity of the biotopes that compose an environmental system and interact with neighbouring systems across different scales [3–5]. The environmental system's health mirrors environmental quality, social well-being, landscape value, and the economic attractiveness of that territory. Each of these features are the components for indirectly measuring the resilience of that system [6–8]. The Sustainable Development Goals of "Building sustainable and resilient cities and communities", "Climate Action", and "Life on Land" (SDGs 11, 13 and 15) clarify the need for protection, recovery, and enhancement to ensure a more sustainable accessibility of terrestrial ecosystems with the purpose of arresting soil degradation and losses of ecosystem services (ESs) [9,10]. According to the State of Europe's Forests [11], on average, 70% of European forests are publicly accessible, 6% are for public recreation, and an index of creativity density recorded within the forests equal to 16 annual visits per inhabitant. FOWLs are valuable and fragile subsystems; their maintenance is fundamental for conserving their value, adaptability, and resilience and for valorising the local economy, as well as guaranteeing the safety of employees, residents, and tourists. Even if these features are widely recognised today, they are insufficient to operationalise a worldwide common response to limit current and potential future losses. For example, Mediterranean forests were threatened in 2021 by numerous fire events, due to high peaks of temperature which were sometimes co-triggered by man's carelessness. In addition, the progressive abandonment of rural settlements due to job demand, remote geographic location, or difficult accessibility, increases the difficulty in managing FOWLs and therefore causes their degradation [12–15] and exposure to natural hazards [16,17].

In light of this scenario, the ESs by FOWLs should be well-conserved and managed for both present and next generations more than ever [16,18–23]. In fact, they play a very important role in the generation of multiple benefits to people, such as of cultural and recreational types [11]. Besides the fact that recreational activities can contribute to the economic growth and attractiveness of a territory, public bodies should bear in mind that these can play a supporting role in FOWL preservation, valorisation, and management. A sustainable management of recreational activities can minimise the "use and consumption" trend in compromising territorial and landscape characteristics (e.g., neglect, inexperience, vandalism, disturbances to wild life, or diffusion of allochthonous flora and fauna species, among others).

Over the last few decades, economists approached the field of ecological economics to explore the relationships between environmental assets (i.e., pure public goods) and their associated economic values [24]. The idea that an environmental asset can express both biophysical and economic values has been recently consolidated in the ES literature [25,26]. The estimation of the FOWL economic value through stated preference methods can help DMs, planners, technicians, and operators to better understand the relevance of implementing ESs within policy decisions, thus integrating FOWL heritage within the learning process between the environment, human beings, and landscape. As stated by the authors of [27], the valuation of forest ecosystem services is mainly motivated by factors such as incentives for forestry management programmes, or payment for ecosystem services (PES), or even discovering people's preferences and their willingness to pay/or accept compensation related to forest heritage [27–34].

This contribution is part of a research project conducted between the 2019 and 2020 by a large group of researchers from Politecnico di Torino (Angioletta Voghera—Scient. Coordinator, Luigi La Riccia, Vanessa Assumma, Maurizio Bocconcino, Marta Bottero, Davide Canone, Federico Dell'Anna, Stefano Ferraris, Gabriella Negrini, Emanuela Rebaudengo, Emma Salizzoni) and commissioned by the Agenzia Fo.Re.S.T.A.S. of the Sardinia Regional Authority. This project was aimed at evaluating the ESs supplied by the Goceano's cork oak landscapes in the central–northern part of Sardinia, focusing on biophysical and economic valuations and selecting specific ESs both on regional and local scales to evaluate and map the multifunctionality value expressed by the cork oak forests [35]. The ESs selected in this valuation are: (i) provisioning—cork production, forage production, biomass production; (ii) regulation—hydrogeological protection, carbon sequestration; (iii) cultural—identity values (for residents and tourists).

The biophysical valuation was developed and described in specific papers [36,37] with regard to provisioning and regulating ESs, whereas this paper focuses on the economic valuation of cultural ESs. The contingent valuation method (CVM) is employed with the aim to explore users' willingness to pay (WTP) with respect to the conservation, valorisation, and management of cork oak landscapes of Sardinia (Italy). The objective of the paper is to monetise the WTP of residents and tourists to safeguard the Goceano cork oak area; residents were asked the tax amount they would be willing to pay annually, while tourists were asked about the one-off amount they would be willing to pay. The valuation approach by means of WTP made it possible to obtain values useful for determining the total economic value (TEV) of the ESs of cork forests in Sardinia.

Therefore, the paper has been structured into the following sections: Section 2 illustrates the study case and focuses on Goceano's cork oak forests; Section 3 is dedicated to the methodological aspects related to the recreational ESs and to the economic evaluation methods for the WTP estimation; Section 4 describes the CVM application; and Section 5 discusses the survey results and provides an estimation of the total economic value (TEV). The results of the study are discussed in Section 6. The last section reports final considerations on the usefulness of the methodology and provides future research perspectives.

2. Study Area: The Goceano Cork Oak Landscape

Cork oak is a Mediterranean autochthonous and spontaneous species that well-adapts to both summer and winter climate conditions, and thanks to its "resilience", the species can be up to a century old. The region of Sardinia (Italy), such as Portugal and Spain, is characterised by a great presence of cork oak forests (*Quercus suber*), thus becoming a structural factor of their landscape. Sardinian communities have benefitted from cork oak timber for centuries and employed it for the production and manufacturing of various products, spanning from building materials, bottling, clothing, and so on. The material derived is completely renewable and does not require the felling of the plant. The cork oak landscape is part of Sardinian cultural heritage in harvesting, extraction, and manufacturing processes as well as in the use and construction of ancient machinery.

In Italy, it is estimated that the area of cork oak forests spans up to 168,000 ha [38]. Most of these forests are located within Sardinia, where cork oak forests cover about 140,000 ha of land both as pure stands or wooded pastures.

In the Sardinian region, forests typify large portions of the landscape (particularly in the subregions of Marghine-Goceano, Gallura, Monte Acuto, Nuorese, Sulcis-Iglesiente, Montiferru, and Mandrolisai, many of which are classified as 'internal areas'), taking the form of both pure stands of cork oaks (around 80,000 ha) and wooded pastures (around 40,000 ha) (see Figures 1 and 2). These are highly productive landscapes and are characterised by strong identity values; indeed, Sardinia is historically the main producer of cork in Italy [39,40].

The Goceano forest complex particularly includes those of Anela, Fiorentini, and Monte Pisanu for a total area of 4800 ha. It is located within the Optimal Territorial Ambit no. 4 (i.e., Ambito Territoriale Ottimale) "SUT Goceano" of the Territorial Regional Plan of Sardinia (TRP) and includes nine municipalities: Anela, Bottidda, Benetutti, Bono, Bultei, Burgos, Esporlatu, and Illorai e Nule.

The study area is considered highly relevant for this experimentation, since cork oaks play an essential role in this delicate ecosystem. In fact, the Goceano forest complex has considerable potential for active forestry and pastoral management; it is characterised by the presence of cork oak forests that are among the most productive in terms of quality and quantity. The persistence of the three forests of traditional forage-pastoral landscapes in this territory, which are made up of open areas of woodlands with a prevalent zootechnical function, is of considerable interest. This ecosystem, which is very delicate if not properly managed, risks disappearing as a result of opposing phenomena, such as the progressive expansion of forests in areas that are scarcely used by livestock, together with the lack of cork regeneration in overburdened areas.

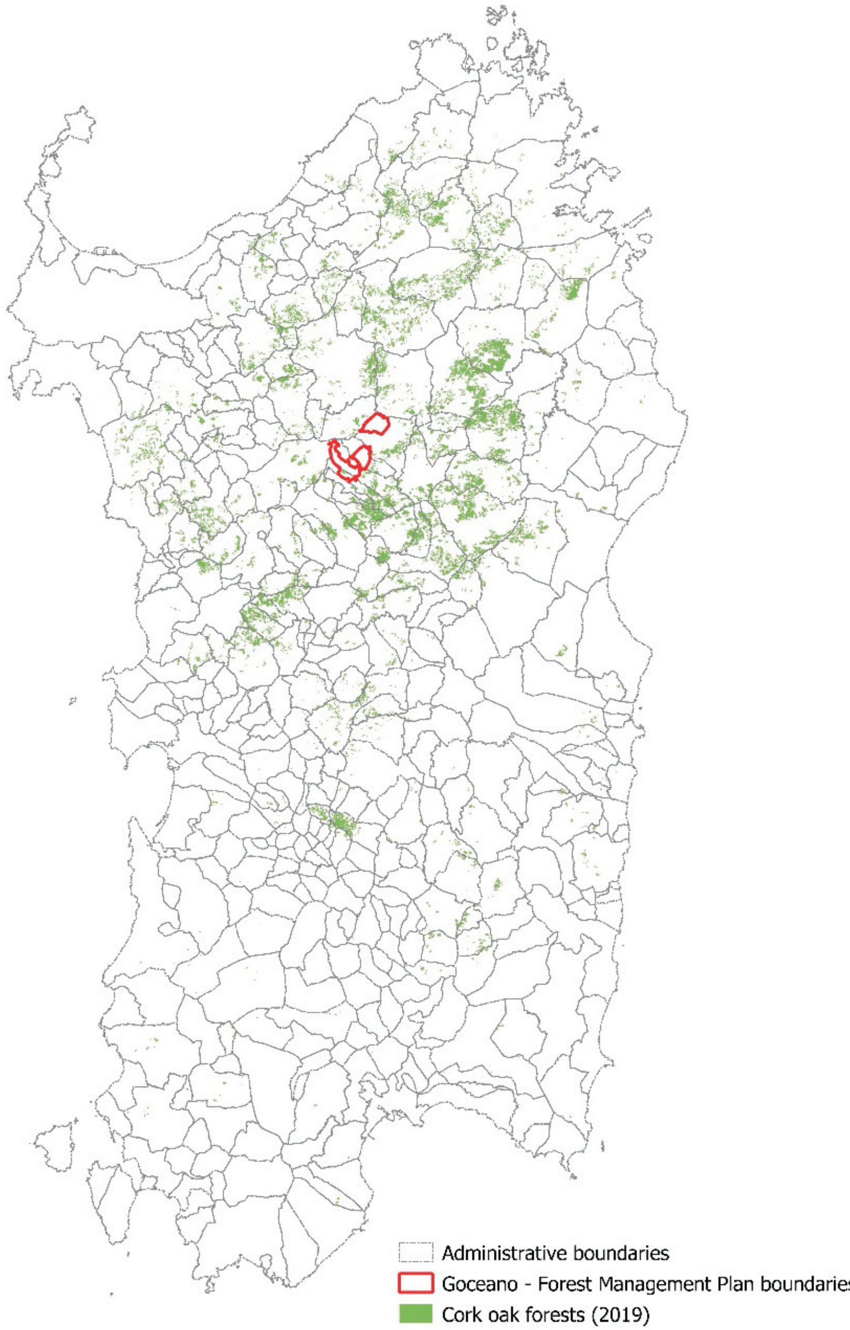

Figure 1. Distribution of cork oak forests in Sardinia. Elaboration: Luigi La Riccia and Angioletta Voghera, 2019.

Figure 2. Cork oak forest landscape in Goceano: Sos Nibberos Protected Area, Monte Pisanu (photograph by Luigi La Riccia, 2019).

Cork oak forests represent one of the best examples of the close relationship between man and nature: forests with a high conservation value alternate with agricultural land, integrating extensive agriculture, forest grazing, hunting, and other recreational uses. In Sardinia, cork oak forests are traditionally multifunctional: they are agroforestry systems in which forest exploitation is almost always associated with grazing and agriculture. The relative weight of each component—forest, agriculture, and animal production—in the overall economic return of the system has changed over time. Recently, agriculture has been responsible for the opening up of large areas of forests, and cultivation in cork oak stands has been carried out extensively during the last century. Livestock, fed on natural vegetation and acorns or improved pastures, has been and still is one of the important products supported by cork oak stands. Other uses of cork oak forests are based on their rich biodiversity: mushroom picking, bee-keeping, and aromatic plants.

Current threats include increasing human pressures on environmental resources such as overgrazing and progressive deforestation, as well as land abandonment, resulting in poor forest management (bush encroachment and fires) caused by the spread of pests and diseases that lead to the decline of cork oak. These threats are generally caused by poor cork extraction and pruning practices that in many cases damage the regenerative tissues of plants, as well as by market competition and fluctuations in the price of cork [40]. These threats are also exacerbated by the effects of climate change.

The cork forest landscape, as mentioned, is a multifunctional landscape since the cork extraction activity never involves the elimination of the trees, but only their decortication (which consists of the separation of the bark from the trunk), which, if correctly performed, does not damage plants. This operation makes it possible to safeguard the biodiversity of these territories since these forests offer shelter to various species of animals, enriching ecosystems and providing them with ecosystem services of regulation, hydrogeological protection and carbon sequestration. These ecosystems are therefore highly resilient and, given the properties of the cork plant, they are also able to deal with the various biotic and abiotic disturbances due to risk factors, such as fires (since cork is essentially fireproof).

From an economic point of view, however, it is necessary to underline the critical issues due to competition on the international market of synthetic products (plastic caps) on cork products and other non-wood products, which are seriously endangering production.

According to [41], the fate of these 'traditional' landscapes depends heavily on innovative management efforts in this market. In this sense, the assessment of ecosystem services and the related mapping is absolutely essential to increase the knowledge of the value of these landscapes [42] and to define, through territorial planning and design, adequate enhancement perspectives complementary to those strictly economically productive.

Through the classification of forest areas differentiated by the level of density, thanks to the availability of data on dendrometric measurements, four forest density classes were therefore identified, together with the relative coefficients useful for calculating the supply and regulation services. The following table therefore shows the annual economic values relating to the supply and regulation SEs together with the total economic value (TEV) (see Table 1 and Figure 3). The integrated interpretation of the data has more substantially materialized the value of the multifunctionality of Sardinia's cork forests: the economic value associated with the production of cork is in fact very high and attests to the important productive function of these territories. It is true, however, that since productivity depends heavily on local trees, cork oaks do not significantly affect the possibility of simultaneously providing other ecosystem services of a more purely environmental nature, such as hydrogeological protection and carbon absorption. For this reason, the trade-offs typically existing between ecosystem services of supply and regulation [43], are more nuanced than in other contexts where the production of wood products prevails.

Table 1. Economic indicators of the ESs of the Goceano cork oaks and TEV (total economic value) percentage breakdown.

ES	Economic Indicator	Estimation Method	Structure	Economic Value (EUR/year)	TEV (%)
Cork production	Market value of cork	Market price (EUR/q)	EUR/year	58,879.15	40.2
Fodder production	Market value of fodder	Market price (EUR/q)	EUR/year	24,066.50	16.4
Biomass production	Market value of biomass for energetic uses	Market price (EUR/q)	EUR/year	24,034.26	16.4
Hydrogeological protection	Surrogacy value of the protective function of forests	Surrogacy cost	EUR/year	26,995.47	18.4
Carbon sequestration	Market value of carbon	Market price (EUR/t)	EUR/year	12,433.55	8.5
				146,409.93	100%

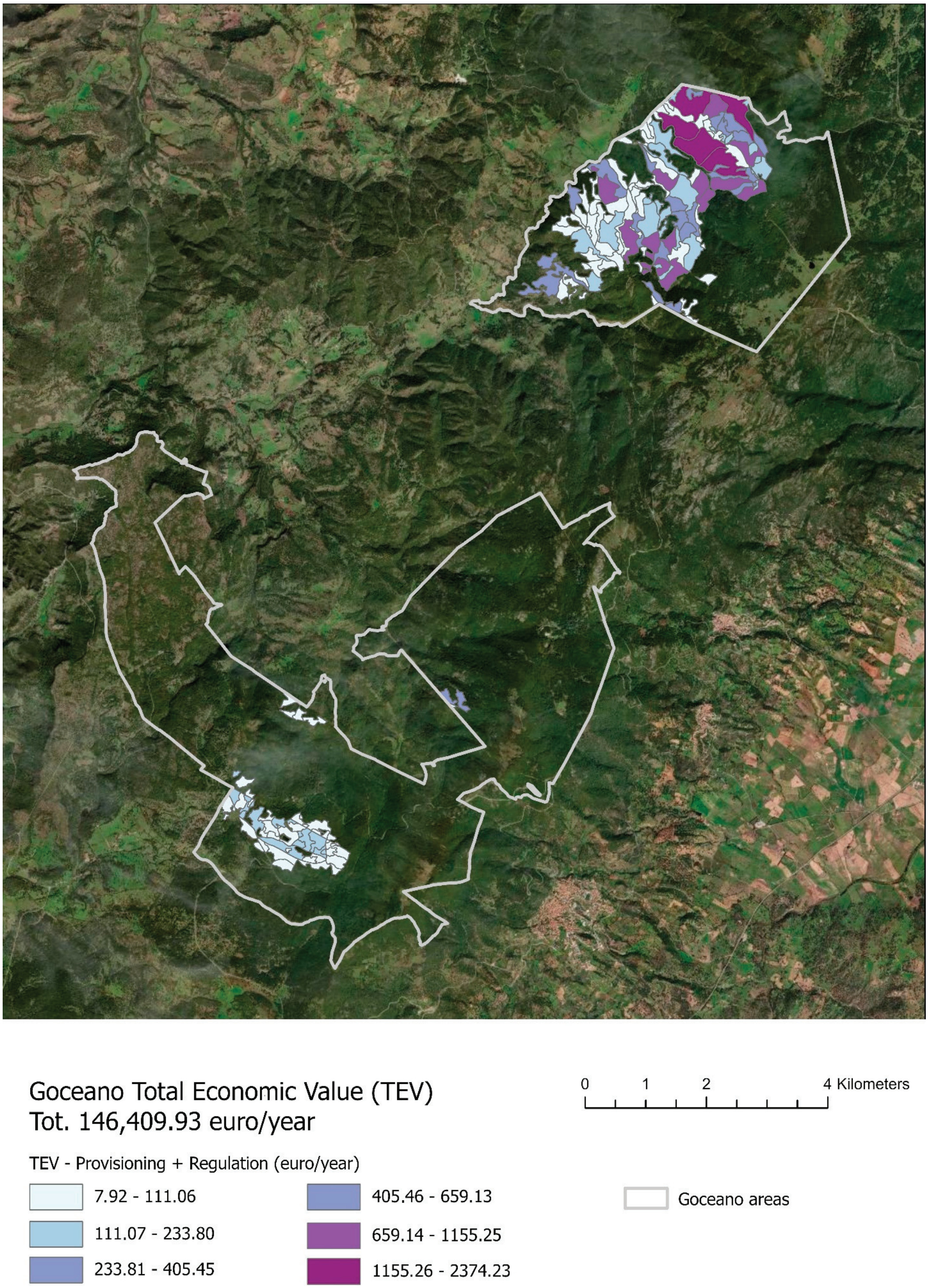

Figure 3. Total economic value of the provisioning and regulation ESs related to cork oak forests in a portion of Goceano. Elaboration: Luigi La Riccia and Angioletta Voghera, 2019.

3. Methodology

Before illustrating the application of the economic valuation, we refer to a general premise on the methods that are able to determine the economic value of environmental goods and services, which are considered useful by other authors.

In economics, goods and services are generally classified into:

- Private assets that are included in the market and regulated by buying and selling rules;
- Public assets that can be: (i) inseparable, because they are not divisible by simpler parts and are delivered to a specific user; (ii) non-competitive, since they are not dominated by market rules; and (iii) non-excludable, because everyone can equally access and use that asset or service [24,44].

For example, cork oak forests well-fit the category of public goods since they deliver multiple benefits to people, such as timber and biomass production, or cultural and recreational features (Table 2).

Table 2. Classification of goods in economics (adapted from [44]).

Criteria	Excludability	Non-Excludability
Competitive	Private goods (e.g., cars, clothes)	Common goods (e.g., water)
Non-competitive	Club goods (e.g., works of art, cinema)	Public goods (e.g., forests, landscape)

In the case of public goods, there are economic methods that help the analyst in building a hypothetical market in which it is possible to establish a monetary value for them by comparing the utility produced by goods with a decrease or increase in income [45].

The principle of TEV is widely recognised for public goods' valuation [46] since both tangible and intangible features are considered. In fact, TEV can be calculated by considering the use value and the not-use value. The first can be further subclassified into: (i) the direct use, meaning that those assets that can be extracted, consumed, or enjoyed (e.g., timber); (ii) indirect use, which is connected to the environment's functioning and services that have a positive effect on people who live nearby (e.g., recreational activities); and (iii) option value, which denotes that the utilisation of an asset for future benefits (e.g., individual's entertainment). The latter refers to intangible aspects, such as: (iv) bequest value, which refers to the value of leaving the asset optima to future generations (e.g., recreation for future generations) and (v) the existence value, to preserve a good by a potential damage or loss and also guaranteeing its inheritance for future generations (e.g., protected assets) [44].

Economists used to group economic valuation techniques into two broad categories:

- The monetary methods are based on monoparameter valuation to measure the benefits generated by a commodity or service. They can be employed with the purpose of stating or revealing preferences [47]. The "stated preference" methods can estimate users' preferences through the willingness to pay (WTP) or the willingness to accept for compensation (WTA), depending on whether the asset to be evaluated represents a positive or negative externality. The "revealed preferences" methods can valuate, for example, the indirect use of environmental and cultural assets by observing the information of private properties detected from real estate markets and that are indirectly connected to the characteristics of the public asset to be evaluated. For example, the hedonic prices method (HP) [48] can estimate the value of an environmental asset by considering a set of variables that influence the monetary values of nearby private properties [49,50]; or the travel cost method (TC) can calculate the expenses costs sustained by tourists for accessing public goods [51–53].
- The non-monetary methods can measure the value of environmental goods by considering individual characteristics and their globality as well. This is typical of composite

index valuation that employs a set of indicators that better represent the characteristics of an asset in order to provide its global performance, such as the economic value of landscapes [8,24,54,55]. Some research studies have recently added value to this stream by coupling non-monetary methods with mathematical modelling for a more dynamic interpretation of complex systems and thus facilitating the design recommendations capable of fostering transformations [56–58].

This paper is focused on the monetary category and more, in detail, on stated preference methods. It develops a CVM-based approach for the WTP estimation, which is intended as the maximum amount that an individual is willing to pay for having a good or use a service [59,60].

A literature review was developed by the authors using the Scopus database (https://www.scopus.com/, accessed on 14 November 2022) to select meaningful contributions in the relevant literature of stated preferences methods for the ESs' valuation and also to investigate their contribution in the field of forest and landscape planning and management:

$$\text{"stated preferences" AND "WTP" AND "ecosystem services"} = 35 \text{ results}$$

$$\text{"stated preferences" AND "WTP" AND "forest"} = 30 \text{ results}$$

$$\text{"stated preferences" AND "forest" AND "landscape"} = 20 \text{ results}$$

$$\text{"stated preferences" AND "WTP" AND "forest" AND "landscape"} = 3 \text{ results}$$

$$\text{"stated preferences" AND "WTP" AND "ecosystem services" AND "forest" AND "landscape"} = 2 \text{ results}$$

Some publications were selected from the literature review because they are retained as significant for the objective of the research work (Table 3). For example, WTP can be estimated to elicit people's preferences on changes in the composition of forest trees [22], as well as on the structure and standing related to nature-based interventions. Ref. [61] focuses on landscape preferences in estimating WTP, whereas [62] deepens this aspect by considering the role of cultural ecosystem services. Ref. [63] employs the Delphi method in contingent valuation to assess WTP for preserving the Amazon rainforest by European households. Ref. [64] explores the WTP in the form of a donation for forest conservation and management. Ref. [65] has recently developed a choice modelling for exploring people's WTP as an ecosystem rehabilitation of a river basin and its ecosystem services.

Table 3. Selection of representative studies on the economic valuation of environmental goods and services.

Author and Year	Description	Field of Application
Amirnejad et al., 2006 [66]	Existence value of Iranian forests through the CVM and dichotomous choice (DC). Use of the logit model to measure the individual WTP.	Ecological economics
Nielsen et al., 2007 [22]	Valuation of public preferences in forest recreational benefits and support of nature-based forest interventions.	Silviculture
Sayadi et al., 2009 [61]	Use of CVM and conjoint analysis to valuate landscape preferences and estimate the WTP for a landscape in Spain.	Rural development
Bastian et al., 2015 [62]	Estimation of the WTP for the appreciation of Saxony landscape in Germany and of its cultural ESs by tourists and visitors.	Landscape management
Tinch et al., 2015 [67]	Choice experiment valuation of changes in UK landscapes to explore the value associated with ES variations under different management regimes. Calculation of WTP off-site, on-site, and ex-post at two different time intervals (off-site).	Landscape management

Table 3. *Cont.*

Author and Year	Description	Field of Application
Cao et al., 2016 [68]	Exploration of influencing factors related to an urban ecosystem in China through logit and oprobit models, and estimation of the WTP for traveling to green spaces, forests, lakes, and rivers in Wenjiang (China).	Urban ecosystem and infrastructure
Price, 2017 [69]	Cost–benefit analysis (CBA) is combined with WTA/WTP for envisioning positive impact interventions.	Landscape economics
Navrud and Strand, 2018 [63]	Delphi method in CVM to measure the WTP by EU households for the protection of the Amazon rainforest.	Environmental protection
Schläpfer and Getzner, 2020 [70]	Empirical strategy based on choice experiment future management for the Austrian forests and investigation of the effects on WTP.	Forest management
Bamwesigye et al., 2020 [71]	Development of CVM for estimating the WTP for forest existence value in Uganda	Landscape management and planning
Alvarez et al., 2021 [72]	Estimation of the differences in WTP for urban and peri-urban forests in Florida (USA) by considering tree nativity, number of species, size of trees, and maintenance costs.	Urban forests
Hanim Mohd Sharif et al., 2021 [64]	Households' willingness to donate for the conservation and management of a recreational forest in Melaka using the double-bound CVM.	Forest management
Khan et al., 2022 [65]	Choice experiment to capture people's preferences for policy scenarios for vulnerable ecosystems.	Water management

The Contingent Valuation Method (CVM)

The contingent valuation method (CVM) is a technique that is generally employed in the valuation of non-market assets and is based on real and potential users' preferences. CVM is employed to estimate the willingness to pay (WTP) as a monetary expression of people's preferences to preserve, improve, or simply access environmental and cultural resources, or the willingness to accept (WTA) compensation related to a modification of the asset value, or a renunciation of accessing it [59]. WTP/WTA estimation can help the evaluator to estimate the total economic value (TEV) of a given asset. The CVM can develop a fictitious market by capturing users' preferences and comparing the utility of a given asset, providing changes in their income without an effective monetary transaction [73]. The CVM can be synthesised according to the following steps:

1. The identification and description of the main characteristics of the asset to be valuated;
2. A representation of a hypothetical market and definition of payment modalities;
3. A selection of a homogeneous champion of the population who could be interested in using that asset;
4. The structuring of the survey addressed to the champion;
5. The implementation of the survey (e.g., questionnaire, interviews, and so on);
6. Survey data collection and elaboration;
7. The descriptive and inferential analysis of data;
8. An estimation of the TEV value.

CVM employment requires the development of a survey. The questionnaire is the most common form of users' engagement to know their preferences concerning a realistic scenario. In this way, the users' choices are led by the same motivations that govern their behaviour in a real market.

The structuring of the questionnaire is one of the crucial steps of this method. For example, the clarity in language, the level of detail in describing the asset, the specification of use circumstances, or even how long and what type of payment is necessary for the asset use, can contribute to the survey reliability and help the evaluator in discovering users' preferences and determine who should belong to a homogeneous champion of the population [74].

There are different WTA/WTP elicitation formats:

1. Open-ended questions: The users are asked to provide a value for WTP/WTA, without any prompting. Some typical questions provided in the questionnaire are:
   (a) "How much would you be willing to pay for using the asset?"
   (b) "How much would you be willing to pay for accepting the non-use of that asset?"

   Even though this method is the most popular, users could have some difficulty in autonomously providing a value, and there is a risk of them skipping questions which they may consider uncomfortable. Open-ended questions should be few but worthwhile.
2. Closed-ended questions: The users are asked to provide their preferences by answering yes or no, or through an interval value of a monetary amount for paying or receiving compensation for that asset (e.g., from EUR 5 to EUR 100), or even an ordinal scale (e.g., "probably yes"), among others [74]. An example of a question could be: "Would you be willing to pay 10 EUR for the forests fire prevention programme?". Since close-ended questions are easier to be answered, these can help in the reduction of strategic answers.
3. Iterative bidding questions: The interviewer initially provides a figure to the individual user. If they accept the figure, a higher figure is provided and the process is repeated until the user decides to stop it. Then, the interviewer proceeds to suggest reductions, until the respondent agrees to the reduced figure. This procedure appears to be the most frequently used. A good practice is to increase or decrease the value of the monetary amount (i.e., starting point) at the beginning of the questionnaire, for example, about twice the initial value. In the final phase, much smaller variations are preferable. The interviewer's skills are very important as they can contribute to the quality of the responses. The individual's ability to understand the declared amount is important for approaching the point of indifference for the interview and, subsequently, to appropriately reduce the variations. A limitation of this method is the production of alternate estimations (i.e., starting-point bias). In the case of a high initial amount, the individual tends to increase the WTP, whereas if the starting point is low, the user will tend to state a value lower than the current value.
4. Dichotomous choice questions: This is an alternative approach to the iterative game, since the starting-point value can be varied randomly from one respondent to another, and the starting point coincides with the ending point [75].
5. Payment card method: This allows the WTA/WTP of users to be identified by considering a set of monetary amounts concerning that asset (e.g., between EUR 5 and EUR 10, and more than EUR 10). Then, respondents are aided in providing more accurate answers by mirroring their maximum WTP/WTA [74]. However, it should be taken into account that the payment card method may imply an anchoring bias. The interviewer, after describing the asset to be valued and the hypothetical market, tries to identify the income class of the respondent. At that point, he/she explains the contents of the form corresponding to the interviewee's income category and, based on this, is asked to set a value for the asset being estimated. This elicitation format has recently been extended with more reliable variants (e.g., circular payment card—PC) [76,77].

A general structure of a questionnaire to be employed in the context of CVM should have: (i) an introductory section, containing general and attitudinal questions to determine the users' familiarity with the asset that is to be evaluated as well as his/her individual perceptions; (ii) a section containing questions to ask users' preferences in the form of WTA or WTP, along with additional questions contributing to the consistency of the answers provided; and (iii) a last section, which is devoted to collecting users' socioeconomic information and can help in interpreting the results in expressing a given WTP/WTA with respect to other users. For example, the WTP can be different for subgroups of users (e.g., age, income, education, job, attitudinal preferences, and degree of attention in providing information with respect to cultural and environmental issues, among others).

The survey can be developed in various ways: by e-mail, telephone, online platforms, or through face-to-face interviews. The last modality is retained to be the most effective because it can provide the interviewer with detailed explanations and additional information about user preferences, even if it consumes considerable time and leads to resource losses. The online modality (e.g., LimeSurvey, Google Forms, or Survey Monkey, among others) can save time and resources, making the survey accessible to everyone and at any time.

Once the survey is concluded, the users' answers can be collected and organised in a Microsoft Excel environment to be subsequently processed through the use of probabilistic models, such as random utility models (RUM) or regression models [78–80].

It is possible to consider different methods for WTP/WTA elicitation. In the case of the open-ended response, simple elaborations of the WTP/WTA values can be developed, whereas in the case of the close-ended responses, statistical elaborations can take greater complexity.

The statistical models which are considered suitable for the estimation are those that can deal with discrete dependent variables, characterised by different specifications in the distribution of the error component. For example, WTP is considered in random utility models (RUM) as a random variable, whereby it is possible, by applying the different specifications, to estimate the most significant descriptive measures, such as the mean, median, and variance [73].

4. Survey Set-Up and Data Collection

The CVM was employed in the research project based on an exploratory approach and is finalised to provide decision makers an overview of the residents and tourists' willingness to pay (WTP) with regard to Goceano's cork oak landscape, and to orient the implementation of future policies in this territory.

The CVM is supported by a partial survey of stakeholders' preferences. This is due to the fact that it would not be possible to interview the entire population involved because it would increase the cost and time of the survey. The questionnaire design and data collection are reported below.

Questionnaire Design

The survey was conducted during 2019 (between July and September) and addressed to a sample of the population to assess, in an exploratory manner, the benefits delivered by the recreational ESs of cork oak forests. The questionnaire was administered to residents, tourists, and regional citizens, both online via Google Form and through face-to-face interviews in the Goceano's context and the regional territory, thanks to the synergic collaboration between the Politecnico di Torino and the Agenzia Forestas of the Sardinian region.

The questionnaire was structured into three sections, where the first section aims to detect the level of knowledge and perceptions about the environmental asset and its services, the second section provides a realistic scenario to determine the individual WTP, and the last section is devoted to the user's socioeconomic profile. The questions were structured according to the funnel technique (i.e., from simple questions that are easy to fill in, to those more specific). Open- and closed-ended questions were considered, as well as numerical preference scales (i.e., Likert scale).

The first section of the questionnaire is user-specific to detect the different points of view and perceptions in relation to cork oak forests:

1. Goceano's residents (those who live and work near cork oak forests and who have their own awareness of the identity value of the environmental asset) were asked, for instance, to indicate their city of residence, or how frequently they go to cork oak forests and the means of transportation used to reach them. Attention was paid to the local perception of their cultural and landscape values and the potential presence of eyesores. Moreover, the types of activity performed there were asked so as to detect the correlation between cork oak forests and recreational activities.
2. Tourists (those who travel for leisure and to visit Sardinia's environmental assets, e.g., Nuragic sites, cork oak forests, and traditional territories) were asked to identify their preferences in visiting cork oak forests as a tourism destination. For example, tourists were asked to provide the name of the places they were staying at (or would stay at) to obtain their degree of proximity to the Goceano's cork oak forests, how they came to know about these woods (e.g., tourist guides, suggestions from relatives and friends, organised trips, or the internet) and the factors which convinced them to go there (e.g., scenic, sport, art and culture, among others), their visiting duration, and the main elements which they considered important for this landscape.
3. Sardinian citizens were asked, for example, to specify their city of residence and the places within the region where they spent or would spend time at, and their reasons of choice. In addition, the respondents were asked whether they had ever visited cork oak forests and if so, in which area in Sardinia. Attention was paid to receptivity and accessibility features, asking about the place of stay, if any, and how they reached the cork oak forests.

Each questionnaire is structured with a scenario description for supporting the WTP elicitation. Below is an example concerning Sardinian citizens on the issue of forest fire risk:

> "*Consider for a moment the current situation in Sardinia: the risk of forest fires, also increasing due to climate change, threatens the existence of the cork forest landscape. Let us suppose that public resources alone are not sufficient to manage the risk related to fires and a non-profit foundation takes on the task of conserving and safeguarding Sardinia's cork-oak forest heritage, such as restoring cork-oak vegetation, nature education activities and scientific research on cork-oaks. These objectives would only be achieved if enough people were willing to finance the foundation by donating a certain amount of money on a one-off basis. In your opinion, what should be the maximum amount of money (EUR) each person should donate to support this foundation for the management of the environmental good? (An only one value can be admitted).*"

The last section of the questionnaire collects socioeconomic information to reconstruct the user profile and of the whole champion. For example, classic questions on age group, level of education, occupation (if any), and income were considered in the questionnaire, and whether the anonymous respondent was a member of any non-profit environmental associations.

Table 4 shows the variables of the questionnaires, with an expected description and coding that are later used for the processing of the regressions using the Statistical Package for the Social Science software (SPSS 27, https://www.spss.it/, accessed on 11 July 2022).

Table 4. Variables of the CVM model.

Variable	Description	Codification
	Dependent Variable	
WTP [a]	Willingness to pay for the conservation and protection of the Goceano cork forests	In monetary terms (Euro)
	Independent Variables	
	Socioeconomic variables	

Table 4. *Cont.*

Variable	Description	Codification
AGE	Respondent's age group; 18–21, 22–24, 25–34, 35–44, 45–54, >55	Individual choice of age group
GEN	Respondent's gender	1 for male, 0 for female
EDU	Respondent's education level	Amount of school years
AFFIL	Respondent's affiliation to non-profit environmental associations	1 for membership, 0 for non-membership
	Respondent's occupation	
WORK_STUD	Respondent is a student	1 representing that the respondent is a student, 0 otherwise
WORK_FARM	Respondent is a farmer/craftsman/merchant	1 representing that the respondent is a farmer, craftsman, or merchant, 0 otherwise.
WORK_ENTREP	Respondent is an entrepreneur	1 representing that the respondent is an entrepreneur, 0 otherwise
WORK_DEALER	Respondent is a dealer	1 representing that the respondent is a dealer, 0 otherwise
WORK_PROFES	Respondent is self-employed	1 representing that the respondent is self-employed, 0 otherwise
WORK_RETIRED	Respondent is retired	1 representing that the respondent is retired, 0 otherwise
	Reason why the respondent visited the Goceano cork oak forests	
MOTIVE_SCENIC	Scenic landscape	1 indicates reason for visit, 0 indicates no reason
MOTIVE_CULTURE	Art and culture	
MOTIVE_SPORT	Sports and outdoor activities	
MOTIVE_OTHER	Other reasons	
	Activities generally carried out in cork oak forests [b]	
ACTIVE_WALK	Walk	1 indicates activity carried out, 0 indicates no activity
ACTIVE_LANDM	Land maintenance and management	
ACTIVE_FOOD	Food and wine	
ACTIVE_RELAX	Relaxation	
ACTIVE_SPORT	Sport	
ACTIVE_OTHER	Other	
	Landscape elements valued and to be enhanced	
LANDSC_MAN	Human–environment coexistence	0 representing no interest and 1 full interest in landscape element
LANDSC_RECREAT	Recreational aspect	
LANDSC_WOOD	Ancient trades in the forest	
LANDSC_SMELL	Olfactory aspect	
LANDSC_FOOD	Food and wine aspect and sylvan pastoral context	
LANDSC_SPIRIT	Spiritual/religious aspect	
	Means of transport used to reach the Goceano cork oaks	
TRANSP_FOOT	On foot	1 indicates used means of transport, 0 indicates unused means of transport
TRANSP_BICYCLE	By bicycle	
TRANSP_CAR	By car	
TRANSP_OTHER	Other means	

Table 4. *Cont.*

Variable	Description	Codification
	Knowledge of the existence of the Goceano cork forests [c]	
MEAN_GUIDES	Consulting tourist guides	1 indicates how it became known, 0 means not used
MEAN_RELATIVE	Relying on organised trips	
MEAN_INTERNET	Surfing the internet	

[a] WTP is expressed as an annual payment for residents. While for tourists, it is expressed as a one-off payment. [b] For residents only. [c] For tourists only.

5. Survey Results

In total, 100 anonymous questionnaires were collected (80% response rate) by face-to-face interviews, but due to incomplete answers, only 78 questionnaires were considered valid; 32 for residents, 46 for tourists.

5.1. Descriptive Analysis of the Sample

The main socioeconomic data of respondents are shown in Table 5. The frequency analysis reveals an equal distribution of people under and over 45 years old (46.9% of the sample between 18 and 44 years old) for residents. The educational profile indicates that more than 90% of respondents have at least a higher education. Respondents' travel attitudes and tourism-related environmental awareness are summarised in Table 6. About half of the resident respondents visit the Goceano cork forests for work (46.9%). The rest of the resident respondents for scenic (34.4%), cultural (9.4%), and sporting reasons (25%). This result testifies to the fact that cork oak forests are frequented mainly by workers, rather than by residents for recreational activities. With regard to recreational activities carried out by residents (Table 7) within the cork forest, the most frequent are walking (34.4%), relaxation (25%), and sports (18.8%). A total of 75% of the respondents stated that they reach the park by car (Table 8). When asked which elements of the cork oak landscape they most appreciated and considered important to enhance (Table 9), the aspect related to human–environment coexistence was the most important (65.9%). The visual aspect follows (53.1%). The organisation of excursions and rest points is also an important aspect (37.5%). The aspect related to ancient forest trades and olfactory followed (18.8% and 15.6%, respectively).

Table 5. Socioeconomic data of respondents.

Age		**18–24**	**25–34**	**35–44**	**45–54**	**>54**
Residents	Freq. (%)	4 (12.5)	3 (9.4)	8 (25)	11 (34.4)	6 (18.8)
Tourists	Freq. (%)	4 (8.7)	5 (10.9)	4 (8.7)	6 (13)	11 (23.9) 16 (34.9)
GEN		Male		Female		
Residents	Freq. (%)	23 (71.9)		9 (28.1)		
Tourists	Freq. (%)	29 (63)		17 (37)		
EDU		No qualification	Primary school	Secondary school	High school graduate	University degree
Residents	Freq. (%)	0 (0)	2 (6.3)	11 (34.4)	16 (50)	3 (9.4)
Tourists	Freq. (%)	5 (10.9)	0 (0)	12 (26.1)	22 (47.8)	7 (15.2)

Table 6. Reasons for residents and tourists to visit the cork oak forests.

Reason		**Motive_Scenic**	**Motive_Culture**	**Motive_Sport**	**Motive_Work**
Residents	Freq. (%)	11 (34.4)	3 (9.4)	8 (25)	15 (46.9)
Tourists	Freq. (%)	28 (60.9)	6 (13)	11 (23.9)	0 (0)

Table 7. Main activities carried out by residents.

Activity		**Active_Walk**	**Active_Landm**	**Active_Food**	**Active_Relax**	**Active_Sport**	**Active_Other**
Residents	Freq. (%)	11 (34.4)	1 (3.1)	0 (0)	8 (25)	6 (18.8)	9 (28.1)

Table 8. Means of transport used to reach the site in question.

Transport Means		**Transp_Foot**	**Transp_Bicycle**	**Transp_Car**	**Transp_Other**
Residents	Freq. (%)	2 (6.3)	2 (6.3)	24 (75)	1 (3.1)
Tourists	Freq. (%)	9 (19.6)	5 (10.9)	30 (65.2)	10 (21.7)

Table 9. Landscape elements and disturbances felt by respondents.

Landscape Elements		**Land_Visual**	**Land_Man**	**Land_Recreat**	**Land_Wood**	**Land_Smell**	**Land_Food**	**Land_Spirit**
Residents	Freq. (%)	17 (53.1)	21 (65.9)	12 (37.5)	6 (18.8)	5 (15.6)	2 (6.3)	3 (9.4)
Tourists	Freq. (%)	22 (47.8)	14 (30.4)	24 (52.2)	12 (26.1)	4 (8.7)	11 (23.9)	3 (6.5)
ENVIRONMENTAL DISTURBANCES		Yes		No				
Residents	Freq. (%)	7 (21.9)		25 (78.1)				
GRAZING ACTIVITIES		Yes		No				
Residents	Freq. (%)	6 (18.8)		26 (81.3)				

5.2. Aggregating and Interpreting WTP

The objective of the paper was to monetise the WTP of residents and tourists to safeguard the Goceano cork oak area. Resident respondents were asked the amount they would be willing to pay annually as a tax and the results obtained are statistically described in Table 10. Tourists were asked about the one-off amount they would be willing to pay and the results obtained are also statistically described in Table 10.

Table 10. WTP stated by residents and tourists for preserving the area.

WTP		**Mean (EUR/Year)**	**SD (EUR/Year EUR)**	**Median (EUR/Year)**	**Mode (EUR/Year EUR)**	**Zero-Bids (%)**	**Min. (EUR/Year EUR)**	**Max. (EUR/Year EUR)**	**N. (-)**
Residents (whole sample)	Freq. (%)	11.78	25.17	1	0	16 (50)	0	100	32
Residents (positive WTP)	Freq. (%)	23.56	31.829	10	10	0 (0)	2	100	16
		Mean (EUR)	SD (EUR)	Median (EUR)	Mode (EUR)	Zero-Bids (%)	Min. (EUR)	Max. (EUR)	N. (-)
Tourists (whole sample)	Freq. (%)	17.57	21.97	10	10	1 (2)	0	100	46
Tourists (positive WTP)	Freq. (%)	17.96	22.06	10	10	0 (0)	1	100	45

Focusing on residents, 50% of the respondents (N = 16) declared a WTP of EUR 0. This result may be due to the fact that about 50% of the sample consists of personnel employed in forest management and maintenance activities. On the other hand, it can be said that residents recognise the site as a public good to be enjoyed free of charge. Considering the sample of full residents, the average WTP is 11.78 EUR/year. Instead, tourists declared a higher WTP, recognising the recreational and cultural value of this natural heritage. The average WTP stands at EUR 17.57 to enjoy the cork oak forests. However, it must be remembered that WTP is a sum of money that should be paid annually, which is why it is lower than that of tourists. The different answers of the respondent sample do not allow a direct comparison of results to identify the overall WTP. In order to be able to aggregate the WTP of residents to that of tourists, a reference was made to the fact that the sum declared by the former is a constant financial performance that occurs at annual intervals and that in order to be able to calculate a total value per resident, it is necessary to anticipate them at the time of estimation by means of the formula for calculating initial accumulation. In particular, a benefit duration of 25 years, equal to the time between generations, and a discount rate of 3% were considered. The estimate resulted in a total WTP per resident of about EUR 205.

5.3. Estimation Results

The econometric estimation models developed in this research provided insight into the associations between the respondents and their WTP. This information complements and enriches the understanding of the main investigative problem of this research, namely the assessment of WTP. The statistical technique used in this study is a multivariate analysis by means of a linear multiple regression analysis for each subgroup identified, taking WTP into consideration as the dependent variable.

A first regression considered all variables to test their significance. In detail, the *p*-value of each variable was taken into account to select the variables to be included in a reduced model. Considering variables with *p*-value < 1%, the reduced model is shown in Table 11. From the results of the reduced model, those who are older are willing to pay less (bAGE = −2.388). This relationship may be due to the type of activities carried out in the forest, perhaps more in line with the habits of young people. In fact, the park is located close to a campsite, which is a very common arrangement among young people. Those with a higher level of education are willing to pay more (bEDU = 0.556). This is likely because a higher income often correlates with an awareness of the ecosystem services provided by the cork oak forest. The entrepreneurs are more willing to pay for the conservation of the area than the others, probably due to the fact that they have a higher income (bWORK_ENTREP = 82.044). Those who have participated in non-profit environmental associations are willing to pay more (bAFFIL = 6.811). This result is expected, as the expressed WTP is influenced by the sensitivity of the respondents. Those who go to the forest more often are willing to pay less (bFREQ = −2.439). This result is probably due to the fact that those who go most are workers in the forest. Referring to the reasons why respondents go to the forest, those who go for cultural reasons are willing to pay less (bMOTIVE_CULTURE = −71.139), while those who benefit from the scenic benefit would be willing to pay more (bMOTIVE_SCENIC = 9.861). The spiritual value of the park is most likely a motivation for visitors to go to the forest. Those who go to the forest to walk are willing to pay more (bACTIVE_WALK = 29.356). The area in question could be one of the areas available for this activity in the surrounding area. Those who manage and maintain the park are willing to pay (bACTIVE_LANDM = −65,670). Respondents seem to be willing to pay more for the elements of the cork oak landscape that refer to the promotion of ancient forest crafts (bLAND_WOOD = 17.691) and the olfactory aspect (bLAND_SMELL = 44.378). Those who noticed elements of environmental disturbance (e.g., visual or acoustic disturbance) in the cork oak forests are willing to pay less (bDIST = −12.997), whereas those who consider pasteurisation as a characteristic element of the Goceano landscape are willing to pay more (bPAST = 5.453). In the restricted model that can be considered reliable, variables are significant and have a correct sign in line with the expected sign.

Table 11. Econometric analysis of the sample of residents.

	Non-Standardised Coefficients				**95.0% Confidence Interval for b**	
Variables	**b**	**Standard Error**	**t**	***p*-Value**	**Lower Limit**	**Upper Limit**
Constant	9.262	1.978	4.682	0.001	4.786	13.737
Socioeconomic variables						
AGE	−2.388	0.229	−10.427	0.000	−2.907	−1.870
EDU	0.556	0.110	5.044	0.001	0.307	0.806
WORK_STUD	−33.575	2.190	−15.332	0.000	−38.529	−28.621
WORK_EMPLOY	−11.965	1.625	−7.364	0.000	−15.641	−8.289
WORK_ENTREP	82.044	2.426	33.816	0.000	76.555	87.532
WORK_DEALER	−36.672	1.969	−18.624	0.000	−41.126	−32.218
WORK_PROFES	−62.157	1.940	−32.037	0.000	−66.545	−57.768
Environmental activities and visiting attitude						
AFFIL	6.811	1.169	5.824	0.000	4.166	9.456
FREQ	−2.439	0.263	−9.288	0.000	−3.033	−1.845
MOTIVE_SCENIC	9.861	1.267	7.786	0.000	6.996	12.726
MOTIVE_CULTURE	−71.139	2.488	−28.589	0.000	−76.767	−65.510
TRANSP_FOOT	11.528	2.296	5.022	0.001	6.335	16.721
TRANSP_CAR	3.010	0.809	3.720	0.005	1.180	4.841
TRANSP_BICYCLE	15.587	1.479	10.540	0.000	12.241	18.932
ACTIVE_WALK	29.356	2.031	14.457	0.000	24.762	33.949
ACTIVE_LANDM	−65.670	2.164	−30.342	0.000	−70.566	−60.774
ACTIVE_RELAX	−5.586	1.005	−5.559	0.000	−7.859	−3.313
LAND_WOOD	17.691	2.179	8.118	0.000	12.762	22.621
LAND_SMELL	44.378	1.419	31.282	0.000	41.169	47.587
LAND_FOOD	−2.815	1.097	−2.566	0.030	−5.296	−0.333
DIST	−12.997	1.993	−6.521	0.000	−17.506	−8.488
PAST	5.453	0.923	5.909	0.000	3.365	7.541
F-value	854.883					
p-value	0.000					
R^2	0.998					

Considering the tourists' answers, the following results were obtained (Table 12). Older people declared a higher WTP (AGE = 3.811). Tourists' WTP increases with increasing years of study (EDU = 1.875). Employees, pensioners, and professionals are more willing to pay more. Those who recognise a cultural value of the property declared a higher WTP (MOTICE_CULTURE = 12.69). Those who stay in accommodations such as BnBs pay more, likely related to economic conditions. Those who recognise recreational and food values are willing to pay more for its preservation.

Table 12. Econometric analysis of the sample of tourists.

	Non-Standardised Coefficients		**t**	***p*-Value**	**95.0% Confidence Interval for b**	
	b	**Standard Error**			**b**	**Standard Error**
(Constant)	136.854	31.626	4.327	0.000	71.431	202.278
Socioeconomic variables						
AGE	3.811	1.883	2.024	0.055	−0.084	7.706
GEN	−17.026	5.562	−3.061	0.006	−28.531	−5.521
EDU	1.875	0.620	3.026	0.006	0.593	3.157
WORK_EMPLOY	22.703	9.014	2.519	0.019	4.056	41.351
WORK_RETIRED	31.878	7.888	4.041	0.001	15.560	48.196
WORK_PROFES	24.250	9.540	2.542	0.018	4.516	43.985
Environmental activities and visiting attitude						
MEAN_GUIDES	−46.486	18.759	−2.478	0.021	−85.292	−7.680
MEAN_RELATIVE	−23.076	7.081	−3.259	0.003	−37.724	−8.428
MEAN_INTERNET	−25.320	10.549	−2.400	0.025	−47.141	−3.498
MOTIVE_CULTURE	12.690	6.948	1.826	0.081	−1.683	27.064
ACCOM_OTHER	−58.438	17.700	−3.302	0.003	−95.053	−21.824
ACCOM_CAMP	−23.761	9.311	−2.552	0.018	−43.023	−4.499
ACCOM_BNB	37.750	14.889	2.535	0.018	6.949	68.551
ACCOM_RELATIVE	13.541	7.013	1.931	0.066	−0.966	28.048
TRANSP_OTHER	−97.447	24.849	−3.922	0.001	−148.851	−46.044
TRANSP_FOOT	−32.435	8.201	−3.955	0.001	−49.401	−15.469
TRANSP_BICYCLE	−85.747	26.169	−3.277	0.003	−139.881	−31.612
TRANSP_CAR	−124.405	25.629	−4.854	0.000	−177.422	−71.388
TIME_ONEDAY	−25.347	6.258	−4.050	0.000	−38.293	−12.401
RETURN_YES	−23.180	7.547	−3.071	0.005	−38.791	−7.568
LANDSC_RECREAT	13.650	4.874	2.800	0.010	3.567	23.733
LANDSC_FOOD	39.956	5.766	6.930	0.000	28.029	51.883
F-value	5.486					
p-value	0.000					
R^2	0.840					

5.4. *Estimation of the TEV*

Table 13 shows the value of the individual WTP for residents and tourists and the overall WTP. The individual WTP was obtained by multiplying the number of residents/tourist arrivals by the respective WTP obtained through the regression model. The data taken into account for the calculation relate to the year 2019, which is when the survey for this study was conducted, prior to the pandemic, which, as we are all aware, disrupted tourism flows, if not cancelled, for reasonable cause.

Table 13. Calculation of the individual WTP of residents, the individual WTP of tourists and the overall WTP mean per Goceano's municipalities.

Goceano's Municipal-ities	Area (km^2)	Resident Individual WTP (Entire Life)	Residents 2019 * (No.)	Residents Individual WTP	Tourism Arrives **	Tourism Individual WTP	Tourists Individual WTP (EUR)	Overall WTP (EUR)
Anela	36.89		620	(EUR)	2019 (no.)		0	7304
Benetutti	94.45		620	127,100	0		0	127,100
Bono	74.54		1809	370,845	729		12,809	383,654
Bottidda	33.71		3481	713,605	128		2249	715,854
Bultei	96.83	205	673	137,965	112	17.57	1968	139,933
Burgos	18.08		897	183,885	35		615	184,500
Esporlatu	18.4		899	184,295	0		0	184,295
Illorai	57.19		382	78,310	0		0	78,310
Nule	51.95		830	170,150	0		0	170,150
Total	482.04	-	1365	279,825	0	-	0	279,825
Mid. value	-		10,956	2,245,980	1004	-	17,640.28	2,263,620

* ISTAT—Atlante statistico dei Comuni 2019 https://asc.istat.it/ASC/, accessed on 17 July 2022. ** Notes: Tourism arrives in proximity of Goceano's cork forests. http://osservatorio.sardegnaturismo.it/it/dashboard/dati-2019, accessed on 11 July 2022 (SIRED, Assessorato del Turismo della Sardegna).

For instance, among the municipalities taken into consideration, the municipality of Bono has the highest individual WTP relative to residents (41,006 euros), followed by the municipality of Benetutti (21,310 euros), whereas the municipality of Esporlatu has the lowest individual WTP relative to residents (4500 euros), likely as a result of the municipality's small population (only 382). Regarding the individual WTP of tourists near cork oak forests, the 2019 visitor movements made available by the Region of Sardinia's Tourism Department were considered. There are certain tourism flows that are not reported because of a lack of tourism accommodation and facilities, or the number of arrivals was much too low that tourism observatories made them unavailable. Due to the lack of data, the number of tourist arrivals for the municipalities concerned was assumed to be zero (i.e., Anela, Burgos, Esporlatu, Illorai, and Nule). In order to obtain the overall WTP, the total WTP of locals and tourists have been summed up. The WTP total sum for the Goceano area is EUR 2,263,620.

The overall value of WTP obtained by summarizing the total WTP for residents and tourists (Table 14) contributes to the final calculation of TEV (Table 15), which is equal to EUR 2,410,030, and thus a monetary valuation of cork oak forests that holds together the ecosystem and cultural-recreational value is obtained.

Table 14. Calculation of the overall WTP mean related to the Goceano's surface area (km^2).

WTP Residents (EUR)	WTP Tourists (EUR)	Overall WTP (EUR)	Overall WTP (EUR/km^2)
2,245,980	17,640	2,263,620	4696

Table 15. Calculation of the final TEV that takes into account both the ecosystemic and cultural-recreative results.

Goceano's Cork Oak Forests Surface (ha)	TEV Ecosystemic	TEV Cultural-Recreative	Overall TEV	Cork Oak Forests Parametric Value (EUR/ha)
4800	146,410	2,263,620	2,410,030	502

6. Discussion

The evaluation carried out can be compared with other studies relevant in the scientific literature. Particularly, the selection of article proposed by the authors of [27] are CVM that cover the time range 2006–2022 and are employed to support forest conservation, management, and restoration. This selection has facilitated the authors in the comparison between their WTP annual mean (USD) and the one obtained for the Goceano's cork oak forests. Thus, Table 16 below validates the results:

Table 16. Comparison of the annual mean WTP value with existing contingent valuation studies. (adapted from [27]).

Authors and Year	Description	Country	Annual Mean WTP Value (USD)
Amirnejad et al. (2006) [66]	Estimation of the existence value of forests	Iran	44.39
Adams et al. (2008) [81]	Conservation of natural protected areas	Brazil	1.65
Chukwuone and Okorji (2008) [82]	Community forests management for conservation of non-timber forest products	Nigeria	6.53
Sattout et al. (2007) [80]	Economic valuation of cedar relics	Lebanon	63.95
Tao et al. (2012) [83]	Valuation of forest ecosystem services	China	46.16
Dumenu (2013) [84]	Economic valuation of urban forests	Ghana	27.17–28
Ansong and Røskaft (2014) [85]	WTP estimation for sustainable forest management	Ghana	11.73–24.02
Arowolo et al. (2014) [86]	WTP valuation for sustainable management of community forests	Nigeria	37
Tuan et al. (2014) [87]	WTP estimation for forest restoration	Vietnam	7.47–8.32
Al-Assaf (2015) [88]	Economic valuation of forest services	Jordan	22.40
Amiri et al. (2015) [89]	Valuation of conservation value of myrtle forests	Iran	22.40
Chen (2015) [90]	WTP for the conservation of urban heritage trees	China	4.71–5.96
Dare et al. (2015) [91]	Management of urban trees forest	Nigeria	32.80
Gelo and Koch (2015) [92]	Valuation of community forestry programmes	Ethiopia	1.24–1.89
Tilahun et al. (2015) [29]	Conservation of frankincense forest	Ethiopia	5.83–6.42
Amare et al. (2016) [93]	Church forests restoration	Ethiopia	1.93
Elmi et al. (2016) [94]	Economic valuation for forest conservation for carbon sequestration	Ethiopia	3.72–6.96
Khuc et al. (2016) [95]	Estimation of urban households' WTP for forest restoration	Vietnam	24.15
Ramli et al. (2017) [96]	Economic value for the conservation of mangrove forests	Malaysia	24.15
Solikin (2017) [97]	WTP valuation to avoid deforestation and degradation	Indonesia	14.48 and (20.25)
Ariyo et al. (2018) [98]	Forest conservation	Nigeria	4.39
Iranah et al. (2018) [31]	WTP visitors' estimation for forest conservation and restoration	Mauritius	4.28–8.85

Table 16. *Cont.*

Authors and Year	Description	Country	Annual Mean WTP Value (USD)
Arabomen et al. (2019) [99]	Economic valuation for urban trees' conservation and environmental services	Nigeria	16.46
Sardana (2019) [100]	Valuation of tourism restoration of agroforest ecosystems	India	3.22
Endalew and Wondimagegnhu (2019) [101]	Conservation of church forests	Ethiopia	7.34
Gordillo et al. (2019) [32]	WTP estimation for forest conservation	Ecuador	42.95–85.09
Bamwesigye et al. (2020) [71]	WTP estimation for existence value of forests	Uganda	16.94
Endalew et al. (2020) [102]	Conservation of church forests	Ethiopia	9.12
Hasan-Basri et al. (2020) [103]	Mangrove forests conservations	Malaysia	4.90
Khai et al. (2020) [104]	Economic valuation for ecosystem conservation	Vietnam	49.35
Sharif et al. (2021) [64]	WTP for conservation of recreational forests	Malaysia	4.48
Truong (2022) [105]	Community perception and participation in forest conservation	Vietnam	0.014
Kassahun and Taw (2022) [106]	WTP valuation for baobab trees' conservation	Ethiopia	3.91

CVM can be considered the most methodologically sound approach to obtain the economic value of natural and cultural assets, as in the case of cork oak forests [80,107,108]. CVM through the estimation of the monetary value can support DMs in the design of suitable policies and actions for protecting, valorising, and managing cork oak forests, and more so in general, FOWLs, thus contributing to their sustainable forest management (SFM) [109]. Moreover, CVM is regarded to be the only one to calculate the economic value of an asset in all its meanings.

However, some aspects should be taken into account since they may affect the valuation and the precision of the results. For instance, a user could be influenced by the payment option provided by the questionnaire regardless of whether it is considered less reliable; or in the case of an iterative game, the beginning value could impact the final estimation. The presence of outliers could also influence the valuation, for example, the user may condition the results of the research with a different response than the real monetary measure that (s)he would have attributed to the valuation objective (e.g., warm glow); or the user may tend to hide his/her preferences, waiting for other users to state their willingness to pay for the commodity or service that (s)he probably will not use (e.g., free rider).

A careful design of the survey and the research experience are fundamental to design the evaluation scenario and reduce the occurrence of strategic behaviours and outliers.

The evaluation method developed in this study has broad employability in various contexts and with regard to particular geographical issues. The strengths of the method lie in the definition of an agile, but at the same time comprehensive, set of indicators of ecosystem services, which allow a dual evaluation (biophysical and cultural) and, above all, is spatialised by GIS, thus making it useful for planning, territorial, and landscape policies [110]. In fact, this method of evaluation of cultural ecosystem services can explicit their role of "bridging concepts". Ecosystem services are an expression of the widespread awareness of the need to integrate environmental issues into territorial policies, as well as an important tool for the definition, implementation, and communication of sustainability policies, capable of effectively combining conservation and development, thus highlighting the added value that ecosystems provide to society and the economy. This potential is obviously closely related to the clarification of their evaluation, mapping, communication, and possible 'payment' (PES), at the heart of various research and institutional initiatives [25,26] for the development of large-scale local planning [111–113], with a view to ensure a high level of biodiversity. From a design perspective, the evaluation of ecosystem services is a particularly useful tool for determining the quality of the territory, health, and resilience, and it is essential in order to support the identification of strategic areas for an ecological network, for the development of green and blue infrastructures, as well as to identify landscape, fruitive, and economic values linked to the territories of the waters. The analysis of the ecological network and the optimisation of the improvement of the connectivity value on ecosystem services [36,37]—through innovative processing in terms of remote sensing (3D visualisations and thermographic survey for the evaluation of indicators specifically related to the fire risk)—is therefore a possible in-depth analysis, which can be developed in a forthcoming research activity, supporting the identification of strategic areas for the network, whose potential for strengthening ecological functionality is highlighted. From this perspective, the increase in ecological connectivity is therefore to be understood as the bearer of a multiplicity of values, not only those strictly related to biodiversity, but also to landscape, fruition, and economic values.

7. Conclusions

The paper proposed a CVM as an exploratory approach to valuate the WTP of Goceano's cork oak forests of Sardinia (Italy). The relatively simple applicability of the method, which also guided the choice of some estimation methods, responds to the desire to prepare a tool that can be largely used in the context of landscape, regional, and urban planning. These same advantages of the method, spatialisation, and easy applicability evidently also constitute the aspects of partial weaknesses, directing it towards a necessary procedural simplification.

From the perspective of a further development of the research here presented, it is possible to foresee, although not wanting to abandon this approach, an in-depth study of some of the indicators identified, with reference to those of energy use or to the extension of the evaluation of cultural ecosystem services (as we have seen, more difficult to estimate). Furthermore, considering this valuation tool as a potential support for planning and managing policies of the cork oak forest landscapes, it is appropriate that the valuation carried out is integrated with an analysis of the trade-offs [114], thus identifying the potential conflicts and synergies between the multiple functions of cork oak forests (first of all, the economic aspect related to crafts) and effectively supporting the choices of planning and managing territories.

In general, considering the issue of ecosystem services in territorial and landscape planning policies supports planning schemes that are oriented towards a sustainable development perspective in which the act of diversity conservation—not only biological (biodiversity), but also landscape and cultural—is central, thus supporting an interpretation of the forests, as well as through an increase in ecological network and the preservation of its core areas.

However, taking into account this last aspect in relation to the regional landscape plan (RLP) of the region of Sardinia—currently under review to include inland territories as the approved instrument (2006) only concerns coastal areas (integration and extension to the whole territory is in progress, as required by the Italian Cultural Heritage and Landscape Code)—these types of analyses could constitute an effective support for elaborating an articulated and complete analysis of the values of the forest landscapes (not only of the cork oak forests) and, consequently, for declining in an appropriate way, at every level of government of the territory, the protection measures (constraints), management, and planning. This need, however, clashes with the complexity of today's territorial framework: the poorly defined methods for an active safeguard of environmental and landscape resources; the need for the reorganisation of urban transformations; the interpretative uncertainty of the SEA procedures of urban plans; the current incompleteness of the guidelines for the adaptation of urban plans to the RLP; and the hydrogeological plan (which detail the elements connected to the reorganisation of knowledge but reduced to the mere adaptation of the cartographic drawings)—all of which are aspects that, at the local level, clearly need different tools and implementation strategies that the current revision of the RLP is called upon to consider.

In conclusion, the experimentation of methods and tools for evaluating ecosystem services allow us to bring together the different spheres—biophysical and cultural—that action on the landscape requires to develop "a multilevel planning (...) through the construction of a supply chain horizontal between responsible subjects, to be pursued from the early stages of elaboration of the regional landscape plan with a concrete participation of local authorities and the use of guide tools for their action adaptable to the specificities of the different landscapes" [115].

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References

1. IPCC. Global Warming of 1.5 °C. In *An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*; Ipcc-Sr15; IPCC: New York, NY, USA, 2019.
2. United Nations. XXVI UN Climate Change Conference UK 2021. Available online: https://ukcop26.org/cop26-goals/ (accessed on 11 July 2022).
3. Gunderson, L.H.; Holling, C.S. *Panarchy: Understanding Transformations in Systems of Humans and Nature*; Island: Washington, DC, USA, 2002.
4. Monaco, R.; Soares, A.J. A New Mathematical Model for Environmental Monitoring and Assessment. *Proc. Math. Stat.* **2017**, *209*, 263–283. [CrossRef]
5. Turner, M.G.; Gardner, R.H. *Landscape Ecology in Theory and Practice, Landscape Ecology in Theory and Practice*; Springer: New York, NY, USA, 2015. [CrossRef]
6. Assumma, V.; Bottero, M.; De Angelis, E.; Lourenço, J.M.; Monaco, R.; Soares, A.J. A decision support system for territorial resilience assessment and planning: An application to the Douro Valley (Portugal). *Sci. Total Environ.* **2021**, *756*, 143806. [CrossRef]
7. Cassatella, C.; Peano, A. *Landscape Indicators: Assessing and Monitoring Landscape Quality, Landscape Indicators: Assessing and Monitoring Landscape Quality*; Springer: Dordrecht, The Netherlands, 2011. [CrossRef]
8. van der Heide, C.M.; Heijman, W.J.M. *The Economic Value of Landscapes, The Economic Value of Landscapes*; Routledge: London, UK, 2013. [CrossRef]
9. Baveye, P.C.; Baveye, J.; Gowdy, J. Soil "Ecosystem" Services and Natural Capital: Critical Appraisal of Research on Uncertain Ground. *Front. Environ. Sci.* **2016**, *4*, 41. [CrossRef]
10. United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development United Nations United Nations Transforming Our World: The 2030 Agenda for Sustainable Development*; A/RES/70/1; United Nations: New York, NY, USA, 2015.

11. Forest Europe. State of Europe's Forests 2020. Available online: https://foresteurope.org/state-europes-forests-2020/ (accessed on 15 July 2022).
12. Assumma, V.; Bottero, M.; De Angelis, E.; Lourenço, J.M.; Monaco, R.; Soares, A.J. Scenario building model to support the resilience planning of winemaking regions: The case of the Douro territory (Portugal). *Sci. Total Environ.* **2022**, *838*, 155889. [CrossRef] [PubMed]
13. Baerenklau, K.A.; González-Cabán, A.; Paez, C.; Chavez, E. Spatial allocation of forest recreation value. *J. For. Econ.* **2010**, *16*, 113–126. [CrossRef]
14. González, R.V.; Diaz-Balteiro, L.; Martínez, E.L.-P. Spatial valuation of recreation activities in forest systems: Application to province of Segovia (Spain) SuFoRun Models and decision SUpport tools for integrated FOrest policy development under global change and associated Risk and Uncertainty View projec. *For. Syst.* **2010**, *19*, 36. [CrossRef]
15. Zandersen, M.; Tol, R.S. A meta-analysis of forest recreation values in Europe. *J. For. Econ.* **2009**, *15*, 109–130. [CrossRef]
16. Riccioli, F.; Marone, E.; Boncinelli, F.; Tattoni, C.; Rocchini, D.; Fratini, R. The recreational value of forests under different management systems. *New For.* **2019**, *50*, 345–360. [CrossRef]
17. Sacchelli, S.; Fagarazzi, C.; Bernetti, I. Economic evaluation of forest biomass production in central Italy: A scenario assessment based on spatial analysis tool. *Biomass-Bioenergy* **2013**, *53*, 1–10. [CrossRef]
18. Bestard, A.B.; Font, A.R. Environmental diversity in recreational choice modelling. *Ecol. Econ.* **2009**, *68*, 2743–2750. [CrossRef]
19. Dhakal, B.; Yao, R.T.; Turner, J.A.; Barnard, T. Recreational users' willingness to pay and preferences for changes in planted forest features. *For. Policy Econ.* **2012**, *17*, 34–44. [CrossRef]
20. Edwards, D.; Jay, M.; Jensen, F.S.; Lucas, B.; Marzano, M.; Montagné, C.; Peace, A.; Weiss, G. Public preferences for structural attributes of forests: Towards a pan-European perspective. *For. Policy Econ.* **2012**, *19*, 12–19. [CrossRef]
21. Horne, P.; Boxall, P.C.; Adamowicz, W.L. Multiple-use management of forest recreation sites: A spatially explicit choice experiment. *For. Ecol. Manag.* **2005**, *207*, 189–199. [CrossRef]
22. Nielsen, A.B.; Olsen, S.B.; Lundhede, T. An economic valuation of the recreational benefits associated with nature-based forest management practices. *Landsc. Urban Plan.* **2007**, *80*, 63–71. [CrossRef]
23. Zandersen, M.; Termansen, M. Assessing Recreational Values of Danish Forests to Guide National Plans for Afforestation. 2013. Available online: https://www.teebweb.org/wp-content/uploads/2013/01/TEEB-case_TEEBNordic_Assessing-recreational-values-of-Danish-forests-to-guide-national-plans-for-afforestation.pdf (accessed on 11 July 2022).
24. Marangon, F.; Tempesta, T. Proposta di indicatori economici per la valutazione del paesaggio. *Estimo Territ.* **2008**, *5*, 40–55.
25. MEA. *Ecosystems and Human Well-Being*; Island Press: Washington, DC, USA, 2005.
26. TEEB. *Teeb-The Economics of Ecosystem and Biodiversity for Local and Regional Policy Makers, Report*; TEEB: Geneva, Switzerland, 2010.
27. Abdeta, D. Willingness to pay for forest conservation in developing countries: A systematic literature review. *Environ. Sustain. Indic.* **2022**, *16*, 100201. [CrossRef]
28. Mekonnen, A. Valuation of community forestry in Ethiopia: A contingent valuation study of rural households. *Environ. Dev. Econ.* **2000**, *5*, 289–308. [CrossRef]
29. Tilahun, M.; Vranken, L.; Muys, B.; Deckers, J.; Gebregziabher, K.; Gebrehiwot, K.; Bauer, H.; Mathijs, E. Rural Households' Demand for Frankincense Forest Conservation in Tigray, Ethiopia: A Contingent Valuation Analysis. *Land Degrad. Dev.* **2015**, *26*, 642–653. [CrossRef]
30. Vásquez-Lavín, F.; Ibarnegaray, V.; Oliva, R.P.; Hernandez, J.I. Payment for Ecosystem Services in the Bolivian Sub-Andean Humid Forest. *J. Environ. Dev.* **2016**, *25*, 306–331. [CrossRef]
31. Iranah, P.; Lal, P.; Wolde, B.T.; Burli, P. Valuing visitor access to forested areas and exploring willingness to pay for forest conservation and restoration finance: The case of small island developing state of Mauritius. *J. Environ. Manag.* **2018**, *223*, 868–877. [CrossRef]
32. Gordillo, F.; Elsasser, P.; Günter, S. Willingness to pay for forest conservation in Ecuador: Results from a nationwide contingent valuation survey in a combined "referendum"–"Consequential open-ended" design. *For. Policy Econ.* **2019**, *105*, 28–39. [CrossRef]
33. Khanal, Y.; Devkota, B.P. Farmers' responsibilization in payment for environmental services: Lessons from community forestry in Nepal. *For. Policy Econ.* **2020**, *118*, 102237. [CrossRef]
34. Naime, J.; Mora, F.; Sánchez-Martínez, M.; Arreola, F.; Balvanera, P. Economic valuation of ecosystem services from secondary tropical forests: Trade-offs and implications for policy making. *For. Ecol. Manag.* **2020**, *473*, 118294. [CrossRef]
35. Common International Classification of Ecosystem Services (CICES). CICES V5.1 Spreadsheet. 2018. Available online: https://cices.eu/ (accessed on 12 February 2020).
36. La Riccia, L.; Voghera, A.; Salizzoni, E.; Negrini, G.; Maltoni, S. Planning Ecological Corridors: A Cost Distance Method Based on Ecosystem Service Evaluation in the Sardinian Cork Oak Forests. *Lect. Notes Civ. Eng.* **2021**, *146*, 301–310. [CrossRef]
37. Salizzoni, E.; Voghera, A.; La Riccia, L.; Negrini, G. I paesaggi delle sugherete in Sardegna: Strategie di progetto per una ruralità in evoluzione. *L'Italia For. E Mont.* **2021**, *7*, 73–79. [CrossRef]
38. INF. Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio. Le Stime di Superficie [WWW Document]. 2005. Available online: https://www.sian.it/inventarioforestale/jsp/dati_introa.jsp?menu=3 (accessed on 17 July 2022).
39. Dettori, S.; Muroni, A.; Puxeddu, M.; Deplano, G.; Filigheddu, M.R. Quantità e qualità delle produzioni sughericole regionali. In *Alla Ricerca Della Qualità Nella Filiera Sughero-Vino*; Balint, G., Antala, B., Carty, C., Mabieme, J.-M.A., Amar, I.B., Kaplanova, A., Eds.; S'Alvure di Massimo Pulisci: Oristano, Italy, 2008; pp. 15–31.

40. MIPAAFT. Rapporto Sullo Stato delle Foreste e del Settore Forestale in Italia-RaF. Arezzo. Available online: https://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/19231 (accessed on 10 March 2021).
41. Cutini, A.; Muscas, F.; Carta, V.; Casula, A.; Dettori, S.; Filigheddu, M.R.; Maltoni, S.; Pignatti, G.; Romano, R. Analisi e Proposte per la Valorizzazione Della Sughericoltura e Della Filiera Sughericola Italiana. Available online: https://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/19629 (accessed on 11 July 2022).
42. Corona, P.; Quatrini, V.; Schirru, M.; Dettori, S.; Puletti, N. Towards the economic valuation of ecosystem production from cork oak forests in Sardinia (Italy). *iForest-Biogeosciences For.* **2018**, *11*, 660–667. [CrossRef]
43. Turkelboom, F.; Leone, M.; Jacobs, S.; Kelemen, E.; García-Llorente, M.; Baró, F.; Termansen, M.; Barton, D.N.; Berry, P.; Stange, E.; et al. When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. *Ecosyst. Serv.* **2018**, *29*, 566–578. [CrossRef]
44. Roscelli, R. Manuale di estimo. In *Valutazioni Economiche ed Esercizio Della Professione*; UTET Università: Torino, Italy, 2014.
45. Pascual, U.; Muradian, R.; Brander, L.; Gómez-Baggethun, E.; Martín-López, B.; Verma, M.; Armsworth, P.; Christie, M.; Cornelissen, H.; Eppink, F.; et al. The economics of valuing ecosystem services and biodiversity Coordinating Lead Authors. *Econ. Ecosyst. Biodivers. Ecol. Econ. Found.* **2010**, *5*, 183–256.
46. Pearce, D.W.; Turner, R.K. *Economia delle Risorse Naturali e Dell'ambiente*; Il Mulino: Bologna, Italy, 1991.
47. Adamowicz, W.; Louviere, J.; Williams, M. Combining Revealed and Stated Preference Methods for Valuing Environmental Amenities. *J. Environ. Econ. Manag.* **1994**, *26*, 271–292. [CrossRef]
48. Tyrväinen, L. The amenity value of the urban forest: An application of the hedonic pricing method. *Landsc. Urban Plan.* **1997**, *37*, 211–222. [CrossRef]
49. Bottero, M.; Bravi, M.; Dell'Anna, F.; Mondini, G. Valuing buildings energy efficiency through Hedonic Prices Method: Are spatial effects relevant? *Valori E Valutazioni* **2018**, *21*, 27–39.
50. Buso, T.; Dell'anna, F.; Becchio, C.; Bottero, M.C.; Corgnati, S.P. Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms. *Energy Res. Soc. Sci.* **2017**, *32*, 94–111. [CrossRef]
51. Armbrecht, J. Use value of cultural experiences: A comparison of contingent valuation and travel cost. *Tour. Manag.* **2014**, *42*, 141–148. [CrossRef]
52. Voke, M.; Fairley, I.; Willis, M.; Masters, I. Economic evaluation of the recreational value of the coastal environment in a marine renewables deployment area. *Ocean Coast. Manag.* **2013**, *78*, 77–87. [CrossRef]
53. Willis, K.G.; Garrod, G.D. An individual travel-cost method of evaluating forest recreation. *J. Agric. Econ.* **1991**, *42*, 33–42. [CrossRef]
54. Ferrara, A.; Salvati, L.; Sateriano, A.; Nolè, A. Performance evaluation and cost assessment of a key indicator system to monitor desertification vulnerability. *Ecol. Indic.* **2012**, *23*, 123–129. [CrossRef]
55. Tagliafierro, C.; Longo, A.; Van Eetvelde, V.; Antrop, M.; Hutchinson, W.G. Landscape economic valuation by integrating landscape ecology into landscape economics. *Environ. Sci. Policy* **2013**, *32*, 26–36. [CrossRef]
56. Assumma, V.; Bottero, M.; Datola, G.; Pezzoli, A.; Quagliolo, C. *Climate Change and Urban Resilience. Preliminary Insights from an Integrated Evaluation Framework*; Springer: New York, NY, USA, 2021; pp. 676–685.
57. Assumma, V.; Bottero, M.; Monaco, R.; Soares, A.J. An integrated evaluation methodology to measure ecological and economic landscape states for territorial transformation scenarios: An application in Piedmont (Italy). *Ecol. Indic.* **2019**, *105*, 156–165. [CrossRef]
58. Monaco, R. A mathematical model for territorial integrated evaluation. In *Smart Evaluation and Integrated Design in Regional Development*; Brunetta, G., Ed.; Ashgate: Farnham, UK, 2015; pp. 97–106.
59. OECD. *Cost-Benefit Analysis and the Environment*; Oxford University Press: Oxford, UK, 2006. [CrossRef]
60. Tagliafierro, C.; Boeri, M.; Longo, A.; Hutchinson, W. Stated preference methods and landscape ecology indicators: An example of transdisciplinarity in landscape economic valuation. *Ecol. Econ.* **2016**, *127*, 11–22. [CrossRef]
61. Sayadi, S.; González-Roa, M.C.; Calatrava-Requena, J. Public preferences for landscape features: The case of agricultural landscape in mountainous Mediterranean areas. *Land Use Policy* **2009**, *26*, 334–344. [CrossRef]
62. Bastian, O.; Stein, C.; Lupp, G.; Behrens, J.; Renner, C.; Grunewald, K. The appreciation of nature and landscape by tourism service providers and visitors in the Ore Mountains (Germany). *Landsc. Online* **2015**, *41*, 1–23. [CrossRef]
63. Navrud, S.; Strand, J. Valuing Global Ecosystem Services: What Do European Experts Say? Applying the Delphi Method to Contingent Valuation of the Amazon Rainfores. *Environ. Resour. Econ.* **2018**, *70*, 249–269. [CrossRef]
64. Sharif, F.H.M.; Malaysia, U.P.; Matthew, N.K.; Shuib, A. Households' willingness to donate for the conservation and management of the ayer keroh recreational forest, melaka. *J. Sustain. Sci. Manag.* **2021**, *16*, 150–165. [CrossRef]
65. Khan, S.U.; Guo, X.; Hu, J.; Khan, A.A.; Talpur, M.A.; Liu, G.; Zhao, M. Who cares and how much? Narrative for advances in aquatic ecosystem services through non-market valuation with spatial dimensions using a discrete choice experiment. *J. Clean. Prod.* **2022**, *337*, 130603. [CrossRef]
66. Amirnejad, H.; Khalilian, S.; Assareh, M.H.; Ahmadian, M. Estimating the existence value of north forests of Iran by using a contingent valuation method. *Ecol. Econ.* **2006**, *58*, 665–675. [CrossRef]
67. Tinch, D.; Colombo, S.; Hanley, N. The Impacts of Elicitation Context on Stated Preferences for Agricultural Landscapes. *J. Agric. Econ.* **2014**, *66*, 87–107. [CrossRef]

68. Cao, X.L.; Liu, G.H.; Zhang, Y.; Li, X.S. Willingness-to-pay for recreation services of urban ecosystem and its value assessment: A case study in the Wenjiang district of Chengdu City, China. *Acta Ecol. Sin.* **2017**, *37*, 2970–2981. [CrossRef]
69. Price, C. Cost–Benefit Analysis and Willingness to Pay for Landscape. In *Landscape Economics*; Palgrave Macmillan: Cham, Switzerland, 2017; pp. 133–149. [CrossRef]
70. Schläpfer, F.; Getzner, M. Beyond Current Guidelines: A Proposal for Bringing Behavioral Economics to the Design and Analysis of Stated Preference Surveys. *Ecol. Econ.* **2020**, *176*, 106720. [CrossRef]
71. Bamwesigye, D.; Hlavackova, P.; Sujova, A.; Fialova, J.; Kupec, P. Willingness to Pay for Forest Existence Value and Sustainability. *Sustainability* **2020**, *12*, 891. [CrossRef]
72. Alvarez, S.; Soto, J.R.; Escobedo, F.J.; Lai, J.; Kibria, A.S.; Adams, D.C. Heterogeneous preferences and economic values for urban forest structural and functional attributes. *Landsc. Urban Plan.* **2021**, *215*, 104234. [CrossRef]
73. APAT. *Il Risarcimento del Danno Ambientale: Aspetti Teorici e Operativi Della Valutazione Economica*; ISPRA: Lombardy, Italy, 2006.
74. Whitehead, J.C. A Practitioner's Primer on Contingent Valuation. Working Papers from East Carolina University, Department of Economics. 2000. Available online: https://econpapers.repec.org/paper/wopeacaec/0008.htm (accessed on 17 July 2022).
75. Bishop, R.C.; Heberlein, T.A. Measuring Values of Extramarket Goods: Are Indirect Measures Biased? *Am. J. Agric. Econ.* **1979**, *61*, 926–930. [CrossRef]
76. Champonnois, V.; Chanel, O.; Makhloufi, K. Reducing the anchoring bias in multiple question CV surveys. *J. Choice Model.* **2018**, *28*, 1–9. [CrossRef]
77. Mahieu, P.-A.; Wolff, F.-C.; Shogren, J.; Gastineau, P. Interval bidding in a distribution elicitation format. *Appl. Econ.* **2017**, *49*, 5200–5211. [CrossRef]
78. Gao, Q.; Ao, C.L.; Chen, H.G.; Tong, R. Spatial Differentiation Research of Non-use Value WTP Based on the Residents'Ecological Cognition—Taking the Sanjiang Plain as a Case. *Acta Ecol. Sin.* **2014**, *34*, 1851–1859. [CrossRef]
79. Gupta, M. Willingness to pay for carbon tax: A study of Indian road passenger transport. *Transp. Policy* **2016**, *45*, 46–54. [CrossRef]
80. Sattout, E.; Talhouk, S.; Caligari, P. Economic value of cedar relics in Lebanon: An application of contingent valuation method for conservation. *Ecol. Econ.* **2007**, *61*, 315–322. [CrossRef]
81. Adams, C.; da Motta, R.S.; Ortiz, R.A.; Reid, J.; Aznar, C.E.; Sinisgalli, P.A.D.A. The use of contingent valuation for evaluating protected areas in the developing world: Economic valuation of Morro do Diabo State Park, Atlantic Rainforest, São Paulo State (Brazil). *Ecol. Econ.* **2008**, *66*, 359–370. [CrossRef]
82. Chukwuone, N.; Okorji, C. Willingness to pay for systematic management of community forests for conservation of non-timber forest products in Nigeria's rainforest region. In *Economics of Poverty, Environment and Natural-Resource Use*; Springer: Dordrecht, The Netherlands, 2008; pp. 117–137. [CrossRef]
83. Tao, Z.; Yan, H.; Zhang, T. Economic Valuation of Forest Ecosystem Services in Heshui Watershed using Contingent Valuation Method. *Procedia Environ. Sci.* **2012**, *13*, 2445–2450. [CrossRef]
84. Dumenu, W. What are we missing? Economic value of an urban forest in Ghana. *Ecosyst. Serv.* **2013**, *5*, e137–e142. [CrossRef]
85. Ansong, M.; Røskaft, E. Local communities' willingness to pay for sustainable forest management in Ghana. *J. Energy Nat. Resour. Manag.* **2014**, *1*, 80–87.
86. Arowolo, A.; Agbonlahor, M.; Okuneye, P.A.; Soaga, J. Adopting a participatory approach to community forests management in rural Nigeria. *Glob. Nest J.* **2014**, *16*, 975–987.
87. Tuan, T.H.; My, N.H.D.; Anh, L.T.Q.; Van Toan, N. Using contingent valuation method to estimate the WTP for mangrove restoration under the context of climate change: A case study of Thi Nai lagoon, Quy Nhon city, Vietnam. *Ocean Coast. Manag.* **2014**, *95*, 198–212. [CrossRef]
88. Al-Assaf, A.A. Applying contingent valuation to measure the economic value of forest services: A case study in Northern Jordan. *Int. J. Sustain. Dev. World Ecol.* **2015**, *22*, 242–250. [CrossRef]
89. Amiri, N.; Emadian, S.F.; Fallah, A.; Adeli, K.; Amirnejad, H. Estimation of conservation value of myrtle (Myrtus communis) using a contingent valuation method: A case study in a Dooreh forest area, Lorestan Province, Iran. *For. Ecosyst.* **2015**, *2*, 30. [CrossRef]
90. Chen, W.Y. Public willingness-to-pay for conserving urban heritage trees in Guangzhou, south China. *Urban For. Urban Green.* **2015**, *14*, 796–805. [CrossRef]
91. Dare, A.M.; Ayinde, I.A.; Shittu, A.M. Urban trees forest management in Abeokuta Metropolis, Ogun State, Nigeria. *Manag. Environ. Qual. Int. J.* **2015**, *26*, 72–83. [CrossRef]
92. Gelo, D.; Koch, S.F. Contingent valuation of community forestry programs in Ethiopia: Controlling for preference anomalies in double-bounded CVM. *Ecol. Econ.* **2015**, *114*, 79–89. [CrossRef]
93. Amare, D.; Mekuria, W.; T/wold, T.; Belay, B.; Teshome, A.; Yitaferu, B.; Tessema, T.; Tegegn, B. Perception of local community and the willingness to pay to restore church forests: The case of Dera district, northwestern Ethiopia. *For. Trees Livelihoods* **2016**, *25*, 173–186. [CrossRef]
94. Negewo, E.N.; Ewnetu, Z.; Tesfaye, Y. Economic Valuation of Forest Conserved by Local Community for Carbon Sequestration: The Case of Humbo Community Assisted Natural Regeneration Afforestation/Reforestation (A/R) Carbon Sequestration Project; SNNPRS, Ethiopia. *Low Carbon Econ.* **2016**, *7*, 88–105. [CrossRef]
95. Van Khuc, Q.; Alhassan, M.; Loomis, J.B.; Tran, T.D.; Paschke, M.W. Estimating Urban Households' Willingness-to-Pay for Upland Forest Restoration in Vietnam. *Open J. For.* **2016**, *6*, 191–198. [CrossRef]

96. Ramli, F.; Samdin, Z.; Ghani, A.N.A. Willingness to pay for conservation fee using contingent valuation method: The case of Matang Mangrove Forest Reserve, Perak, Malaysia. *Malays. For.* **2017**, *80*, 99–110.
97. Solikin, A. *Willingness to Pay and Willingness to Work to Avoid Deforestation and Forest Degradation*; Springer: Singapore, 2017; pp. 119–129. [CrossRef]
98. Ariyo, O.C.; Okojie, L.O.; Ariyo, M.O. Villagers Willingness to Pay for Forest Conservation in Ibadan, Oyo State, Nigeria. *Asian J. Agric. Ext. Econ. Sociol.* **2018**, *23*, 1–14. [CrossRef]
99. Arabomen, O.; Chirwa, P.; Babalola, F. Willingness-to-pay for Environmental Services Provided By Trees in Core and Fringe Areas of Benin City, Nigeria 1. *Int. For. Rev.* **2019**, *21*, 23–36. [CrossRef]
100. Sardana, K. Tourists' Willingness to Pay for Restoration of Traditional Agro-forest Ecosystems Providing Biodiversity: Evidence from India. *Ecol. Econ.* **2018**, *159*, 362–372. [CrossRef]
101. Endalew, B.; Wondimagegnhu, B.A. Determinants of households' willingness to pay for the conservation of church forests in northwestern Ethiopia: A contingent valuation study. *Cogent Environ. Sci.* **2019**, *5*, 1570659. [CrossRef]
102. Endalew, B.; Wondimagegnhu, B.A.; Tassie, K. Willingness to pay for church forest conservation: A case study in northwestern Ethiopia. *J. For. Sci.* **2020**, *66*, 105–116. [CrossRef]
103. Hasan-Basri, B.; Samdin, Z.; Ghani, A.N. Willingness to pay for conservation of mangrove forest in kuala perlis, Malaysia. *J. Ekon. Malays.* **2020**, *54*, 89–99.
104. Khai, H.V.; Van, N.P.; Yabe, M. Economic Value of an Ecosystem Conservation Project: A Case Study of U Minh National Forest in the Vietnamese Mekong Delta. *J. Fac. Agric. Kyushu Univ.* **2020**, *65*, 165–171. [CrossRef]
105. Truong, D.D. Community awareness and participation in biodiversity conservation at Phong Nha-Ke Bang National Park, Vietnam. *Biodivers. J. Biol. Divers.* **2021**, *23*, 581–592. [CrossRef]
106. Kassahun, E.; Taw, T.B. Willingness to Pay for Conservation of African Baobab Tree in Ethiopia (A Case Study of Abergele Woreda): Contingent Valuation Approach. *J. Sustain. For.* **2021**, *41*, 212–222. [CrossRef]
107. Eregae, J.E.; Njogu, P.; Karanja, R.; Gichua, M. Economic Valuation for Cultural and Passive Ecosystem Services Using a Stated Preference (Contingent Valuation Method (CVM)) Case of the Elgeyo Watershed Ecosystem, Kenya. *Int. J. For. Res.* **2021**, *2021*, 5867745. [CrossRef]
108. Gao, H.; Ouyang, Z.; Zheng, H. Perception and attitudes of local people concerning ecosystem services of culturally protected forests. *Acta Ecol. Sin.* **2013**, *33*, 756–763. [CrossRef]
109. Agnoletti, M.; Santoro, A. Cultural values and sustainable forest management: The case of Europe. *J. For. Res.* **2015**, *20*, 438–444. [CrossRef]
110. Ingaramo, R.; Salizzoni, E.; Voghera, A. Valuing Forest Ecosystem Services for Spatial and Landscape Planning and Design. *Valori E Valutazioni* **2017**, *19*, 65–78.
111. Albert, C.; Geneletti, D.; Kopperoinen, L. Application of ecosystem services in spatial planning. In *Mapping Ecosystem Services. Advanced Books*; Burkhard, B., Maes, J., Eds.; Pensoft Publishers: Sofia, Bulgaria, 2017; p. e12837. [CrossRef]
112. von Haaren, C.; Albert, C.; Galler, C. *Spatial and Landscape Planning: A place for Ecosystem Services*; Routledge: London, UK, 2016; pp. 568–581. [CrossRef]
113. Caprioli, C.; Bottero, M.; Zanetta, E.; Mondini, G. Ecosystem Services in Land-Use Planning: An Application for Assessing Transformation Scenarios at the Local Scale. In *New Metropolitan Perspectives. NMP 2020. Smart Innovation, Systems and Technologies*; Bevilacqua, C., Calabrò, F., Della Spina, L., Eds.; Springer: Cham, Switzerland, 2021; Volume 178. [CrossRef]
114. Braat, L.C.; de Groot, R. The ecosystem services agenda: Bridging the worlds of natural science and economics, conservation and development, and public and private policy. *Ecosyst. Serv.* **2012**, *1*, 4–15. [CrossRef]
115. Peano, A. Una visione territorialista di natura e paesaggio. *Urbanistica* **2009**, *139*, 82–87, INU Edizioni.

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Article

Managing Complex Knowledge in Sustainable Planning: A Semantic-Based Model for Multiagent Water-Related Concepts

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Abstract: The concepts of green infrastructures, nature-based solutions and ecosystem services are today considered an integral part of the broader theme of the urban bioregion, with an intrinsic character of complexity. It is certainly difficult to structure bioregional processes in a balanced and sustainable way, able to keep local energy production and consumption cycles closed. It is a complex issue of knowledge bases, and problems are increased by the participatory dimension of environmental planning. In fact, when rational planning models have failed in the face of prominent individual needs and environmental complexity, a path has emerged towards the inclusion of multiple citizens' and stakeholders' knowledge. The cognitive structure of the plans has thus changed from systems of exclusively expert, formal knowledge to systems of diffused, multi-agent knowledge. This has involved richness but also significant problems in understanding and managing knowledge bases. In this complexity, there are some common peculiarities when it comes to socio-environmental systems. A common feature of the reference domains of ecosystem services, nature-based solutions and green infrastructures is the water resource. A management model of hydrological data, which are structurally relevant and cross-sectoral in environmental planning actions, could represent a flagship initiative. The used approach could be conveyed to more complex and extensive areas of the environmental domain in a perspective of sustainable planning. The present paper is part of a research work oriented toward handling complex environmental subjects, such as green infrastructures, nature-based solutions or ecosystem services, with a knowledge modelling approach. This approach is based on semantic extensions, elaborated form the concept of semantic web, to allow shared interpretations of knowledge coming from different languages and scientific domains. It is also based on using applied ontologies, elaborated from the concept of ontology-based classification, to support a structured organization of knowledge contents. The main research objective is therefore to investigate about a knowledge management system with semantic extensions, populated with hydrological knowledge contents, as well as to propose a preliminary functional architecture. A simple ontology of data is extracted, aiming at clarifying and improving inter-domain communication, so as to enhance a common semantic understanding in a complex environmental system.

Keywords: sustainable planning; bioregion; knowledge management; ontology; decision support system

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1. Introduction

Within an ecosystem-oriented reflection, the concepts of green infrastructures, nature-based solutions and ecosystem services are today commonly considered an integral part of the theme of the urban bioregion. And an inherent character of complexity is associated with the concept of urban bioregion. Complexity certainly suggests high operational and management difficulties, but it also witnesses the richness of our spatial, relational and social contexts. The present paper is part of a research work aiming to address and manage complex environmental issues using the concept of *semantic web* [1], which allows shared interpretations of knowledge coming from different languages and scientific domains.

According to Thayer, in fact, a bioregion is a space limited by non-political but natural borders around geographical, climatic, hydrological and ecological features supporting living communities [2]. This interpretation involves the need to define spatial planning and organizations that are capable of structuring those processes in a balanced and sustainable way. The difficulty of such a structuring effort is actually quite clear, even by just recalling the historical roots of this bioregional thought. In fact, one can look at the pioneering reflections of Howard and Geddes between the late nineteenth and early twentieth centuries, up to Lewis Mumford's studies. It can be noted that the correspondence between ecological regionalism and spatial planning and organization tends to remain a theoretical expectation. In particular, the subsequent human-led transformative actions, especially of a technological and industrial type, tended to break ecosystem cycles rather than to favor natural co-evolution over time [3–5]. Cities, especially, which are huge transformation entities on territories, are finally carrying out processes of constant divergence between productions of natural life and consumptions developed by urban metabolism. Newman and Jennings argue that cities stimulate consumption of resources beyond the actual availability of their related regions. This makes that territory essentially unable to support the city as a socioeconomic ecosystem and subject to further passive transformation and consumption [6], p. 188. The possibility of operationally setting up an urban bioregion is therefore dependent on the possibility of closing local production and consumption cycles. In a world where more than half of the population now resides in urban areas, these processes are clearly and intrinsically necessary for the survival of urban areas themselves [6], p. 189. Indeed, it is a literally complex context, which calls for the restoration of its sustainable ecosystem layout through suitable environmental planning strategies [2], p. 144. But this strategic approach actually proves to be similarly complex in itself. In fact, following the previous reasoning, it should involve spatially articulated and dynamically differentiated decisions towards the natural environment, the physically transformed environment, the bioregional environmental regeneration circles, the careful management of local resources, as well as towards the social and individual needs and behaviors, the local closing circles of supply and demand [6], p. 212. And in order to implement these decisions, the approach should be structured on knowledge bases of related phenomena, processes and agents, as a support to informed and sustainable decisions. Indeed, when environmental planning places a knowledge-oriented emphasis on ecosystem services, green infrastructures and nature-based processes, it fits quite well into this perspective. In that case, it can definitely represent the attempt to structure levels and paths to support the re-functionalization of an urban bioregion [2], p. 54.

In this context, a famous reflection by Reiniger [7] states that bioregional planning represents an opportunity for understanding the complexity of ecosystems in relation to regional culture. The theme of knowledge therefore clearly emerges as a central element in eco-systemically sustainable spatial planning activities.

In general, environmental planning today tends to be based on knowledge from social participation. Then, such knowledge becomes more and more structurally integrated with the expert knowledge of the domain [8,9]. Plans increasingly use rationalities of multi-agent knowledge [10], coming from place-based (rather than general) systems of knowledge and reasoning [11,12]. Within plans, in particular within territorial community plans, the transition from systems of exclusively expert, formal knowledge to systems of diffused, multi-agent knowledge has created significant problems of understanding and managing the knowledge itself [13]. This circumstance has paved the way for new methods of environmental planning, in general based more on 'soft' and 'hard' computations than in the past. They are assisted by specific tools to deal with extended dialogues, with massive amounts of words and associated linguistic variables, as well as with languages from different scientific domains [12,14–17]. New approaches to quantitative geography and spatial cognition have also brought new ideas and methods into the planning domain [18–22].

Indeed, even some doubts have arisen about the effectiveness of traditional participatory planning. Urban and territorial systems show highly complex socio-environmental processes and dynamics, difficult to manage in participatory arenas with their typical turbulence and 'distortions' [23]. When only ideals of democracy and mediation shape participatory planning, unaware of the knotty problems and tasks of knowledge engineering to be addressed, the situation clearly becomes very challenging.

A participatory environmental plan involves large amounts of data. They come from informal multi-agent arenas managed to foster democracy and task success but also from the formal knowledge of scientific experts. Therefore, the relevant planning steps are made particularly challenging by the need to interpret and structure both formal and informal, multi-source data sets. The aim is to trigger this multiform system of knowledge on the architectures of a spatial plan, traditionally fixed and rigid, as well as to address the dynamic character of knowledge in environmental processes—a hard nondeterministic (*NP-hard*) problem able to produce unsustainable plans, if unproperly managed [24].

Problems are also emphasized by the fact that the participatory dimension of environmental planning is often oriented to mediate between two extremes of free action or inaction (that is, using urban structures with little or no consideration of the natural environment or conversely leaving the natural environment uncontaminated). Until recently, given a transformational aim, policymakers have sought consensus strategies with the participating community to achieve that aim [25]. Indeed, it tends to be an outdated approach now, due to a new political and planning consciousness, stimulated by the protection of the systemic and indivisible nature of the natural environment—humans included—and not necessarily prevailing [26].

Arguably, many facets of the logic of environmental and, in particular, participatory planning can be seen as essentially outdated. Today, democratic planning methods and models are increasingly conceptualized as cognitive exercises [27]. Many scholars recognize them as voluntary processes of multi-agent, multi-source and cross-domain knowledge in the field of socio-environmental cognition [10,28,29].

Clearly, in this highly complex context, the need for models and architectures of data processing and knowledge management becomes essential. The management of this universe of formal, informal, multi-domain and multi-agent data takes place through conceptualizations of different origins. Yet these conceptualizations need to interact with one another and to remain connected through relations with explicit significance links. This would allow the support of knowledge and decision-managing in bioregional areas. It is also clear that in an environmental context, the treatment of elements and primitives cannot be easily undertaken, given the intricate relations characterizing ecosystems. However, there are still some common peculiarities when dealing with socio-environmental systems, especially based on urban bioregions, which affect structural and infrastructural areas of ecological regeneration. In fact, a common feature of the knowledge domains of ecosystem services, nature-based solutions and green infrastructures is the water resource. It can be said that efforts to implement knowledge management models in the field of water and hydrology can have a double value. On the one hand, the model could act as a support architecture for knowledge management and decisions in an area that is cross-cutting and structural in environmental planning. Secondly, an effort to model knowledge in the hydrological field could represent a flagship initiative. It would aim at possibly extending the approach to more complex and extensive areas of the environmental domain—in a sustainable planning perspective.

A study toward an applied ontology model for environmental decision-making and planning is proposed here, just as in the above context. It is based on the concept of formal interpretation of languages originating from the semantic web to allow shared interpretations of knowledge coming from different languages and scientific domains [1]. The use of the ontological approach in environmental planning can be found in the recent literature of planning models [20]. It derives from the need to manage the environmental, social and relational complexity of anthropized ecosystems in a dynamic and multi-agent perspective. For example, previous studies have proved to be interesting for structuring the various spatial and cognitive levels of cities: environmental, social, building, functional, etc. [30]. These are attempts to include aspects of complexity in environmental management and planning, traditionally linked to more manageable environmental reductionisms and standardizations of social behaviors [14,15]. Scientific research is still in a preliminary stage, due to greater difficulty compared to traditional models, and so is the present study; yet it shows encouraging perspectives.

The work is oriented just towards the above research direction. That is, the main research question is to explore the possible setting up of a semantic-based model to manage multiagent water-related knowledge as a reference model for environmental planning purposes. A specific objective has been to analyze the model's aptitude to support the creation and development of water-related knowledge contents enriched with semantic extensions [1]. A further research objective has been to investigate the possible interoperability of the system architecture in a sustainable planning perspective. Therefore, after the present introduction, the second section explores aspects of interaction between system and user, framed in the actual research context, as well as the perspectives of realization and implementation of a knowledge management system, particularly concerning knowledge contents. Additionally, a deeper argument on the ontological approach is provided in the same section, for better clarity. The paper ends with a final section commenting on possible ontological modeling based on web ontology language (*OWL*) features, with follow-up remarks.

2. Materials and Methods

Hydrology has always been an interdisciplinary science, with important connections to physical geography, general geosciences and civil engineering. The hydrological cycle joins many other domains of the natural sciences and the integration of the latter, for a broader and more in-depth understanding of water systems, requires the collaboration of several scientists from the respective domains [31].

Hydrology is also an applied science, and the knowledge that belongs to it has important practical implications. Engineering professionals of different branches, natural science professionals, hydrologists, public health professionals, policy makers, economists, social professionals, ecologists, geoscientists, urban planners, employees of the public and private organizations that are interested in the landscape are part of the water resource management processes [32]. Thus, even the improvement of water management may depend on an increase in the degree of interdisciplinarity [33].

The clarification of the theoretical and practical differences of the aforementioned disciplines as well as the correct specification of the respective data and language differences becomes of great importance [34,35]. Interdisciplinarity is evidently linked to issues of language and semantic meaning. For this very reason, there is currently an increase in the demand for knowledge management IT platforms that can provide support for the management of water resources [36]. Here, we intend to explore the establishment and use of a knowledge management system (KMS) extended with semantic technologies in the scientific domains of hydrology, toward the definition of a useful tool to address some of the needs described [37].

Furthermore, the possibility for a large group of users to easily create, test, reuse, extend and maintain contents and meanings would be a further advantage of the tool in question.

The idea is to create and test a web platform that allows describing a certain set of knowledge in a simple way for the average user (everyone who has the ability to write an email, for example) and automatically obtain a formalized description of this set. This formal description, usable by computers via web semantic technologies (semantic extension), is expressed in the OWL language. As the ability to express and formally represent information increases, the level of complexity of the technology used increases rapidly. Figure 1 shows how increasingly complex computer-based technologies (from databases to xml to RDF up to OWL2) make it possible to represent knowledge expressible with increasingly articulated formal languages (from taxonomies to logical theory). This makes this knowledge increasingly interoperable by information technology (IT) systems, from syntactic interoperability to semantic interoperability.

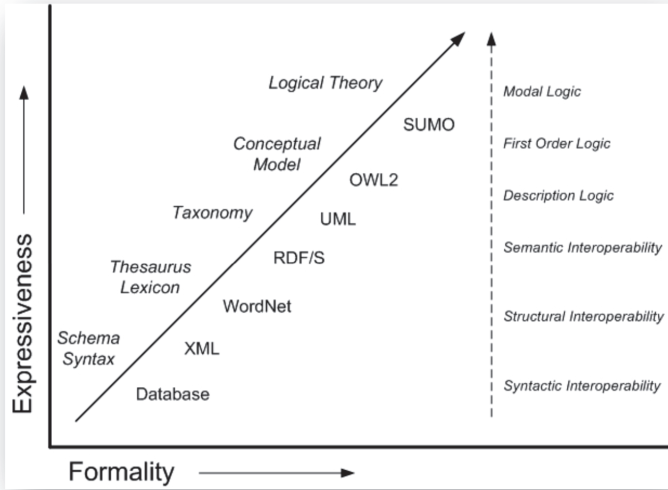

Figure 1. The different levels of knowledge representation with computer-based technics and the corresponding formal language levels, adapted from Pease [38].

The web platform allows the tracking of the changes made by users to each content and to decide on the truthfulness of the information in a collective way. Subsequently, by means of the semantic extensions implemented in the platform itself, this information is reformulated, and as a last step, it is possible to extract an ontology relating to the information defined by the users. After having created the platform, in order to verify the functional architecture in a practical way, a set of information from the hydrology domain was entered into the platform—in particular, a classification (taxonomy) of the hydrological models extended up to four models well known in the literature (taxonomy instances).

The first objective of this work is, therefore, the implementation of a knowledge management system with semantic extensions and the creation of an initial knowledge base in the hydrological domain. The second, minor goal is to demonstrate KMS interoperability across water-related disciplinary boundaries by establishing an ontology for the sample knowledge base. The purpose of the ontology is to help improve communication within and outside the hydrology community, ensure a common semantic understanding of concepts and provide a tool for metadata processing.

2.1. The User-System Interaction Scheme

The functional architecture envisaged for the knowledge management system object of this work is articulated in a series of strongly connected processes with both feedback and feedforward characteristics. Generally, all the activities that affect the system are more or less rigidly linked in continuous cycles, due both to the extension of the domain of interest of the hydrological sciences and to the current trend of unlimited growth of information volumes.

The processes have the particularity of being almost all collective and are traced over the entire period of operation in a punctual manner to events. The collective elicitation of knowledge, in this operating scheme, is of particular importance because it ensures the truthfulness of the contents; from this point of view, the possibility of tracing the operations carried out also becomes important.

Four large groups of information activities can be distinguished: processes internal to the knowledge management system of a basic type, internal processes of management of semantic structures, processes to and from the outside oriented to the Semantic Web and processes to and from the ontology-oriented exterior.

In the knowledge management internally allowed by the platform, two cycles of evolution of content and meaning can be identified from a logical point of view: contents can be entered, searched, compared, updated and increased, and at the same time, the meanings can be modified with actions on categories, properties and structures.

The agents that perform operations in this structure can be both human and artificial, and one of the main objectives of the semantic web is precisely to make meanings accessible to software agents. The interaction of the platform could take place both through ad hoc developed connections and through the Application Programming Interfaces (API) made available by the platform itself.

Different kinds of expertise are necessary according to the interaction between system and agent: expertise on the hydrology domain affects the whole system; expertise on ontologies affects the whole system and becomes particularly important in the processes of extraction and processing of internal ontologies; expertise on Semantic Web technologies affects the whole system and assumes greater importance in the connection with other semantic systems; IT system engineering expertise affects the basic level administration of the system. A graphical representation of the processes and actors involved in the functioning of the system is available in Figure 2.

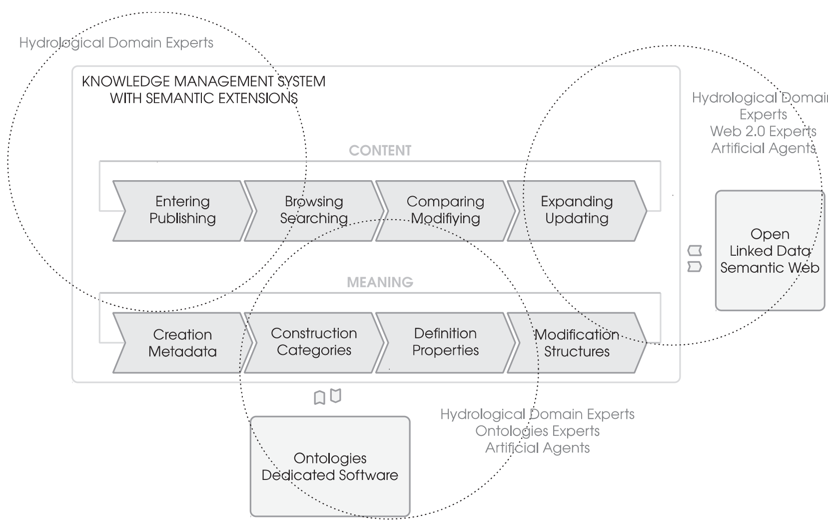

Figure 2. The evolution of KMS with semantic extensions [39].

2.2. The Implementation of the Knowledge Management System

Semantic Mediawiki was chosen among different types of semantic wikis available on the market.

For the architecture of the platform, we have chosen to use free software in the open source versions in order both to comply with the provisions of the Agency for Digital Italy (AGID) and to have the possibility of directly making changes to any level of the software structure (see Appendix A). The architecture as a whole has also been implemented on virtual machines to meet among others the following requirements: independence from specific hardware, portability, versioning, development, maintenance, easier backup-recover "baremetal". The virtualization environment was Oracle VM Virtualbox, and the host operating system was Ubuntu LTS server—both shown in Figure 3 as Virtual

Host tier. The architecture used for Mediawiki with Semantc Mediawiki (SMW), shown as Application Layer in Figure 3, was implemented on Linux operating system, Apache web server, Mysql database and on an application server developed in php language—all shown as the Lamp Stack in Figure 3.

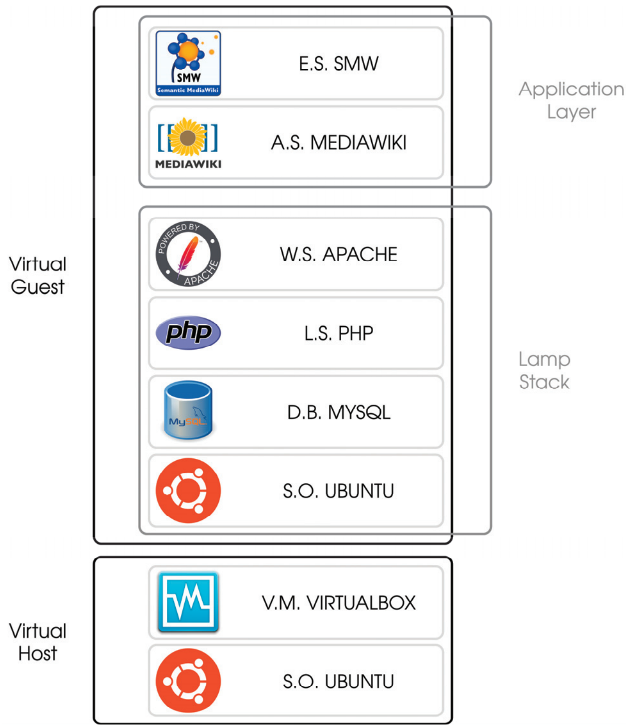

Figure 3. The software stack (simplified) of the KMS [39].

For the Mediawiki, the Semantic Mediawiki extension and numerous other development "packages" were installed, configured and modified at a later time (e.g., ICU International Components for Unicode, Lua Scripting Language, Page Forms, TemplateData, Scribunto, DataValues Validators, ParserHooks, WikiEditor) (see Appendix A). For the purposes of this research, the platform website was made available on the private network of the Department of Civil Engineering at Polytechnic University of Bari.

2.3. The Knowledge Content

The creation of content, within a knowledge management system such as the one used, is a process of continuous creation, enrichment and revision both at the level of basic information and at the level of the structure of meaning.

This system provides for an operation extended to many users, and all the "actions" carried out within it are both subjected to a continuous process of collective verification and validation and punctually tracked.

Specifically, the data used in the initial phase for the population of the KMS were deduced from the scientific literature and monographic texts of the hydrological sciences domain; see, for example, refs. [32,33].

The data collected were entered into the KMS using the tools made available by the system itself: a classification of typical topics of hydrology that extends from the general definitions to the properties of some models (instances) known in the literature [38,40] has been introduced, enriched and modified over time. The scheme of the highest level taxonomy is shown in Figure 4.

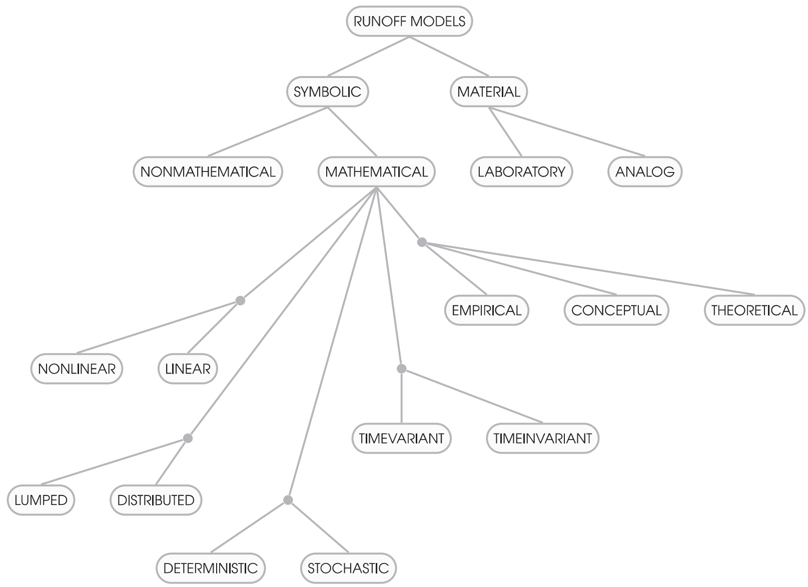

Figure 4. General Taxonomy of Hydrological Models [39].

Then, four instances of hydrological models were selected from specific studies and added to the knowledge base managed by the system:

- DREAM [41]: "a Distributed model for Runoff, Evapotranspiration, and Antecedent soil Moisture simulation" [39].

  A schema of a part of data submitted is reported in Table 1:

Table 1. DREAM model features.

Feature	Value
Model Name	DREAM
Author's Name	S. Manfreda
Author's Name	M. Fiorentino
Author's Name	V. Iacobellis
Model Distribution Type	Semi-distributed
Modules Number	2
Time Scale	Daily
Time Scale	Hourly
Basin Dimension	Medium Sized
Application Zone	South of Italy
Developement Language	NA
Last Version	2005
Online Availability	NA
Download Address	NA
License Type	NA
Creation Date	2005

- GEOTOP2 [42,43]: "it simulates the combined energy and water balance at and below the land surface accounting for soil freezing, snow cover and terrain effects" [39].

  A schema of a part of data submitted is reported in Table 2:

Table 2. GEOTOP2 model features.

Feature	Value
Model Name	GEOTOP2
Author's Name	S. Endrizzi
Author's Name	S. Gruber
Author's Name	M. Dall'Amico
Author's Name	R. Rigon
Model Distribution Type	Distributed
Modules Number	NA
Time Scale	Daily
Time Scale	Hourly
Basin Dimension	NA
Application Zone	North of Italy
Developement Language	NA
Last Version	2017
Online Availability	YES
Download Address	NA
License Type	open
Creation Date	2005

- THALES [44–46]: "a physically based hydrologic model, which divides the watershed into irregular elements based on the streamlines and equipotential lines instead of representing them by regular rectangular grids. As many aspects of the hydrologic response depend on topography, this type of terrain-based model is an important development to accurately representing the surface and sub-surface runoff processes" [39].

  A schema of a part of data submitted is reported in Table 3.

Table 3. THALES model features.

Feature	Value
Model Name	THALES
Author's Name	Rodger B. Grayson
Author's Name	Günter Blöschl
Author's Name	Ian D. Moore
Author's Name	Thomas A. McMahon
Model Distribution Type	Distributed
Modules Number	2
Time Scale	Houorly
Basin Dimension	Small to Medium Sized
Application Zone	NA
Developement Language	NA
Last Version	NA
Online Availability	NO
Download Address	NA
License Type	NA
Creation Date	1992

- TOPMODEL [47–50]: "a physically based, distributed watershed model that simulates hydrologic flux-es of water (infiltration-excess over-land flow, saturation overland flow, infiltration, exfiltration, subsurface flow, evapotranspiration, and channel routing) through a watershed. The model simulates explicit groundwater/surface water interactions by predicting the movement of the water table, which determines where saturated land-surface areas develop and have the potential to produce saturation overland flow" [39]. A schema of a part of data submitted is reported in Table 4.

Table 4. TOPMODEL model features.

Feature	Value
Model Name	TOPMODEL
Author's Name	Keith Beven
Model Distribution Type	Distributed
Modules Number	NA
Time Scale	NA
Basin Dimension	Small to Medium Sized
Application Zone	NA
Developement Language	FORTRAN
Last version	NA
Online Availability	YES
Download Address	NA
License Type	open
Creation Date	NA

Tables 1–4 respectively show some of the fundamental characteristics of the hydrological models chosen. Starting from these characteristics and from the general taxonomy of Figure 2, using either a simple markup language made available by the platform or forms created ad hoc at the beginning categories, subcategories and then properties with the related datatypes were implemented.

The "meaning" in KMS was gradually broadened with progressive new interventions, namely

- definition of categories and sub-categories, see an example in Table 1;
- definition of properties and data types, see an example in Table 2;
- implementation of categories and properties with semantic markings;
- implementation of templates and modules for both new annotations and special requests;
- export/link of contents to other CMSes or data-repositories;

From the simple semantic markup entered by the users of the platform, some of which are shown in Tables 5 and 6. The system is called to reconstruct a space of logical statements in a formalized and machine-understandable way.

Table 5. Some of the higher categories and subcategories implemented in the system [39].

Category	Higher Category	Semantic Markup
Hydrology	-	`[[Category:Hydrology]]`
Hydrological Model	Hydrology	`[[Category:Hydrological_Model]]`
Runoff Model	Hydrological Model	`[[Category:Runoff_Model]]`

Table 6. Some properties defined in the KMS with related Markup and Data-Type [39].

Property	Semantic Markup	Data-type
Model Name	[[HasName:]]	Text
Author Name	[[HasAutNam:]]	Page-List
Model Distribution	[[HasDistribution:]]	Text
Modules Number	[[HasNModules:]]	Number
Time Scale	[[HasTempScale:]]	Text-List
Basin Dimensions	[[HasBasDim:]]	Text-List
Application Zone	[[HasZone:]]	Text-List

Table 6. *Cont.*

Property	Semantic Markup	Data-type
Developement Language	[[HasSviLan:]]	Text-List
Last Version	[[HasLasVer:]]	Number
Online Availability	[[IsOnLine:]]	Boolean
Download Address	[[HasDownAddr:]]	URL
License Type	[[HasLicType:]]	Text
Creation Date	[[HasCreatDate:]]	Date
Short Description	[[HasShDesc:]]	Text
Long Description	[[HasLnDesc:]]	Text
Reference Works	[[HasPubbl:]]	External identifier-List
Operativ System	[[HasOS:]]	Text
Source Availability	[[HasSource:]]	Boolean
Software Dependencies	[[HasSoftDep:]]	Text
Manuals Availability	[[HasManu:]]	Boolean
Last Version Date	[[HasLaVerDate:]]	Date
Genre of Data Input	[[HasDataInType:]]	Text
Genre of Data Output	[[HasDatOutType:]]	Text
Calibration Data	[[HasCalibDate:]]	Text
ORCID Identification	[[HasORCID:]]	External identifier
Author Affiliation	[[AutAffil:]]	Text-List
Author Email Address	[[AutEmail:]]	Email

2.4. Ontological Approach

In order to check the interoperability of the system in a sustainable planning perspective, the possibility of the system to relate to other open data repositories and to serve as a tool for processing metadata was verified [51]. This perspective was explored with the bottom-up construction of a simple ontology for the tested knowledge base [52].

As Gruber [51] puts it, an ontology defines the "specification of a conceptualization of a domain of knowledge". It is aimed at the specific characteristics of a conceptual system, with objectives related to understanding the elements of interest and the relationships between those elements. In essence, an ontology is interested in highlighting an explicit set of constraints existing within a domain. In an extended and general perspective, an ontology puts an assertion concerning a way in which the world is seen. In this framework, it is frequently composed through a language that can be read and processed by automatic machines [53].

There is a preliminary and preparatory phase for the construction and refinement of an ontology. This is the so-called ontological analysis phase of the reference domain. It is an important phase, intrinsically and intimately linked to the process of ontological construction. In fact, it uses and is inspired by ontological principles in order to frame, study and research a given issue, a given theme or problem. This exercise aims to pursue a fine understanding of the elements recognized or recognizable as involved in the construction process, as well as the characters and types of emerging relationships. It also scans the situations that the analyst considers possible [52].

From what has been said, it is clear that the so-called ontological analysis represents the truly difficult stage in the processes of research and construction of an ontology. However, this also indicates that it is the part that mostly determines the quality level of an ontological characterization effort. In highly complex contexts, situations and/or processes—for example, in social or environmental systems—the quality of the ontological analysis defines the effectiveness or even the real usefulness of an ontology [54].

A key concept in this framework is the so-called interpretative or semantic interoperability [52]. One of the structurally emerging problems in these cases is, in fact, the existence of differentiated visions of the world linked to the intrinsic, e.g., agentive, and cognitive meaning of conceptualization. Indeed, it is a matter of dealing with the management of different conceptualizations of reality in methodological and operational terms through the search for appropriate formalizations. The ultimate aim of these formalizations specifically concerns the possibility of guiding the creation of knowledge and information management systems endowed with some relevant characteristics. First of all, it is true that a formal ontology should faithfully reflect the vision of reality with respect to the point of view of the observer. However, it is also true that this representation should not be cryptic or opaque with respect to the cognitive aspects of reference, and it must not be a cognitive black box [53]. These aspects, together with the need for an internal logical structural consistency, represent the necessary framework to guarantee the aforementioned semantic interoperability.

Starting from the previous Gruber's definition concerning ontology as a conceptual structure of a domain of knowledge, it is possible to think of a formal ontology as the attempt to formally specialize such a definition. The constitutive constraints of this structuration primarily concern the formalization of the language through univocal and clear terminological and interpretative specifications. They also concern the use of explicit references to the philosophical foundations that motivate the categories adopted.

It is therefore evident that ontologies, through a fine conceptualizing action, perform a critical task in the organization of complex knowledge. An ontology can be expressed in diversified but similarly useful ways, depending on the reference contexts. Its relevance and value lay in the ability to model the content of knowledge, regardless of the use of natural language (e.g., WordNet) or more formalized language (e.g., web ontology language, *OWL*). In this sense, the construction should be preceded by structural analyses of the subject, as well as of the objectives of the ontology and of the agents involved in the areas of use and operation. Depending on the results of such analyses, it is subsequently possible to identify the object/objects of the modeling and the ways of organizing the knowledge base.

The reference context of the ontological analysis and construction process of this study is a hydrological knowledge domain embedded in an environmental system. These are conceptual areas characterized by significant and recognized complexity [40]. An ontological approach, articulated according to the previous reasoning, seems suitable to investigate the structuring of KMS based on ontologies.

The ontology should help improve discussion within and outside the communities of involved agents to ensure a common semantic understanding of concepts as well as to provide a useful tool for the rigorous definition of descriptive metalevels [55]. Concerning the knowledge base, an ontology is proposed which describes concepts and relationships extracted from the KMS using the implemented and characterized features and expressed firstly using OWL and then Json-LD [55]. A thorough representation of the ontology cannot be included in the paper as it is too rich, nested and articulated in several relational levels. However, in order to give a general idea of the organizational structure of the ontology, sketchy representations are provided as excerpts to help a larger awareness. In particular, a graphical representation of a small part of the final ontology is shown in Figure 5 using OntoGraph—a tool providing support for interactive navigation of OWL ontology relationships.

Another part of the extracted ontology is shown in the Class Hierarchy view of Protégé, an open source ontology editor and framework for building OWL-based ontological models (Figure 6). Concepts, instances, properties and relations are structured here as multi-nested classification trees, which in fact represent the backing framework of the image previously excerpted in Figure 5.

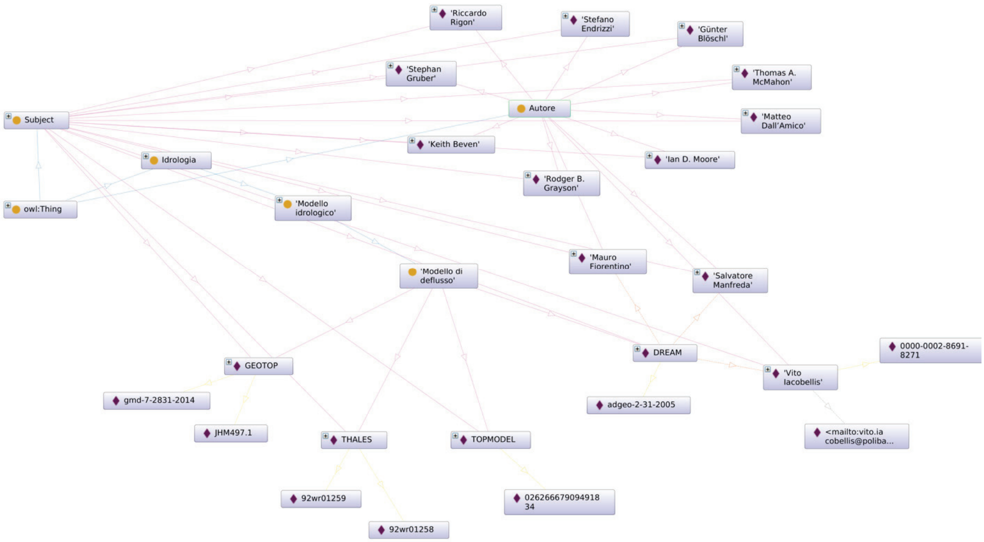

Figure 5. Part of the extracted ontology in OntoGraph.

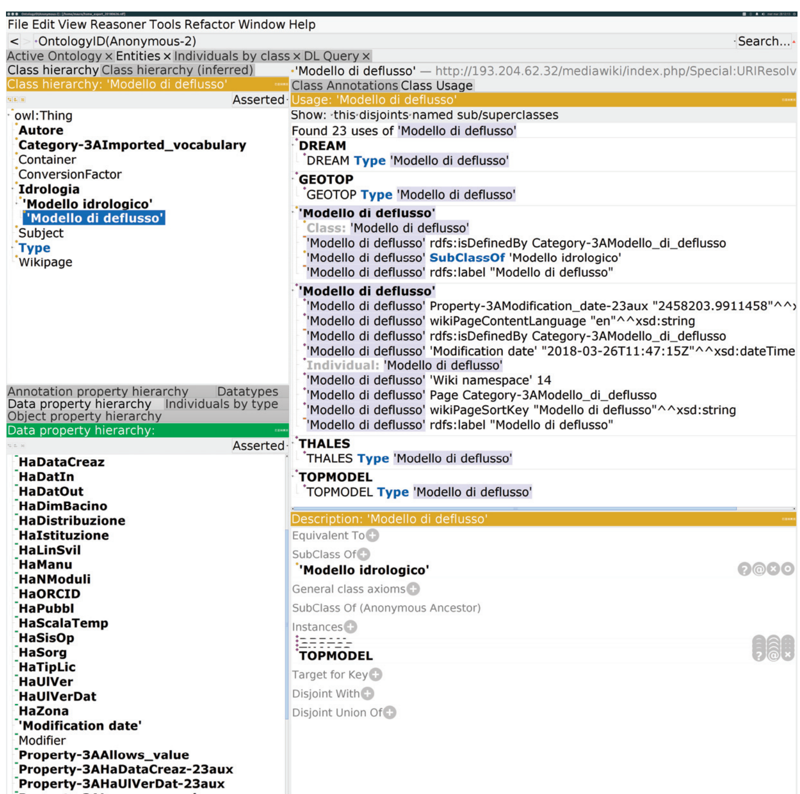

Figure 6. Class Hierarchy View of part of ontology in Protégé (excerpt).

Therefore, the final part of the research has focused on the management of complexity in hydrological knowledge, proposing to investigate the construction of a knowledge management system useful for operational decisions in the water domain.

3. Discussion and Conclusions

The domain of reference of the present work is the concept of the urban bioregion with its inherent system complexity. In this context, the setting up of a semantic-based model to deal with multiagent water-related concepts has been explored. The research first explored the system's ability to support the creation and development of knowledge contents enriched with semantic expression. Subsequently, a second objective was to investigate the possible interoperability of the system in a sustainable planning perspective. Particularly, the possibility of the system to relate to other open data repositories and to serve as a tool for processing metadata was explored [51]. This perspective was explored in the final part of the work with the bottom-up construction of a simple ontology for the tested knowledge base [52], thus further showing the platform's ability to clarify the disciplinary boundaries related to water.

Concerning the manageability of complex hydrological knowledge, the model seems to be more effective than traditional approaches [40]. In particular, it gives operational suggestions towards the management of multisource and multiagent knowledge, both in formal and informal contexts. This represents an interesting improvement perspective, as it allows for the creation of integrated and dynamically updatable knowledge bases—complex, in one word [37].

Looking at a system capable of dealing with the complexity of hydrological knowledge, the research therefore seems to confirm the possibility of supporting water-oriented decisions and policies in more informed ways—being akin to complex knowledge. The consequent greater ability to fine-tune concepts and meanings seems to also suggest better perspectives of unambiguity and, therefore, less discretionary interpretations of knowledge—a well-known problem in policymaking [11].

In this framework, the model seems therefore useful to support more informed and effective decisions and policies in the water domain at different scales of environmental planning. And based on the above, it seems that this type of approach to knowledge management can represent an encouraging perspective for broader sustainable land management and planning operations. In fact, water and hydrology are structural aspects for any decision-making question related to the futures of cities and environments, especially in terms of urban bioregion. In particular, various objectives of the UN 2030 Agenda consider water resources as essential in the bioregional future of the territories, with specific references in goals 11 and 12 [56], p. 423.

Indeed, the aspects of social, environmental, procedural, relational and cognitive complexity represent intrinsic parts of the domain addressed by planning actions. Therefore, an approach that operationally preserves this complexity should be extremely useful for those planning actions. In fact, the issue of knowledge management is one of the most intricate parts of environmental planning. There is extensive literature on the importance of the contributions of expert knowledge, which is codified, formalized and based on domain-dependent scientific conceptualizations [13]. An architecture based on ontological models with semantic extensions could manage such multisource knowledge data in a systemic and structured way. But even non-expert knowledge, the unstructured and informal knowledge exchanged by community members is today an indispensable contribution to planning processes [57]. That is, the management of both expert and non-expert knowledge, characterized by different languages and conceptualizations, represents a very interesting objective for environmental planning, despite the underlying complexity. And this is a very topical objective, particularly when dealing with possible architectures to support the multiscale governance of urban bioregions [55]. The planning, decision-making and management activities of urban bioregions today need to look at the aspects of resources with a diffused, formal and informal cognitive approach. This could largely benefit from the large amount of data now available and from the various forms of ordering and classification that are increasingly available. In this complex but critical and unavoidable context of knowledge, the effort to explore and define knowledge management architectures represents a very interesting perspective. The present study about the analysis and structuring of water-resource ontologies makes it possible to reflect on the potential of approaches of this kind. Furthermore, its inherent interoperability and structural trans-domain interconnectivity suggest possible scope enlargements and generalizations. Indeed, a perspective would be to aim at its possible replicability, or possible extension at least, to other complex domains in the bioregional context.

Clearly, the present study provides only synthetic accounts and operational scenarios in this sense. Nonetheless, it is able to open interesting follow-up perspectives, and its development will be pursued by our group in the near future.

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Appendix A

With reference to Section 2.2, open-source software links are:

Apache	https://httpd.apache.org/	Accessed on 3 February 2023
Extension: page forms	https://www.mediawiki.org/wiki/Extension:Page_Forms	Accessed on 3 February 2023
Extension: scribunto	https://www.mediawiki.org/wiki/Extension:Scribunto	Accessed on 3 February 2023
Extensions: parserhooks	https://github.com/JeroenDeDauw/ParserHooks	Accessed on 3 February 2023
Extensions: validators	https://github.com/DataValues/Validators	Accessed on 3 February 2023
Extension: templatedata	https://www.mediawiki.org/wiki/Extension:TemplateData	Accessed on 3 February 2023
Extension: wikieditor	https://www.mediawiki.org/wiki/Extension:WikiEditor	Accessed on 3 February 2023
Icu	http://site.icu-project.org/	Accessed on 3 February 2023
Lua	http://www.lua.org/	Accessed on 3 February 2023
Mediawiki	https://www.mediawiki.org/	Accessed on 3 February 2023
Mysql	https://www.mysql.com/	Accessed on 3 February 2023
Php	https://php.net/	Accessed on 3 February 2023
Semantic-mediawiki	https://www.semantic-mediawiki.org/	Accessed on 3 February 2023
Ubuntu	https://www.ubuntu.com/	Accessed on 3 February 2023
Virtualbox	https://www.virtualbox.org/	Accessed on 3 February 2023

References

1. Berners-Lee, T.; Hendler, J.; Lassila, O. The semantic web. *Sci. Am.* **2001**, *284*, 34–43. [CrossRef]
2. Thayer, R.L. *LifePlace: Bioregional Thought and Practice*; University of California Press: Berkeley, CA, USA, 2003.
3. Geddes, P. *Cities in Evolution*; Williams: Edinburgh, UK, 1915.
4. Mumford, L. *Technics and Civilization*; Harcourt Brace and Company: New York, NY, USA, 1934.
5. Howard, E. *Garden Cities of Tomorrow*; MIT Press: Cambridge, MA, USA, 1965.
6. Newman, P.; Jennings, I. *Cities as Sustainable Ecosystems: Principles and Practices*; Island Press: Washington, DC, USA, 2012.
7. Reiniger, C. Bioregional planning and ecosystem protection. In *Ecological Design and Planning*; Steiner, F.R., Thompson, G.F., Eds.; Wiley: New York, NY, USA, 1997; pp. 185–200.
8. Uittenbroek, C.J.; Mees, H.L.P.; Hegger, D.L.T.; Driessen, P.P.J. The design of public participation: Who participates, when and how? Insights in climate adaptation planning from the Netherlands. *J. Environ. Plan. Manag.* **2019**, *62*, 2529–2547. [CrossRef]

9. Scott, T.A.; Carter, D.P. Collaborative governance or private policy making? When consultants matter more than participation in collaborative environmental planning. *J. Environ. Policy Plan.* **2019**, *21*, 153–173. [CrossRef]
10. Frank, A.U.; Bittner, S.; Raubal, M. Spatial and cognitive simulation with multi-agent systems. In *Spatial Information Theory*; Montello, D.R., Ed.; Springer: Cham, Switzerland, 2001; pp. 124–139.
11. Healey, P. *Collaborative Planning: Shaping Places in Fragmented Societies*; Macmillan: Houndmills, UK, 1997.
12. Forester, J. *The Deliberative Practitioner: Encouraging Participatory Planning Processes*; MIT Press: Cambridge, MA, USA, 1999.
13. Fischer, F. *Citizens, Experts, and the Environment: The Politics of Local Knowledge*; Duke University Press: Durham, UK, 2000.
14. Borri, D.; Camarda, D.; Grassini, L. Distributed Knowledge in Environmental Planning: Hybrid IT-Based Approaches in Scenario-Building Contexts. *Group Decis. Negot.* **2006**, *15*, 557–580. [CrossRef]
15. Borri, D.; Camarda, D.; De Liddo, A. Multi-agent environmental planning: A forum-based case-study in Italy. *Plan. Pract. Res.* **2008**, *23*, 211–228. [CrossRef]
16. Borri, D.; Camarda, D.; Pluchinotta, I. Planning urban microclimate through multiagent modelling: A cognitive mapping approach. In *Cooperative Design, Visualization, and Engineering, CDVE2013*; Luo, Y., Ed.; Lecture Notes in Computer Science; Springer: Berlin/Heidelberg, Germany, 2013; Volume 8091, pp. 169–176.
17. De Liddo, A.; Concilio, G. Making Decision in Open Communities: Collective Actions in the Public Realm. *Group Decis. Negot.* **2017**, *26*, 847–856. [CrossRef]
18. Cutini, V. Centrality and land use: Three case studies on the configurational hypothesis. *Cybergeo Eur. J. Geogr.* **2001**. [CrossRef]
19. Herold, M.; Couclelis, H.; Clarke, K.C. The role of spatial metrics in the analysis and modeling of urban land use change. *Comput. Environ. Urban Syst.* **2005**, *29*, 369–399. [CrossRef]
20. Rabino, G.; Caglioni, M. Theoretical approach to urban ontology: A contribution from urban system analysis. In *Ontologies for Urban Development*; Teller, J., Lee, J., Roussey, C., Eds.; Studies in Computational Intelligence; Springer: Berlin/Heidelberg, Germany, 2007; Volume 61, pp. 109–119.
21. Freksa, C.; Newcombe, N.S.; Gardenfors, P.; Wolfl, S. (Eds.) *Spatial Cognition VI, Learning, Reasoning, and Talking about Space*; Springer: Berlin/Heidelberg, Germany, 2008.
22. Batty, M. *The New Science of Cities*; MIT Press: Cambridge, MA, USA, 2013.
23. Stapper, E.W.; Duyvendak, J.W. Good residents, bad residents: How participatory processes in urban redevelopment privilege entrepreneurial citizens. *Cities* **2020**, *107*, 102898. [CrossRef]
24. Simon, H.A. *The Sciences of the Artificial*; MIT Press: Cambridge, MA, USA, 1969.
25. Susskind, L.; Cruikshank, J.L. *Breaking the Impasse: Consensual Approaches to Resolving Public Disputes*; Basic Books: New York, NY, USA, 1987.
26. Lichfield, N.; Barbanente, A.; Borri, D.; Khakee, A.; Prat, A. (Eds.) *Evaluation in Planning: Facing the Challenge of Complexity*; Springer: Dordrecht, The Netherlands, 2013.
27. Wilkins, D.E.; des Jardins, M. A call for knowledge-based planning. *AI Mag.* **2001**, *22*, 99. [CrossRef]
28. Borri, D. Frames, multiagents and good behaviours in planning rationales. In *Making Strategies in Spatial Planning: Knowledge and Values*; Cerreta, M., Concilio, G., Monno, V., Eds.; Springer: Dordrecht, The Netherlands, 2010; pp. 235–256.
29. Stufano Melone, M.R.; Borgo, S.; Camarda, D. Space in Socio-technical Systems: Exploring the Agent-Space Relation. *Lect. Notes Comput. Sci.* **2021**, *12953*, 489–502.
30. Stufano Melone, M.R.; Borri, D.; Camarda, D.; Borgo, S. Knowledge of places: An ontological analysis of the social level in the city. In *Smart Planning: Sustainability and Mobility in the Age of Change*; Papa, R., Fistola, R., Gargiulo, L., Eds.; Springer: Berlin/Heidelberg, Germany, 2018; pp. 3–14.
31. Montanari, A.; Young, G.; Savenije, H.H.G.; Hughes, D.; Wagener, T.; Ren, L.L.; Koutsoyiannis, D.; Cudennec, C.; Toth, E.; Grimaldi, S.; et al. "Panta Rhei—Everything Flows": Change in hydrology and society—The IAHS Scientific Decade 2013–2022. *Hydrol. Sci. J.* **2013**, *58*, 1256–1275. [CrossRef]
32. Krueger, T.; Maynard, C.; Carr, G.; Bruns, A.; Mueller, E.N.; Lane, S. A transdisciplinary account of water research. *WIREs Water* **2016**, *3*, 369–389. [CrossRef] [PubMed]
33. Gong, W.; Gupta, H.V.; Yang, D.; Sricharan, K.; Hero, A.O., III. Estimating epistemic and aleatory uncertainties during hydrologic modeling: An information theoretic approach. *Water Resour. Res.* **2013**, *49*, 2253–2273. [CrossRef]
34. Di Baldassarre, G.; Brandimarte, L.; Beven, K. The seventh facet of uncertainty: Wrong assumptions, unknowns and surprises in the dynamics of human–water systems. *Hydrol. Sci. J.* **2016**, *61*, 1748–1758. [CrossRef]
35. Nearing, G.S.; Tian, Y.; Gupta, H.V.; Clark, M.P.; Harrison, K.W.; Weijs, S.V. A philosophical basis for hydrological uncertainty. *Hydrol. Sci. J.* **2016**, *61*, 1666–1678. [CrossRef]
36. Borri, D.; Camarda, D.; Grassini, L. Complex Knowledge in the Environmental Domain: Building Intelligent Architectures for Water Management. *Lect. Notes Comput. Sci.* **2005**, *3533*, 762–772. [CrossRef]
37. Beven, K. Facets of uncertainty: Epistemic uncertainty, non-stationarity, likelihood, hypothesis testing, and communication. *Hydrol. Sci. J.* **2016**, *61*, 1652–1665. [CrossRef]
38. Pease, A. *Ontology: A Practical Guide*; Articulate Software Press: New York, NY, USA, 2011.
39. Patano, M.; Camarda, D.; Iacobellis, V. The Cooperative Management of Complex Knowledge in Planning: Building a Semantic-Based Model for Hydrological Issues. *Lect. Notes Comput. Sci.* **2020**, *12341*, 279–288. [CrossRef]
40. Devia, G.K.; Ganasri, B.P.; Dwarakish, G.S. A Review on Hydrological Models. *Aquat. Procedia* **2015**, *4*, 1001–1007. [CrossRef]

41. Manfreda, S.; Fiorentino, M.; Iacobellis, V. DREAM: A distributed model for runoff, evapotranspiration, and antecedent soil moisture simulation. *Adv. Geosci.* **2005**, *2*, 31–39. [CrossRef]
42. Rigon, R.; Bertoldi, G.; Over, T.M. GEOtop: A Distributed Hydrological Model with Coupled Water and Energy Budgets. *J. Hydrometeorol.* **2006**, *7*, 371–388. [CrossRef]
43. Endrizzi, S.; Gruber, S.; Dall'Amico, M.; Rigon, R. GEOtop 2.0: Simulating the combined energy and water balance at and below the land surface accounting for soil freezing, snow cover and terrain effects. *Geosci. Model Dev.* **2014**, *7*, 2831–2857. [CrossRef]
44. Grayson, R.B.; Blöschl, G.; Moore, I.D. Distributed parameter hydrologic modelling using vector elevation data: THALES and TAPES-C. In *Computer Models of Watershed Hydrology*; Singh, V.P., Ed.; Water Resources Publications: Littleton, CO, USA, 1995; pp. 669–696.
45. Grayson, R.B.; Moore, I.D.; Mcmahon, T.A. Physically based hydrologic modeling: 1. A terrain-based model for investigative purposes. *Water Resour. Res.* **1992**, *28*, 2639–2658. [CrossRef]
46. Grayson, R.B.; Moore, I.D.; McMahon, T.A. Physically based hydrologic modeling: 2. Is the concept realistic? *Water Resour. Res.* **1992**, *28*, 2659–2666. [CrossRef]
47. Beven, K.J.; Kirkby, M.J. A physically based, variable contributing area model of basin hydrology/Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. *Hydrol. Sci. J.* **1979**, *24*, 43–69.
48. Beven, K.; Kirkby, M.; Schofield, N.; Tagg, A. Testing a physically-based flood forecasting model (TOPMODEL) for three U.K. catchments. *J. Hydrol.* **1984**, *69*, 119–143. [CrossRef]
49. Beven, K.; Lamb, R.; Quinn, P.; Romanowicz, R.; Freer, J. TOPMODEL. In *Computer Models of Watershed Hydrology*; Singh, V.P., Ed.; Water Resources Publications: Littleton, CO, USA, 1995; pp. 627–668.
50. Beven, K.; Freer, J. A dynamic TOPMODEL. *Hydrol. Process.* **2001**, *15*, 1993–2011. [CrossRef]
51. Gruber, T.R. Toward principles for the design of ontologies used for knowledge sharing? *Int. J. Hum.-Comput. Stud.* **1995**, *43*, 907–928. [CrossRef]
52. Guarino, N. Formal ontology, conceptual analysis and knowledge representation. *Int. J. Hum.-Comput. Stud.* **1995**, *43*, 625–640. [CrossRef]
53. Asim, M.N.; Wasim, M.; Khan, M.U.G.; Mahmood, W.; Abbasi, H.M. A survey of ontology learning techniques and applications. *Database* **2018**, *2018*, bay101. [CrossRef] [PubMed]
54. Borgo, S.; Borri, D.; Camarda, D.; Stufano Melone, M.R. An ontological analysis of cities, smart cities and their components. In *Technology and the City: Towards a Philosophy of Urban Technologies*; Nagenborg, M., Stone, T., González Woge, M., Vermaas, P.E., Eds.; Springer: Cham, Switzerland, 2021; pp. 365–387.
55. Yates, J.S.; Harris, L.M.; Wilson, N.J. Multiple ontologies of water: Politics, conflict and implications for governance. *Environ. Plan. D Soc. Space* **2017**, *35*, 797–815. [CrossRef]
56. Huck, W. *Sustainable Development Goals: Article-by-Article Commentary*; Nomos Verlag: Baden, Germany, 2022.
57. Khakee, A.; Barbanente, A.; Borri, D. Expert and experiential knowledge in planning. *J. Oper. Res. Soc.* **2000**, *51*, 776–788. [CrossRef]

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Article

Green Infrastructure and Slow Tourism: A Methodological Approach for Mining Heritage Accessibility in the Sulcis-Iglesiente Bioregion (Sardinia, Italy)

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Abstract: In European countries many measures are carried out to improve the disadvantaged conditions and socio-economic marginality of rural areas in comparison with central places. These conditions also affect the quality of travel for visitors and tourists. Therefore, in response to a 'new' tourist demand, motivated also by the restrictions following the spread of the COVID-19 virus in recent years, the institutions and the different local actors are working more incisively to improve rural areas. The rural tourism services offer, combined with the Green Infrastructure (GI) project, at different scales—from local to regional—interesting territorial development strategies to achieve the Agenda 2030 objectives. This contribution considers the Sulcis-Iglesiente-Guspinese area, in the Sardinia Region (IT), as a case study. In this area, the landscape context is marked by past mining activity, and the project of a path of historical, cultural, and religious values has proven to be an activator of regenerative processes, in environmental, social, and economic terms. The present study proposes a methodological approach to develop an index (FI—feasibility index) to assess the feasibility of the Stop Places (SPs) project along a horse trail to integrate the current slow mobility of bicycles and pedestrians in the bioregion.

Keywords: green infrastructures; slow tourism; rural tourism; bioregion

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1. Introduction

According to UNWTO, rural tourism is a "type of tourism activity in which the visitor's experience is related to a wide range of products generally linked to nature-based activities, agriculture, rural lifestyle/culture, angling and sightseeing" [1]. This type of tourism can be combined with the slow philosophy of travel that suggests a non-invasive and sustainable use of space. Slow tourism is a way of traveling focused on in-depth experience to understand the ecosystem of places and the landscapes in progress, with a limited impact on the environment, especially when the community chooses to travel by sustainable transport models (walk, bike, horse) [2,3]. In the rural context, this approach is a priority for local actors who are planning their landscapes under the banner of economic competitiveness and the protection of natural and cultural resources. Slow movement normally takes place along specially created or 'recovered' paths that represent the essence of the place. The rediscovery of identity traces and the consequent development of projects consider the territory as a common resource/service on which the well-being and quality of life of the resident and host population depends. In this profile, the value of common pool resources is combined with that of green infrastructures that assume the role of 'glue' between natural and semi-natural areas, and agricultural and built-up areas.

Green infrastructures (GIs), at the local scale, prove to be increasingly strategic in achieving the objectives of the 2030 Agenda. According to the European Commission (EC), a GI is "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services [4]. It incorporates green spaces—or blue ones if aquatic ecosystems are concerned—and other physical features in terrestrial—including coastal—and marine areas" [5]. Moreover, GIs can provide multiple environmental, social, and economic benefits. These include paths and other infrastructures for slow mobility.

The EU's Green Infrastructure Strategy (2019) [6] confirms that the connection of natural capital in Europe is to be strengthened. In this sense, the quality of the GIs, understood as a provider of ecosystem services (ESs) and as a system well integrated and spatially connected, has a significant effect on the conservation and improvement of the environment [7]. This is why integrating the GI objectives into strategic planning processes and spatial planning tools is an absolute priority [8].

Another aspect to consider is that the projects of paths and cycle paths, which constitute the network to favor slow mobility [9], contribute to the realization of GIs, recognized as drivers of territorial regeneration.

This is what is emerging in the Sulcis-Iglesiente bioregion, located in the south-western part of the Autonomous Region of Sardinia (Sardinia Region) in Italy. This area went through a phase of economic conversion based on sustainable slow tourism development [10–12], as a result of abandoned mines [13].

Within this framework, the objective of this manuscript is to define a methodological approach to develop a feasibility index (FI) to assess the feasibility of the Stop Places (SPs) project scenarios along a horse trail to integrate current slow mobility methods (walking and biking), improving accessibility to the mining heritage. The paper is organized as follows:

1. First section—Introduction and Literature Review—focuses on the overview of the recent literature of GI and of its integration with slow tourism and bioregion concepts;
2. Second section—Materials and Data—discusses the topic of green infrastructures and slow mobility in the Sulcis-Iglesiente region and presents principles and approaches for horse trails planning;
3. Third section—Methodology—proposes a methodological approach to assess the feasibility of the Stop Places (SPs) scheme along a horse trail;
4. Fourth section—Case Study—is dedicated to the methodology application in the Stop Places (SPs) along a horse trail in the Sulcis-Iglesiente bioregion;
5. Fifth section—Results—reports and discusses the main research results carried out.
6. Sixth section—Discussion—discusses the major findings within the framework derived from the literature review;
7. Seventh section—Conclusion and Future Development—is dedicated to the conclusions together with the future developments of the research.

1.1. Rural and Slow Tourism—Green Infrastructure

Composing 83% of the total land area of the European Union (EU), the rural world is home to some 137 million inhabitants (30% of the total population) and is characterized by its landscape diversity. These diversities are also expressed through multiple weaknesses linked to depopulation and a weak socio-economic network. In the last twenty years, in order to counteract the elements that increase the peripherality of these areas in relation to urbanized areas, Europe has outlined an agenda of action plans and programs focused on growth, employment, and the sustainable development of spaces. However, the implementation of Agenda 2000 has also triggered several reforms of development and cohesion policies in the agricultural sector, which has seen a new model based on the multifunctionality of the rural territory [14–16]. In particular, the diversification of the rural economy, in addition to placing the agricultural production sector in a new framework, has made it possible to address with greater attention the critical issues related to environmental protection and the quality of life of native communities [17]. In addition, as a result of the restrictions of the COVID-19 pandemic, the EU supports the rural world through the European Agricultural Fund for Rural Development 2021–2027 (EAFRD): funding that can be spent by the different Rural Development Programs (RDPs) at national and regional levels to foster inclusive, cohesive, and sustainable development [18].

The opportunities for rural territories to improve local development can be seized in the diversified panorama of sustainable tourism activities. In particular, rural tourism explicated in different forms according to the territory and the communities that are involved in it is prefigured as a tool for the conservation of the landscape and the growth of the socio-economic value of places through a structured offer of goods and services [19,20]. There is no universal definition of rural tourism and through the years there have been many definitions enunciated that differ based on the aspects considered, such as socio-cultural, administrative, demographic, and economic [21]. In 1998, the European Commission defined rural tourism as " ... the activities of a person travelling and staying in rural areas—without mass tourism—other than those of their usual environment for less than one consecutive year for leisure, business and other purposes (excluding the exercise of an activity remunerated from within the places visited" [22]. The multifunctional organization of the rural space thus acquires a new guise where synergies between local operators (public and private) can be expressed through cultural, environmental, sporting, and educational initiatives planning, which also holds all the benefits deriving from the implementation of multimodal transport for the accessibility of tourist destinations, according to the MAAS (mobility as a service) perspective, where the public transport system is the more ecologically and socially sustainable [23,24].

The activation of this integrated offer plays a fundamental role in the processes of revitalization and local development because it makes it possible to preserve the territorial identity of the many rural villages and, at the same time, allows tourists to enjoy an 'experiential' journey [25–27]. According to Eurostat data, in 2021, in the 27 Member States, 36% of tourist nights were spent in rural areas, which offers around 12 million beds [28]. The choice of a holiday in contact with nature and the authenticity of places is even more motivated by the changes brought to daily life by the COVID-19 pandemic. Health insecurity and restrictions have prompted tourists to seek 'staycation' and 'slow' travel experiences [29–32]. Thus, in response to the criticality of overtourism, rural tourism experiences are combined with the slow philosophy (slow tourism). This last trend, born with the 'slow food' movement, allows us to deepen our knowledge of places by perceiving their most authentic aspects. The enjoyment of landscape assets, the respect for the environment, and the propensity to use sustainable means of transport are just some of the fundamental characteristics of 'slow' travel—walking, cycling, horseback riding, etc. [2,3]. Furthermore, the experience of slow travel is completed when visitors and tourists choose to travel through destinations following sustainable infrastructures. In this context, the scientific debate on GIs began to appear in the 1990s and, today, the term plays a key role in policies and strategies aimed at resolving critical environmental issues [33]. Following the debates, several definitions of GIs have been enunciated [34,35]. The European Commission, since 2013, has launched a special strategy to support the green economy through the development of GIs, and has defined them as: "Green Infrastructure can be broadly defined as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. More specifically GI, being a spatial structure providing benefits from nature to people, aims to enhance nature's ability to deliver multiple valuable ecosystem goods and services, such as clean air or water" [36]. The Commission published two further guidance documents in 2019 to encourage a more integrated approach and increase investment and planning in this field. These documents reinforce the idea that the sites included in the Natura 2000 Network represent the core of the GI strategy to which were added "[...] biodiversity-rich green spaces such as parks, private gardens, hedges and vegetated buffer strips along rivers or structure-rich agricultural landscapes with certain features and practices, and artificial features such as green roofs, green walls, or eco-bridges and fish ladders [...]" [37].

GI takes the form of an interconnected network of spaces (urban, peri-urban, and rural) of significant environmental, cultural, and visual value. Although the scientific debate on the types of areas that can contribute to the realization of a GI is still in constant evolution [38], it is believed that its function is to simultaneously preserve and provide environmental services to affected communities, which include, for example, biodiversity and wildlife, mitigation of air quality, recreation, environmental beauty, and protection of disasters [34,39].

Investing in GIs completes the European program "Biodiversity strategy for 2030" [40], activated to protect member states' biodiversity. The roadmap for rural spatial planning therefore requires the creation of an ecosystem network where green goods and grey goods and services are integrated in a sustainable way [41,42]. GIs have an ecological, cultural, social, and economic function: the resident community is motivated to follow a healthy lifestyle, which includes the adoption of sustainable and slow mobility and the possibility of creating spaces of 'community friendliness' more in contact with the natural element [43].

1.2. Bioregion and Sardinia Mining Landscape

The GI plan to provide a network of 'new' ecosystem services is part of the vision of the bioregion [44,45]. This term originated in the 1970s along the American West Coast. The authors Peter Berg and Raymond Dasmann (1977) [46] can be defined as the fathers of the concept and the consequent alternative approach that sees localism as an opportunity to safeguard landscapes. The bioregion is defined as a geographical space and 'place of consciousness' in which environmental sustainability, knowledge, and conscious management of resources allows for a 're-inhabitation of place', as introduced by Berg in his studies [47]. An environmentalist vision that has since developed in other countries and, in the Italian case [48], thanks to the territorialist studies of Magnaghi [49,50]. The bioregion project idea requires an integrated, multidisciplinary approach at different scales capable of strengthening the cultural identity of the area networks while creating a dynamic balance between the different rural and urban centers [51] and material and immaterial dimensions [52]. Thus, bioregionalism, in its capacity as a territorial regeneration project, qualifies as an essential paradigm for addressing the critical issues of rural areas.

The island of Sardinia represents, due to its environmental characteristics, a peculiar condition: the geological, paleontological, and mineralogical elements, biological rarities and endemisms, forest stands and wetlands, spectacular natural landscapes in the morphology of the coasts and of the internal reliefs, the underground cavities and the archaeological finds all make it a small but whole continent. Sardinia is famous in the international mining world for the richness of its geology, of its ore deposits and of its mines [53]. On the 24,000 square kilometers that make up the area of this island, all the geological eras, from the late Precambrian onwards, are represented through an enormous variety of heterogeneous rocks, minerals, and fossils. The mining vocation of Sardinia is manifested in the large number of scattered mines on the entire surface of the island, of different productive, scientific, and cultural value, but all indispensable for understanding the extraordinary evolution of events, which, in more than 8000 years of uninterrupted events, have marked the history of the use of the territory by man [54].

From the lower Paleozoic up to the present, mineral genetic processes have developed, producing the concentration of metals and minerals of industrial interest in deposits of different types, genesis, and entity. The orogenetic events and the imposing granitic intrusions have activated hydrothermal circuits, with depositions of various types of mineralization, such as talc-chlorite and mineralizations with magnetite and sulphide. The deposition of carbonate sediments starting from the Jurassic, was completed at the end of the Mesozoic, when Sardinia emerged completely and several layers of coal deposited in the south-western area (Sulcis), combined in a calcareous-marly succession. The importance of each area, within the framework of mining sites, is related to the development of a particular mineral deposit: from the metalliferous ore deposits to the presence of the important copper mining (Funtana Raminosa), which played a significant role in the history of metallurgy in the Mediterranean area, starting from the Neolithic age. From the zinc and silver metal deposits, exploited since the Roman colonization, to the metallic antimony deposits, exploited since the Phoenician and Punic invasions, which made the area of Sarrabus-Gerrei the second island mining district between 1800 and 1900. The most important mines are present in the so-called "metal ring of the Iglesiente", where lead, silver, and zinc mineralizations are located in the carbonatic geological formations which, at over 500 million years old, are the oldest paleontological dated rocks in Italy.

The mining activity of Sardinia has primarily involved the communities that have followed one another in the exploitation of subsoil resources; the traces of this industry, which has been influenced by the same historical events of the island, are clearly visible in the territory. It has undergone profound changes that currently characterize it. The features of the natural landscape are visibly marked by the material culture, social organizations, and settlements that have arisen around the mining activities, which have generated new and original forms of landscape and social and cultural environments, such as to characterize vast areas with a precise identity of universal value, unique and representative of the entire Mediterranean geo-cultural region. Considering all these values, the Sardinia Region, through the Sardinian Mining Authority, has intended to promote, starting from 1997, with the involvement of all institutional subjects authorities, first of all the Local Authorities concerned, the establishment of the Historical Environmental Geo-Mining Park of Sardinia (Geo-Mining Park) [55], which includes the most important mining districts, located in the Sulcis-Iglesiente-Guspinese, but also the most significant mining structures located in other areas of the island.

As part of this renewed awareness, the Santa Barbara Path (SBP) [56] has been established (Figure 1) in the Sulcis-Iglesiente bioregion (2017), as well as the homonymous Foundation—the Santa Barbara Path Foundation (SBPF) [57]—which represent a real challenge taken on by local communities themselves and, subsequently, by the local administrations, to promote a virtuous process of territorial transformation.

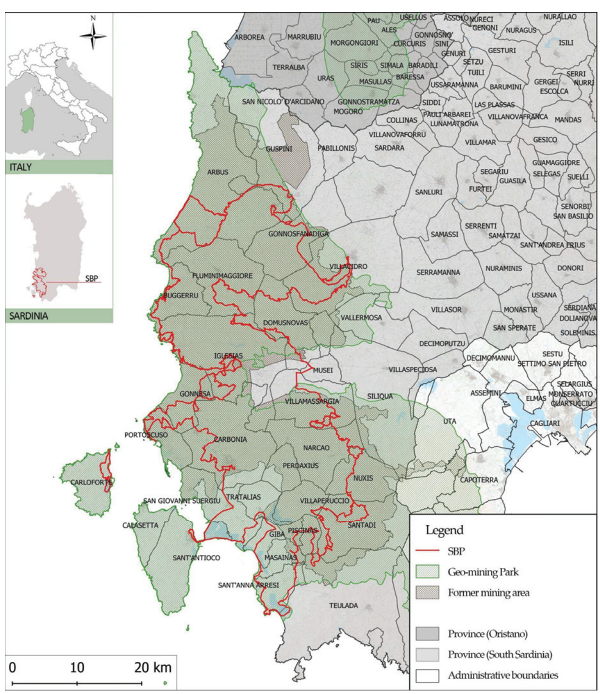

Figure 1. The SBP, in the Sulcis-Iglesiente bioregion (Author: M. Ladu, 2023).

2. Materials and Data

2.1. Study Area—The Santa Barbara Path and Horse Trail Proposal Network

The Santa Barbara Path (SBP) is an itinerary drawn in the Sulcis-Iglesiente area, in south-western Sardinia, an historical region that was the most important district for national and international mining until the 1990s, when the crisis hit the sector, causing the mines' dismantling [58]. As a consequence, the mining landscape is marked by large open-air and underground works, mine adits, tunnels, and numerous mine wastes.

The principal result of this extensive mining activity is the economic depression that required the rethinking of a new development, also through forms of sustainable tourism [59] capable of enhancing the great heritage of industrial archeology [60] in a particularly beautiful mining and coastal landscape [61].

The SBP, which extends along a 500 km ring, organized into 30 tracks, follows the traces drawn by mining activities in the past decades in a unique landscape in transition—or landscape in progress—understood as the outcome of different stages of human–nature interaction [62]. In this sense, the SBP represents a response to the demand for a particular type of rural and slow tourism [63] associated with the use of GIs, which, in the Sulcis-Iglesiente region (mining bioregion), arises as a driving force for economic development.

Over the last few years, the SBP has been included in the regional register of historical-religious walks of Sardinia and in the Atlas walk of Italy of the Ministry of Cultural Heritage and Activities.

In line with the objectives of the Geo-Mining Park, the SBPF constantly promotes different types of accessibility as a primary condition for a new development phase based on the concept of rural and slow tourism [64], according to principles that guide the political strategies of the regional level [65]. As a matter of fact, the construction of a horse trail, connected to the SBP and to the cycle path (a thematic route connected to the great cycling network of Sardinia) [66], represents one of the most important projects carried out by the SBPF (Figure 2). The horse trail consists of a ring route of over 500 km, divided into 18 tracks and 19 Stop Points (SP), which crosses 24 municipalities.

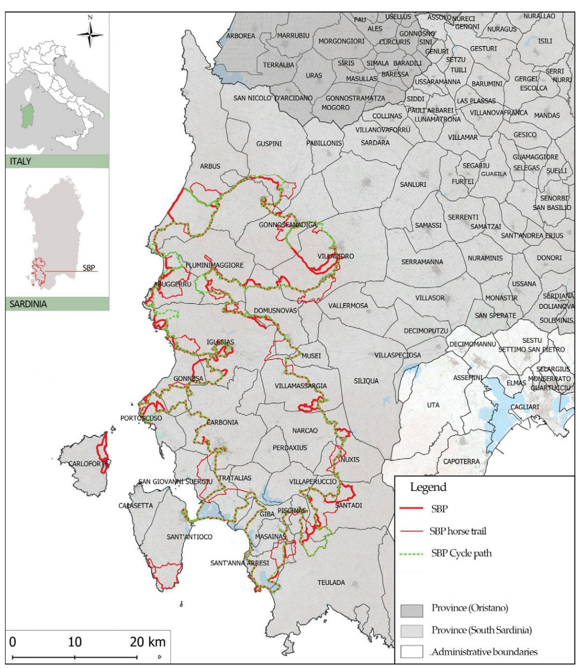

Figure 2. The SBP, in relation with the SBP cycle path and the new SBP horse trail (Author: M. Ladu, 2023).

In this sense, the SBPF intends to enhance the SBP as a GI for rural and slow tourism for several integrated aspects: the recovery of the old mining tracks; provision of a different travel way (walk, bike, and by horse); and the offer of a widespread and low-cost hospitality system, which integrates the existing one. If the project of the tracks is in progress, that of the Stop Places (SP) represents an important challenge.

Following previous research [67,68], we propose a methodological approach to develop an index (FI—feasibility index) to assess the feasibility of the Stop Places (SPs) scheme along a horse trail to integrate current slow mobility methods (walking and biking), referring not so much to the stages, for which the project is already in progress, as to the SPs, understood as the main nodes of a network of routes (walk, bike, horse) to support slow integrated mobility.

2.2. Planning Horse Trails: Principles and Approaches

The geographical Italian context hosts several horse trails, which differ in various aspects: characteristics of the areas crossed—mountainous, hilly, plain, coastal territory; localization—they may fall within protected natural areas [69,70], along the rivers [71] and, in some cases, follow historic roads and ancient transhumance routes [72] or old railways [73]; length (km); number of tracks; provision of facilities and services along the route to support the riders and the equids themselves; and connection with other existing slow mobility networks [74], such as cycle paths and walks [75]. One of the most important is the horse trail in the Gran Sasso and Monti della Laga National Park (Ippovia Gran Sasso—Abruzzo Region) [76], which represents the longest horse trail in Europe (520 km). It crosses 36 municipalities, following the paths which, for centuries, have connected villages and towns separated by the Gran Sasso, a massif in the Apennine Mountains of Italy, which have always been used by farmers. Other notable horse trails in Italy are those that cross regional and national parks, such as the Appia Antica Regional Park (Lazio Region), the Maremma Natural Park (Tuscany Region), the Majella National Park (Abruzzo Region), and the Alta Langa Park (Piedmont Region). As a matter of fact, recent research confirms the importance of nature in the expectations of horse trail ride tourists [77].

The horse trails' planning and management requires the observation of several criteria to ensure the safety and well-being of horseback riders and horses [78,79], according to the environmental context [80]. The main aspects to be considered concern [81]:

- Surface, which should be well-drained, firm, and free of sharp stones or other hazards that could cause injury to a horse's hooves;
- Dimension, which should be wide enough for horses to pass each other safely and free of obstacles that could be dangerous for horses and riders;
- Grade, which should be moderate, with no steep inclines or declines that could be difficult for horses to navigate;
- Signage, which should be clear and include information about trail difficulty, distance, and any potential hazards;
- Maintenance, which should be ensured regularly;
- Equestrian facilities, which should include areas for horse camping, loading and unloading horses, and parking for horse trailers.

Some important references for the horse trail planning in Italy are (Figure 3):

- The National Board of Environmental Equestrian Guide (ENGEA—Ente Nazionale Guide Equestri Ambientali) guide for obtaining certification. The Certified Horse Trail Classification Index (ICIC—Indice di Classificazione Ippovie Certificate) reflects the degree of difficulty of each horse trail [82];
- The specification for the design of Italian horse trails drawn up by Italian Equestrian Sports Federation (FISE—Federazione Italiana Sport Equestri) [83];
- The specification for the design of Italian horse trails certified by the Italiana Equestrian Tourism Federation and Trec-Ante (FITETREC-ANTE—Federazione Italiana Turismo Equestre e Trec—Ante) [84].

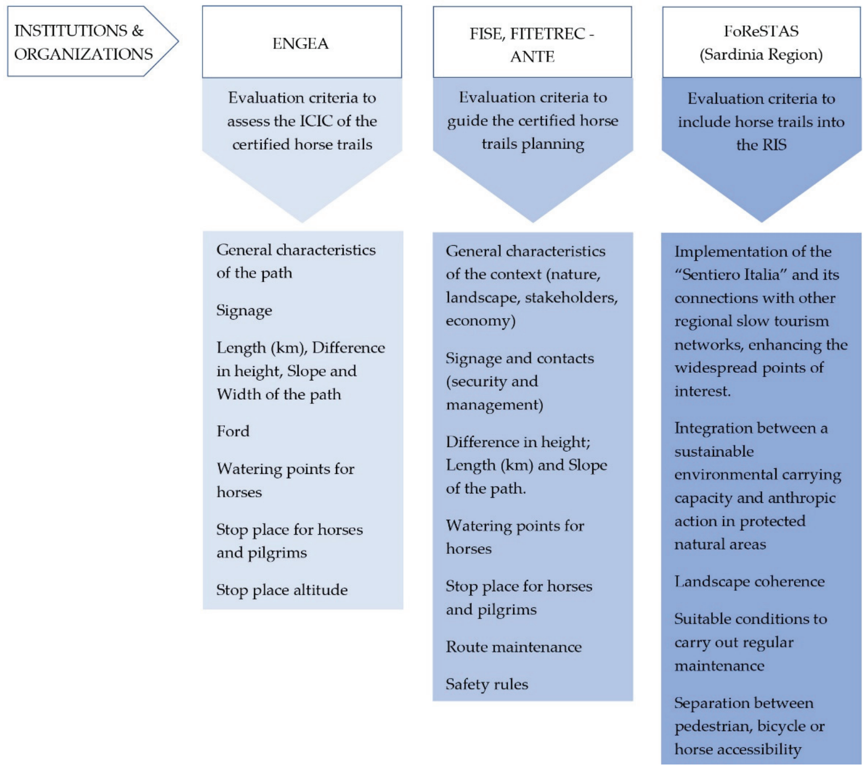

Figure 3. Evaluation criteria for the horse trail planning. Italian references (Author: M. Ladu, 2023).

This topic is particularly important in Sardinia, where the rural landscape constitutes the connective structure of the wider scenario of the regional landscapes [85], which has long been at the core of territorial development policies.

The Sardinia Region, with Regional Law No. 16/2017 [86] recognizes the use of equines (horses and donkeys) for enhancing the tourist and environmental heritage of Sardinia. This is possible through specific interventions aimed at the creation of a network of horse trails and the functional recovery of facilities for logistical, resting, and support needs of riders and animals. Specifically, Article 28 of the Law defines technical criteria regarding the Network of Hiking, Bicycle Hiking, and Horse Trails. The Sardinian Horse Trails Network (RIS—Rete delle Ippovie della Sardegna) represents a subset of the paths of the Sardinian Hiking Network (RES—Rete Escursionistica della Sardegna) for which the walkability on horseback is validated. The measure also establishes a special regional register of Sardinia's horse trails. The updating of this register is regulated by the Plan for the Establishment and Management of the Sardinian Hiking Network (RES), under the coordination of the Regional Forestry Agency for Land development and environment of Sardinia (FoReSTAS—Agenzia forestale Regionale per lo Sviluppo del Territorio e l'Ambiente della Sardegna).

Indeed, horse trails find wide application in Sardinia because there is a long tradition of horse farming and some types are particularly suitable for trekking [87].

According to FISE and FITETREC-ANTEA, the SPs along the horse trail are defined as the system of facilities that provide hospitality for riders and/or shelter for horses in boxes, stalls, pens, suitably equipped with water and hay, which guarantee their safety and well-being.

In addition, ENGEA identifies the following types of accommodation facilities (farmhouses, hostels, guesthouses, refuges, hotels, or clubs), and the minimum characteristics of each one. This leads to the definition of four main types of SPs, which combine different services to support riders and horses.

The first ENGEA certification in Italy was awarded in 1998 to the horse trail named "On the Griffon's Route" in Sardinia. The "Magical Cala Luna Beach" horse trail is also included, to date [88]. The first one is 130 km long and runs from the city of Alghero to the Sale Porcus Oasi in the Sinis peninsula (Province of Oristano), crossing one of the most internal stretches of the west coast, which is highly interesting for its landscape. The horse trail, which is an average difficulty, thanks also to its modest elevation gain ranging from 0 to 780 m asl, can be covered in 7 days. The second one, with a length of 136 km, crosses a complex territory, from the internal areas of the Barbagia (Supramonte mountains of Orgosolo, Baunei, and Urzulei) to the east coast (beach of Cala Luna) recording a difference in altitude ranging from 0 to 1200 m asl. The horse trail, of medium-high difficulty, can be hiked in 3 or 5 days.

At the regional level, one of the most ambitious projects concerns the "Costa-a-Costa" horse trail [89], which crosses central Sardinia from the east coast to the west coast. This path mostly retraces old mule tracks and itineraries existing between beaches, Mediterranean scrub, wilderness, and internal prairie. Each SP ends with the stabling of horses and the welcoming of riders. The horse trail, about 135 km long, is divided into six tracks.

The regional level horse trail system is also expanding thanks to the interventions financed by the Sardinia Region to increase the RES and RIS [90].

The proposal for a new SBP horse trail in the historic Sulcis-Iglesiente region is part of this renewed awareness on the opportunity of horse tourism, in addition to walking and biking.

3. Methodology

Moving in the research field focused on the accessibility of mining heritage and geosites [13,91], this study proposes a methodological approach to develop a feasibility index (FI) to assess the feasibility of the Stop Places (SPs) project scenarios of the horse trail, in terms of Internal Coherence (IC) criteria and External Coherence (EC) criteria, to integrate slow mobility methods (walking and biking).

In line with the methodological approach adopted in recent studies to define the complex index for supporting urban policies and planning [73] and developed by the authors themself in previous research [64], to define a set of indicators to assess the attractivity index of the SBP tracks, the methodology consists of three quali-quantitative phases (Figure 4):

1. Phase_01—which develops a typing matrix according to a set of typing elements selected by the literature review and practices analyzed. The typing matrix allows each SP to be analyzed according to landscape, infrastructure, number of functions, rank, and ownership characteristics, from which specific project scenarios are derived (output);
2. Phase_02—which defines a coherence matrix according to a set of Internal Coherence (IC) criteria and External Coherence (EC) criteria for each SP's project scenario. The IC criteria, which refer to the intrinsic characteristics specific to each SP project scenario, are: the number and variety of functions, the intervention types planned (maintenance, restoration, new construction), the building time required (short, medium, long), and the circular solutions (water, energy, etc.) adopted. The main EC criteria, which refer to the external factors specific to the SP context, are the environmental and landscape constraints and the local planning regulations in force;
3. Phase_03—which defines the feasibility index (FI) of SP's project scenarios through a quantitative criteria aggregation.

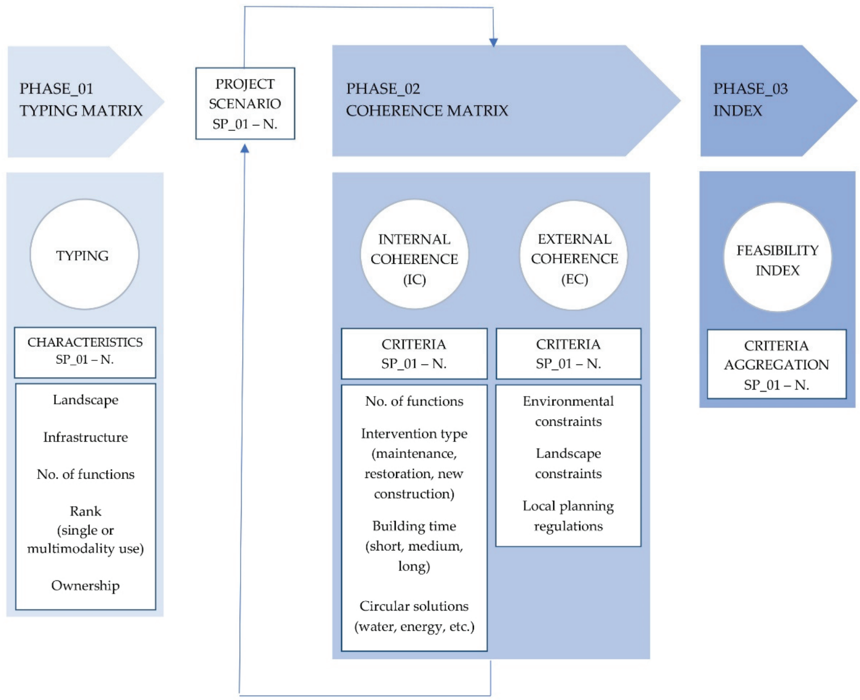

Figure 4. Methodological framework (Author: M. Ladu and G. Balletto, 2023).

The methodology provides feedback between the Phase_02 and the project scenarios (output). As a matter of fact, a possible lack of coherence with the IC and EC criteria, such as the incompatibility with the regulatory framework, may require the need to redefine the project scenario.

In line with previous research which proposed guidelines and protocols for the design of touristic paths, according to the combined use of ecological and historical approaches [92], as well as other complex models to manage the anthropic pressure in protected environmental areas [93], in this study, the IC and EC criteria meet the objectives at the core of various case studies examined (Section 2.2), primarily that of the SBPF, which are in line with the 2030 Agenda Sustainable Development Goals (SDGs). They may be summarized as follows:

- The sustainable planning of horse trails, as well as that of paths (walking and biking) to support the regeneration of former mining landscapes and deprived internal areas, in order to guide a new course of development based on rural and slow tourism (Goal 3; Goal 8; Goal 9; Goal 13; Goal 15; Goal 17);
- The reuse of the existing buildings (mainly heritage of industrial archaeology, properties of abandoned mining villages) to ensure a network of accommodation facilities for the well-being of pilgrims (walking, biking and horse riding) and horses (boxes, paddocks, and support services), in order to realize the SPs during the short to medium term, thus reducing the time for the commissioning of the horse trail (Goal 11; Goal 12; Goal 13; Goal 15; Goal 17);
- The compliance of the SP's project scenarios with the multifunctionality and circularity criteria, through the redevelopment of existing buildings aimed at achieving water and energy self-sufficiency, and the realization of equipped areas for horses stabling, with primary services (water and energy self-sufficiency, water recovery, and waste recycling). Such conditions are key prerequisites for ensuring environmental and

economic sustainability even in the subsequent phase of use and management of the horse trail and its SPs (Goal 6; Goal 7; Goal 11; Goal 12; Goal 13; Goal 15).

3.1. Feasibility Index—FI

The Phase_03 is dedicated to the definition of the FI, edited by the authors and in line with the literature on the construction of complex indices [94] of the SP project scenarios through assigning specific weight to the criteria of IC and EC. In particular, the FI can be defined as a half of the sum of the weighted sum (p_i and p_e) of the IC and EC, as below.

The proposal of the quantitative index (FI) relating to a SP scenario project is closely linked to the coherence IC and EC, which constitute the main feasibility assumptions.

$$\mathrm{FI} = \frac{1}{2}\left[\frac{\sum_{i=1}^{n}(p_i \times \mathrm{IC})}{\sum_{i=1}^{n}\mathrm{IC}_i} + \frac{\sum_{e=1}^{n}(p_e \times \mathrm{EC})}{\sum_{e=1}^{n}\mathrm{EC}_e}\right] \quad (1)$$

where $i = 1, 2, 3, \ldots n$; $e = 1, 2, 3, \ldots n$, where $0 \leq p_i \leq 1$, $0 \leq p_e \leq 1$, $0 \leq \mathrm{FI} \leq 1$.

The weight assignment to each criteria (IC and EC) have the following characteristics: p_i and p_e tend to 1 when the SP project scenario meets full IC and EC.

In particular, if FI = 0–0.25, it represents a critical scenario (Level 4); if FI = 0.26–0.50, it represents an average critical scenario (Level 3); if FI = 0.51–0.75, it represents an average positive scenario (Level 2); if FI = 0.76–1, it represents a positive scenario (Level 1).

4. Case Study

The above methodology was applied to three SPs of the horse trail of SBP, which have been selected by virtue of their geographical, landscape, physical, and functional characteristics. Moreover, the public or private nature of the SPs is of importance because the ownership significantly affects the implementation of the projects. The SPs falling in private areas are already configured, in most cases, as existing stables or riding clubs. On the contrary, the SPs falling in public areas are places where the design is required, especially with regard to the structures for the well-being of equids (horse-box, paddocks, and other services), for which the feasibility study is necessary. For this reason, the case studies selected to apply the methodology refer only to those SPs located on publicly owned areas.

The case studies fall in three different municipalities in the South Sardinia Province, within the perimeter of the Geo-Mining Park DM 08/09/2016 (Figure 5):

- SP_04 "Posada Pitzinurri", municipality of Arbus;
- SP_08 "Monti Mannu", municipality of Villacidro;
- SP_14 "Parco is Muras", municipality of Giba.

A more detailed description is presented below:

SP_04 "Posada Pitzinurri" falls in the former mining village of Pitzinurri, in the Ingurtosu area, in the Municipality of Arbus. Located in the SP is a building acquired thanks to the agreement signed between the SBPF and the Municipality of Arbus, already used as accommodation for SBP users and, therefore, for the overnight stay of riders of the future horse trail. Along the SBW, accommodation facilities for the well-being of pilgrims (walking, biking, and horse riding) are called 'Posadas' (small accommodation). Adjacent to this facility, which is named "Posada di Pitzinurri", there is an area containing stone structures, in a ruined state. These are the remains of ancient mining buildings. These structures can be found on the left bank of a small river called "Riu de Naracauli" that flows into the artificial lake of Pitzinurri. Measures to restore the structures, combined with those to excavate and consolidate the bank, would provide space for horse stalls.

However, SP_08 "Monti Mannu" falls within the Monti Mannu Forest, which is a naturalistic, environmental forest complex of Monti Mannu-Oridda-Marganai, in the municipality of Villacidro. In the SP, which is larger than the previous one, there is the old "Locanda del Parco", a building that since 2018 has been acquired by the SBPF. The locanda has been designated as accommodation (Posada) for SBP users and overnight stays for riders of the future horse trail after the restructuring works. Approximately 120 m away from this structure, which is named "Posada di Monti Mannu", is the forest compendium consisting of a main building (forest barracks) and its outbuildings. In addition, there is a partially equipped area for equids to rest.

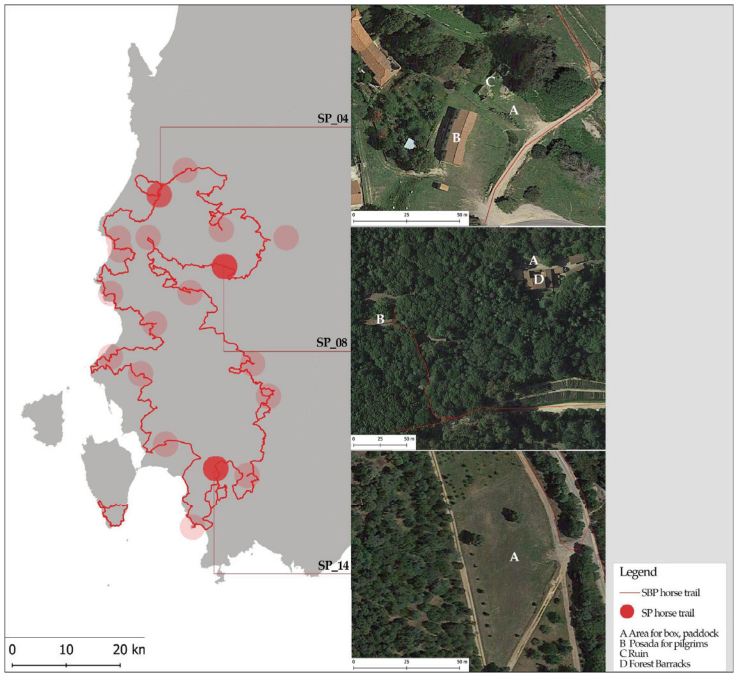

Figure 5. Framing of the SPs along the horse trail, selected as case studies (Author: M. Ladu, 2023).

The SP_14 "Parco is Muras" lies in an area earmarked for Municipal Park parking lots ("Parco is Muras"), in the municipality of Giba. In a partnership with the Municipal Administration, a portion of the area, where the terrain is likely to be flat, will be used to accommodate equids that will ride the SBW horse trail. Compared to the SPs previously considered, no accommodations for pilgrims insist on SP_14, and also no buildings to be redeveloped or rehabilitated.

The application of the three phases of the methodology described above is shown below. Specifically, Tables 1 and 2 report the typing matrix (Phase_01) and project scenarios, and the Internal Coherence (IC) and External Coherence (EC) matrix (Phase_02), respectively, related to the following SPs: SP_04, SP_08, SP_14.

For Phase_01, the main data source for typing the three SPs are the Sardinia Region website [95], the SBPF, the Cadastre website, and the authors themself, who produced data through desk analysis and on-site surveys.

The desk analysis refers to the collection and systematization of data from the following institutional sources:

- The SBPF, which represents the main source of information relating to the SBP horse trail project;
- The Cadastre website, which allows the public to know the public or private nature of those areas selected by the SBPF to develop the SP project scenarios;
- The Geoportal of the Sardinia Region, which represents the main source of data relating to the environmental and landscape characteristics of the place (regulatory framework affecting the areas);

- The official website of the Local Administrations involved in the SBPF horse trail project, which represents the main source of the urban planning tool in force.

The on-site survey in those areas selected by the SBPF to implement the SPs has been fundamental to technically analyze the physical, landscape, and environmental characteristics of the site and provide guidelines for the SPs project scenario.

The project scenarios (output) proposed are the result of the joint work carried out by the SBPF and the authors themself (Table 1).

Table 1. Typing matrix and project scenarios related to the case studies (Author: M. Ladu, 2023).

PHASE_01—TYPING MATRIX

			SP_04	**SP_08**	**SP_14**	**DATA SOURCE**
TYPING	Landscaping	Environmental	✓	✓	✓	Sardinia Region website
		Anthropic	✓	✓	-	
	Infrastructural	Ports, airports, railways	-	-	-	
		Road network	✓	✓	✓	
		Water supply network	✓	✓	-	
		Electric distribution grid.	✓	✓	-	
	Functional	Buildings and/or areas for horse well-being (horse-box, paddocks and other services)	✓	✓	✓	Authors SBPF Cadastre website
		Buildings for pilgrim well-being (accommodation and other services)	✓	✓	-	
		Buildings for other services	-	Forestry barracks and other buildings	-	
	Of rank	Single mode (only for pilgrim by horse)	-	-	✓	
		Multimodal (for pilgrim by walk, bike, horse)	✓	✓	-	
	Ownership	Public property	✓	✓	✓	
		Private property	-	-	-	

OUTPUT

		SP_04	**SP_08**	**SP_14**	**DATA SOURCE**
Project Scenario	Buildings and/or areas for horse well-being (horse-box, paddocks and other services)	✓	✓	-	Authors SBPF
	Buildings for pilgrim well-being (accommodation and other services)	✓	✓	-	
	Equipped areas for horse well-being (horse-box, paddocks and other services)	✓	-	✓	
	Buildings for other services		✓	-	

For Phase_01 (Table 1), it can be seen that the typification of the three SPs allows for the development of specific project scenarios (output). In the SPs in which no buildings to be redeveloped or rehabilitated exist, the project scenario coincides with the construction of equipped areas for boxes and paddocks; in the SPs where there is a building stock already used for housing or to be redeveloped or recovered for accommodation or other services, the project scenario contemplates the construction of facilities for animal welfare (boxes, paddocks, and support services), facilities for the well-being of pilgrims (walking, biking, and horse riding), and other services to support the users of the horse trail in addition to the ones mentioned above.

Table 2. Coherence matrix: IC and EC criteria related to the project scenarios developed for each case study (Author: M. Ladu, 2023).

PHASE_02—COHERENCE MATRIX						
			SP_04	**SP_08**	**SP_14**	**DATA SOURCE**
IC Criteria	No. functions	Buildings and/or areas for horse well-being (horse-box, paddocks and other services)	✓	✓	-	Authors SBPF
		Buildings for pilgrim well-being (accommodation and other services)	✓	✓	-	
		Equipped areas for horse well-being (horse-box, paddocks and other services)	✓	-	✓	
		Buildings for other services	-	✓	-	
	Intervention types (Presidential Decree 380/2001, Art.3; Art. 6)	Free building activities for the construction of horse-box, paddocks and other services	-	-	✓	
		Ordinary maintenance, extraordinary maintenance or building renovation of existing buildings	✓	✓	-	
		Restoration and conservative rehabilitation for the recovery of the ruins	✓	-	-	
		New Construction (NC)	-	-	-	
	Building time	Short term	-	-	✓	
		Medium term	✓	✓	-	
		Long term	✓	-	-	
	Circular solutions (technological performance of buildings)	Water and energy self-sufficiency	✓	✓	✓	
		Water recovery	✓	✓	✓	
		Waste recycling (organic material from horses)	✓	✓	✓	
		Soil permeability	✓	✓	-	
EC Criteria	Regulatory Framework	Environmental constraints	✓	✓	✓	Sardinia Region website
		Landscape constraints	✓	✓	✓	
		Local plan in force	-	✓	✓	Local authorities

For Phase_02 (Table 2), the data source corresponds to the SBPF and the authors themself, who implemented a set of criteria for the IC and EC matrix.

It is important to underline that the intervention types (IC criteria) are those defined in Italy by the Presidential Decree 380/2001 (Art.3; Art. 6) and subsequent additions:

- Ordinary maintenance (MO—Manutenzione Ordinaria), extraordinary maintenance (MS—Manutenzione Straordinaria), building renovation (RE—Ristrutturazione Edilizia) of existing buildings;

- Restoration (R—Restauro) and conservative rehabilitation (RC—Risanamento conservativo) for the recovery of the ruins;
- New Construction (NC);
- Free building activities for the construction of horse-box, paddocks, and other services (EL-Edilizia Libera).

The regulatory framework indicated to assess the EC of each SP consists of:

- Environmental constraints, relating to the presence of protected natural areas (oases, regional or national natural parks, Natura 2000 Network sites) and areas managed by the FoReSTAS agency;
- Hydrogeological constraints;
- Landscape constraints, which refer to a comprehensive regulatory framework, at regional and national level, as the Italian Code on cultural heritage and landscape (Law enacted by decree no. 2004/42) and the Regional Landscape Plan (PPR—Piano Paesaggistico Regionale);
- Local plan in force (land use regulation referred to areas interested by the SP).

The assessment of the feasibility index (FI) (Phase_03) requires the determination of specific weights for each Internal Coherence (IC) and External Coherence (EC) criteria, consistent with the SBPF goals (Table 3).

Table 3. Attribution of ranges and specific weights to the IC and EC criteria to the SPs project scenarios developed for each case study (Author: M. Ladu, 2023).

	Range		Weight	
IC Criteria	N_f	1	$P_{i(Nf)}$	0.5
		2–3		0.8
		4–n		1
	N_m	1–2	$P_{i(Nm)}$	1
		3–4		0.8
		5–n		0.5
	N_c	1	$P_{i(Nc)}$	0.5
		2–3		0.8
		4–n		1
EC Criteria	N_{ce}	0	P_e	0
		1–2		0.5
		3–n		1

The Internal Coherence (IC) criteria and their weights (p_i) can be summarized as follows:

Nf = number of expected functions in each SP (animal welfare facilities, pilgrim accommodation facilities, equipped areas, other services);

if $Nf \Rightarrow$ n the weight $p_{i(Nf)} \Rightarrow 1$, consistent with the goal of providing the greatest number and variety of services and functions at the horse trail SPs: pilgrim well-being facilities (walking, biking, horse riding), animal welfare facilities (box, paddock) and other services.

Nm = number of months required for the planned intervention in each SP, to be carried out in the short, medium, or long term, through the following typologies: ordinary and extraordinary maintenance (MO, MS, RE, R, RC) of public housing heritage to ensure accommodations and services for pilgrims and places for horses; free building activities for the construction of facilities for animals (EL);

if $Nm \Rightarrow 0$ the weight $p_{i(Nm)} \Rightarrow 1$, consistent with the need to bring the horse trail up to speed as soon as possible.

Nc = the number of circularity requirements of the SP project (water, energy, organic material waste, etc.);

if $Nc \Rightarrow$ n the weight $p_{i(Nc)} \Rightarrow 1$, consistent with the goal of ensuring primary services according to the circular economy principle (water and energy self-sufficiency), water and waste recycling, and soil permeability.

The External Coherence (EC) criteria and their weight (p_e) referring to landscaper constraints, and zoning regulations can be summarized below:

Nce = number of external coherences

if $Nce \Rightarrow 3$ the weight $p_{e(Nce)} \Rightarrow 1$; thus, the SP project is consistent with landscape constraints and urban planning discipline.

5. Results

The application of the method for assessing the FI to the three selected SPs (SP_04, SP_08, SP_14) gives rise to the following results (Tables 4–6).

Table 4. FI value for the SP_04. (Author: M. Ladu and G. Balletto, 2023).

SP		Value		Weight		$P_i \times$ CI
SP_04	IC Criteria	N_f	3	$P_{i(Nf)}$	0.8	2.4
		N_m	12	$P_{i(Nm)}$	0.5	6
		N_c	4	$P_{i(Nc)}$	1	4
	Total		**19**			**12.4**
		Value		**Weight**		$P_e \times$ **CE**
	EC Criteria	N_{ce}	2	P_e	0.5	1
	Total		**2**			**1**
		FI (PT_04)				**0.57**
		Level				**2**

Table 5. FI value for the SP_08. (Author: M. Ladu and G. Balletto, 2023).

SP		Value		Weight		$P_i \times$ CI
SP_08	IC Criteria	N_f	3	$P_{i(Nf)}$	0.8	2.4
		N_m	4	$P_{i(Nm)}$	0.8	3.2
		N_c	4	$P_{i(Nc)}$	1	4
	Total		**11**			**9.6**
		Value		**Weight**		$P_e \times$ **CE**
	EC Criteria	N_{ce}	3	P_e	1	3
	Total		**3**			**3**
		FI (PT_08)				**0.93**
		Level				**1**

The SP_08 achieves the highest FI value of 0.93, followed by the SP_14, with an FI of 0.91. SP_04 records the lowest value, with an FI of 0.57. More precisely, FI = 0.93 and FI = 0.91 correspond to a positive scenario (Level 1). At the same time, FI = 0.57 corresponds to an average positive scenario (Level 2).

Contributing to the highest value of FI for SP_08 were: the high number and variety of functions (3); the short time required for the redevelopment and change facilities use, estimated at 4 months; the high number of circularity feature criteria met by the project (4); and the level of EC, highest (3). The SP_14 project scenario, while also having the highest degree of EC (3), as it is consistent with landscape constraints and urban planning discipline, has a slightly lower FI value than SP_08 because it suffers from the absence of an existing building stock capable of accommodating pilgrim well-being services and other functions to support the horse trail. In fact, the only function contemplated by the SP_14 project scenario is the equipped area for the establishment of boxes and paddocks.

Table 6. FI value for the SP_14. (Author: M. Ladu and G. Balletto, 2023).

SP		Value		Weight		$P_i \times$ CI
SP_14	IC Criteria	N_f	1	$P_{i(Nf)}$	0.5	0.5
		N_m	2	$P_{i(Nm)}$	1	2
		N_c	3	$P_{i(Nc)}$	0.8	2.4
	Total		**6**			**4.9**
		Value		**Weight**		**$P_e \times$ CE**
	EC Criteria	N_{ce}	3	P_e	1	3
	Total		**3**			**3**
		FI (PT_14)				**0.91**
		Level				**1**

Finally, the lower value of FI of SP_04 is mainly determined by two factors: as far as IC is concerned, the number of months required to carry out the restoration work on the structure in the state of ruins, near the Posada, and which could house horse boxes; as far as EC is concerned, the lack of coherence with urban planning regulations.

The scenario presented, which emerged from the proposed method to assess the FI of the SPs along the SBP, highlighted the opportunities that can be generated by the functional reuse of existing buildings, mainly in terms of the number and variety of services offered for the well-being of pilgrims and horses. The redevelopment of the existing buildings according to circularity criteria also has a strong influence in determining the IC of the scenarios, as well as the timing for the realization of the interventions. On the other hand, the lowest FI derived by a limited EC highlights how much coherence with the superordinate constraints and with the urban planning discipline affects the determining of the feasibility of the projects.

In light of these results, specific strategies are required to overcome the average positive scenario and, as a consequence, to increase the level of feasibility of the SBW horse trail project. First of all, the SBPF may prioritize the implementation of the SPs project scenarios that record the highest FI, thus reducing the time for the commissioning of the horse trail. Moreover, with reference to SPs project scenarios that record a low FI, if the determining factor is the low number and variety of functions, the SBPF could implement the horse trail planning strategies involving nearby nodes and centralities along the path. At the same time, if the determining factor is the low degree of coherence with existing urban planning regulations, the SBPF may promote concertation processes with the local authorities directly involved.

6. Discussion

Beginning with the analysis of the literature on safety and well-being criteria for riders and horses in the planning and management of horse trails [78,79], and with due respect for the environmental values that characterize the different territorial context [80], this study aimed to define typing and Internal and External Coherence matrices to assess the feasibility of SP project scenarios to be implemented, taking into consideration multiple aspects.

As compared to the literature reviewed in Section 2.2, concerning horse trails planning [82–84,86] and the horse and rider rest well-being facilities design [78,79], this study introduces a set of Internal and External Coherence (IC and EC) criteria to evaluate the SP project scenarios. In particular, the IC criteria derive from a set of Italian directives and guidelines, and previous research focused on the main fields of investigation of this study, which have been appropriately analyzed and organized to develop the FI:

- Italian directives and guidelines related to the protection and management of equids, issued by the Ministry of Health (Ministero della salute) [96–98];
- Principles and criteria for the horse trail planning/design, resulting from existing horse trails or proposed schemes [71,73,76,81];
- Principles and criteria for the horse trail planning/design, clarified in reports issued by institutions and organizations in Italy, at a national and regional level [82–84,87,90];
- Principles and criteria for horse services and other facilities design (box and paddock) [78,79,99,100].

The EC criteria derive from the analysis of the literature concerning the management and impact assessment of horse trails in protected areas [69,70,77,80,93], and, above all, from the systematization of the environmental and landscape constraints and of the land use according to the local plans in force in the SPs.

Guided by the approaches of Bambi et al. [78], who have planned two different solutions of structures for the horses observing the principles of low impact, low cost, easy installation, and complete reuse, additional Internal Coherence criteria were identified: the number and variety of functions, possible interventions, construction time, and circular solutions in both buildings and stalls, including stormwater recovery and self-production of energy.

The criteria were combined through an analytical approach, where specific weights were assigned to each IC and EC consistent with the goals of the promoting organization (in this case, the SBPF), inspired by those of the 2030 Agenda, and the challenges imposed by the ecological transition.

However, this was possible mainly because, as described in Section 2.1, the SBP horse trail project is a work in progress, particularly with regard to SPs. This condition is a prerequisite for the development of methodology. The promoting organization's (SBPF) principles, goals, and priorities are the ones that guide the assignment of a specific weight to each identified criterion. Thus, the importance given to multifunctionality, to the reuse of existing building stock, to the short-to-medium time of implementations of interventions, and to circular solutions in defining the SP scenario have had a decisive impact on the calculation of the IF. This takes a sort of priority score considering the objectives of the main stakeholders [73]. The assigning to EC criteria weights, that is, to the constraining framework and urban planning regulations insisting on the SP areas, seems to appear less impactful in directing policies, precisely because these are established and difficult to change.

The decision to propose an FI to assess the feasibility of SPs, intended as the main integrated nodes of a path network (walking, biking, horse riding) to support horse mobility, highlights how the study makes a scientific contribution with reference to a more circumscribed, but still complementary, dimension of the research field investigating the accessibility of mining heritage and geosites [13,91].

The importance attached to the reuse of existing physical structures [73], including the ancient tracks related to the miners' landscape, are common elements of the main approaches analyzed. These elements add to the necessary and prioritized action of systemic ecological restoration, but also to the recognition of nodes in the complex spatial matrix design of accessible places [13].

Hence, the SPs along the horse trail can also be considered nodes integrating with the other core sites of different value, function, and rank. In this context, the Sulcis-Iglesiente's complex and wide bioregion, which is characterized by a significant tie between GIs and mining heritage, is suitable to host the most recent trends of rural and slow tourism, also combining the fruition of resources toward sports activities [101]. The SBW horse trail as a whole (tracks and SPs), like other slow mobility planning perspectives in Italy and beyond [71], may strengthen the spine of a network of ecological services and existing public facilities, enhancing the relations with the small/medium urban centers it goes through according to the specific characters and lifestyles of these contexts.

7. Conclusions and Future Developments

The cohesive goal included in the territorial planning of countries at an international level has stimulated the creation of different methodologies for 'structuring areas' that should be safeguarded and managed in a sustainable and multifunctional perspective. This study examined the issue related to the slow use of the mining landscape (also in terms of tourism), identifying the creation of a bioregion and the adoption of green infrastructures as useful strategies for re-territorializing rural areas in a particularly sensitive area characterized by a landscape in transition that is a result of ceased mining activity. Furthermore, these initiatives at various levels have contributed to strengthening the current network of protected areas and other effective conservation measures.

In particular, the first section was dedicated to the literature review concerning three main topics which, although represent well-defined research fields, have been investigated according to an integrated approach. We considered the integration of the concept of rural and slow tourism, green infrastructure (GI), and bioregion fundamental to achieve the main purpose of the paper. Such a preliminary phase represented a starting point for developing the following sections.

The second section was dedicated to the analysis of the study area, the Sulcis-Iglesiente-Guspinese bioregion, in the south-western part of the Region of Sardinia, which has already been the subject of previous analyses and field research carried out by the working group. Moreover, the area studied has long been the subject of strategies and policies for territorial valorization at different scales. In addition to the institution of the Geo-Mining Park, other examples are the creation of the Santa Barbara Path Foundation (SBPF), and the establishment of the Santa Barbara Path (SBP) and the local network. These initiatives enabled a regenerative process of the places in environmental, social, and economic terms. Subsequently, the SBPF launched a project aimed at enhancing the existing path (for walking and biking and, more recently, horse riding). The horse trail is an itinerary that only partially coincides with the SBP, which is alternated by SPs that serve as equipped stopping nodes.

The third section proposed a methodological approach to develop a feasibility index (FI) to assess the feasibility of the Stop Places (SPs) project scenarios along a horse trail. The FI derives from the result of typing matrices and coherence matrices for each SP project scenario, implemented in the fourth section of the paper, where three SPs were selected as the case study to assess the methodology.

From the policy maker's point of view, the FI is useful in providing support for planning future actions in a hierarchical way, considering the stakeholder's objectives and the first ambition to carry on the horse trail project as part of a more general perspective aimed at integrating the SBP (walking, biking, horse riding) with the Green Infrastructure network, to reap the benefits of adopting multifunctional strategies based on ecosystem services within the related bioregion. In this sense, the future line of research should take into account the effects of re-territorialization related to diluting rural identity, diminishing place distinctiveness, and depleting the cultural and economic sustainability.

Such initial setup of the FI is a basis for future research and applications.

The future developments of this study will cover the assessment of the FI for all the SPs along the SBP horse trail, in order to guide the whole planning process in an integrated way. The application of the methodology may require the need to modify the set of indicators underlying the definition of the FI. As a matter of fact, the FI assessment here suggested should be implemented in line with the goals, priorities, and criteria to be pursued and observed in a particular context, such as that of the Sulcis-Iglesiente bioregion, characterized by a significant mining heritage.

As a matter of fact, the main challenge of this research work lies in the effective collaboration between public bodies involved in the SBP horse trail planning, as well as other local operators interested in investing not only in the tourism sector, but also in taking advantage of the multifunctionality of the context. Furthermore, it is important to underline that the success of the SBP horse trail will also depend on the smart community activities, which, by disseminating and sharing information, promote the SBP and its multi-accessibility (walking, biking, horse riding). In this sense, among the External Coherence criteria (EC) selected for the definition of the FI, the pedestrians', bikers', and, above all, riders' perceived accessibility could also be considered and implemented in the future [102].

In conclusion, it is believed that the methodology proposed can represent a reference framework applicable to other territorial contexts to achieve the European policy's goals for the medium- and long-term landscape conservation and valorization.

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Glossary

EC	External Coherence
ENGEA	Ente Nazionale Guide Equestri Ambientali (Board of Environmental Equestrian Guide)
FI	Feasibility index
FISE	Federazione Italiana Sport Equestri (Italian Equestrian Sports Federa-tion)
FITETREC-ANTE	Federazione Italiana Turismo Equestre e Trec—Ante (Italian Eques-trian Tourism Federa-tion and Trec-Ante)
FoReSTAS	Agenzia forestale Regionale per lo Sviluppo del Territorio e l'Ambiente della Sardegna (Regional Forestry Agency for Land development and environment of Sardinia).
GI	Green infrastructure
IC	External Coherence
ICIC	Indice di Classificazione Ippovie Certificate (Certified Horse Trail Classification Index)
RES	Rete Escursionistica della Sardegna (Sardinian Hiking Network)
RIS	Rete delle Ippovie della Sardegna (Sardinian Horse Trails Network)
SBP	Santa Barbara Path
SBPF	Santa Barbara Path Foundation
SP	Stop Place

References

1. UNWTO—World Tourism Organization. *UNWTO Tourism Definitions*; UNWTO: Madrid, Spain, 2019.
2. Lumsdon, L.; McGrath, P. Developing a conceptual framework for slow travel: A grounded theory approach. *J. Sustain. Dev.* **2011**, *3*, 265–279. [CrossRef]
3. Privitera, D. Turismo lento e territori insulari. Il caso studio Favignana. *Boll. Della Assoc. Ital. Di Cartogr.* **2020**, *169*, 145–153.
4. Colavitti, A.M.; Floris, A.; Serra, S. Urban standards and ecosystem services: The evolution of the services planning in Italy from theory to practice. *Sustainability* **2020**, *12*, 2434. [CrossRef]
5. EC. Commission Staff Working Document. Technical Information on Green Infrastructure (GI) SWD (2013) 155 Final 6 May, Brussels. 2013. Available online: https://ec.europa.eu/environment/nature/ecosystems/docs/green_infrastructures/1_EN_ACT_part1_v5.pdf (accessed on 1 February 2023).
6. European Union. 2019. Available online: https://eur-lex.europa.eu/legal-content/IT/TXT/PDF/?uri=CELEX:52019DC0236&qid=1562053537296 (accessed on 25 March 2020).
7. Lai, S.; Leone, F.; Zoppi, C. Green infrastructure and protected areas: A study concerning Sardinia. In *Building the Urban Bioregion. Governance Scenarios for Urban and Territorial Planning*; Colavitti, A.M., Serra, S., Eds.; SdT Edizioni: Firenze, Italy, 2022; pp. 373–392.
8. Lai, S.; Leone, F.; Zoppi, C.; Isola, F. An Operational Framework. In *Green Infrastructure and Regional Planning*; Franco Angeli: Milano, Italy, 2022; pp. 1–186.
9. Romano, F.; La Rocca, R.A. Slow Mobility and Cultural Tourism. Walking on Historical Paths. In *Smart Planning: Sustainability and Mobility in the Age of Change*; Springer: Berlin/Heidelberg Germany, 2018; pp. 301–322.
10. Tomi’c, S.; Lekovi´c, K.; Stoiljkovi´c, A. Impact of motives on outcomes of the travel: Slow tourism concept. *Školabiznisa* **2018**, *2*, 68–82.
11. Agarwal, S.; Busby, G.; Huang, R. Slow tourism. In *Special Interest Tourism: Concepts, Contexts and Cases*; CABI: Wallingford, UK, 2017; pp. 183–195.
12. Balletto, G.; Milesi, A.; Battino, S.; Borruso, G.; Mundula, L. Slow tourism and smart community. The case of Sulcis-Iglesiente (Sardinia-Italy). In *Computational Science and Its Applications-ICCSA 2019*; Misra, S., Gervasi, O., Murgante, B., Stankova, E., Korkhov, V., Torre, C., Rocha, A.M., Taniar, D., Apduhan, B., Tarantino, E., Eds.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 184–199.
13. Bereti´c, N.; Plaisant, A. Setting the Methodological Framework for Accessibility in Geo-Mining Heritage Settings—An Ongoing Study of Iglesiente Area (Sardinia, Italy). *Sustainability* **2019**, *11*, 3556. [CrossRef]
14. IFEL. Le politiche dell’Unione Europea per lo Sviluppo rurale. In *Contesto, Quadro Normativo, Prospettive Future, Dipartimento Fondi Europei e Investimenti Territoriali*; Osservatorio Sulle Politiche di Coesione: Roma, Italy, 2017.
15. Battino, S.; Lampreu, S. The Role of the Sharing Economy for a Sustainable and Innovative Development of Rural Areas: A Case Study in Sardinia (Italy). *Sustainability* **2019**, *11*, 3004. [CrossRef]
16. Silva, L. The impact of the COVID-19 pandemic on rural tourism: A case study from Portugal. *Anatolia* **2021**, *33*, 157–159. [CrossRef]
17. Sardone, R.; Monda, M. La diversificazione dell’agricoltura: Tra esigenze conoscitive e lacune informative. *Ital. Rev. Agric. Econ.* **2019**, *74*, 41–52.
18. European Commission. Available online: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/rural-development_it#ruraldevelopmentprogrammes (accessed on 15 November 2022).
19. Ana, I.M. Ecotourism, agro-tourism and rural tourism in the European Union. *Cactus Tour. J.* **2017**, *15*, 6–14.
20. Apostolopoulos, N.; Liargovas, P.; Stavroyiannis, S.; Makris, I.; Apostolopoulos, S.; Petropoulos, D.; Anastasopulou, E. Sustaining Rural Areas, Rural Tourism Enterprises and EU Development Policies: A Multi-Layer Conceptualisation of the Obstacles in Greece. *Sustainability* **2020**, *12*, 7687. [CrossRef]
21. Aytuğ, H.K.; Mikaeili, M. Evaluation of Hopa’s rural tourism potential in the context of European Union tourism policy. *Procedia Environ. Sci.* **2017**, *37*, 234–245. [CrossRef]
22. Eurostat. *Community Methodology on Tourism Statistics*; European Commission: Luxembourg, 1998.
23. Liu, Q.; Liu, Z.; An, Z.; Zhao, P.; Zhao, D. A modal shift due to a free within-destination tourist bus scheme: Multimodality and transport equity implications. *Res. Transp. Bus. Manag.* **2022**, 100863. [CrossRef]
24. Masiero, L.; Hrankai, R.; Zoltan, J. The role of intermodal transport on urban tourist mobility in peripheral areas of Hong Kong. *Res. Transp. Bus. Manag.* **2022**, 100838. [CrossRef]
25. Cevallos Suarez, M.P.; Cevallos Pinguil, T.C.; Cabanilla Vásconez, E.A. Enfoques del desarrollo en espacios rurales:a propuesta agro-turística comunitaria. In *Comunidades, Territorios y Turismo en América Latina*; Zizumbo Villarreal, L., Monterroso Salvatierra, N., Eds.; Editorial Torres Asociados: Mexico City, Mexico, 2020.
26. Olimovich, S. Agrotourism as one of the prospective directions of the tourist industry. *Am. J. Soc. Sci. Educ. Innov.* **2020**, *2*, 254–259. [CrossRef]
27. Brundu, B.; Battino, S.; Manca, I. The sustainable tourism organization of rural spaces. The island of Sardinia in the era of staycation. In Proceedings of the ICC2021—30th International Cartographic Conference, Florence, Italy, 14–18 December 2021; Volume 4, p. 15.
28. Eurostat. Available online: https://ec.europa.eu/eurostat/web/tourism/data/database (accessed on 15 November 2022).

29. Everingham, P.; Chassagne, N. Post COVID-19 ecological and social reset: Moving away from capitalist growth models towards tourism as Buen Vivir. *Tour. Geogr.* **2020**, *22*, 555–566. [CrossRef]
30. Fletcher, R.; Murray Mas, I.; Blazquez-Salom, M.; Blanco-Romero, A. Tourism, Degrowth, and the COVID-19 Crisis. Political Ecology Network. 2020. Available online: https://politicalecologynetwork.org/2020/03/24/tourism-degrowth-and-the-covid-19-crisis/ (accessed on 1 February 2023).
31. Ioannides, D.; Gyimóthy, S. The COVID-19 crisis as an opportunity for escaping the unsustainable global tourism path. *Tour. Geogr.* **2020**, *22*, 624–632. [CrossRef]
32. Sharma, D.G.; Thomas, A.; Paul, J. Reviving tourism industry post-COVID 19: A resilience-based framework. *Tour. Manag. Perspect.* **2021**, *37*, 100786. [CrossRef]
33. Mariotti, G.; Camerada, M.V.; Lampreu, S. Funzioni e benefici delle infrastrutture verdi: Dal contrasto ai cambiamenti climatici al posizionamento turistico delle città. *Doc. Geogr.* **2021**, *2*, 171–182.
34. Benedict, M.A.; McMahon, E.T. *Green Infrastructure: Linking Landscapes and Communities*; Island Press: Washington, DC, USA, 2006.
35. Ahern, J. Green infrastructure for cities: The spatial dimension. In *Cities of the Future Towards Integrated Sustainable Water and Landscape*; Novotny, V., Brown, P., Eds.; IWA Publishing: London, UK, 2007; pp. 267–283.
36. European Union. Building a Green Infrastructure for Europe. 2013. Available online: https://ec.europa.eu/environment/nature/ecosystems/docs/green_infrastructure_broc.pdf (accessed on 1 February 2023).
37. European Commission. Guidance on a Strategic Framework for Further Supporting the Deployment of EU-Level Green and Blue Infrastructure. 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0236&from=IT (accessed on 1 February 2023).
38. Sallay, Á.; Mikházi, Z.; Gecséné Tar, I.; Takács, K. Cemeteries as a Part of Green Infrastructure and Tourism. *Sustainability* **2022**, *14*, 2918. [CrossRef]
39. Zhang, Z.; Meerow, S.; Newell, J.P.; Lindquist, M. Enhancing landscape connectivity through multifunctional green infrastructure corridor modelling and design. *Urban For. Urban Green.* **2019**, *38*, 305–317. [CrossRef]
40. European Union. *EU Biodiversity Strategy for 2030 Bringing Nature Back into Our Lives*; Publications Office of the European Union: Luxembourg, 2021.
41. Firehock, K. *Strategic Green Infrastructure Planning: A Multi-Scale Approach*; Island Press: Washington, DC, USA, 2015.
42. García Corral, F.J.; Caparrós Martínez, J.L.; Milán García, J.; Martínez Vázquez, R.M. Infraestructuras Verdes y el Proyecto "Marca Pueblo" como freno a la despoblación en Andalucía (España). *Rev. Cienc. Soc. RCS* **2022**, *28*, 33–50.
43. Oliveria Fernandes, C.; Olivetti, G. Planning for Sustainable Tourism Based on Green Infrastructure: A Multiscale Methodology for Revitalizing Depopulated Rural Landscapes. In *Landscapes and Architecture—Processes and Practices Towards Sustainable Development*; Loures, L., Ergen, M., Eds.; IntechOpen: London, UK, 2021.
44. Poli, D. (Ed.) *I Servizi Ecosistemici Nella Pianificazione Bioregionale*; Firenze University Press: Firenze, Italy, 2020.
45. Duží, B.; Fanfani, D. *Urban Bioregion Concept: From Theoretical Roots to Development of an Operational Framework in the European Context*; 2019. Available online: https://www.researchgate.net/publication/338127221_Urban_bioregion_concept_from_theoretical_roots_to_development_of_an_operational_framework_in_the_European_context (accessed on 1 February 2023).
46. Berg, P.; Dasmann, R. Reinhabiting California. *Ecologist* **1977**, *7*, 399–401.
47. Dezio, C. A bioregional reading of the rural landscapes of the Italian inner areas and the regenerative potential of rural tourism. The case study of the VENTO project. *Ciudades* **2020**, *23*, 49–69. [CrossRef]
48. Budoni, A. Il bioregionalismo nel contesto della regionalizzazione urbana Il caso della bioregione pontina. *Contesti Città Territ. Progett.* **2018**, *1*, 142–161. [CrossRef]
49. Magnaghi, A. (Ed.) La regola e il Progetto. In *Un Approccio Bioregionalista Alla Pianificazione Territoriale*; University Press: Firenze, Italy, 2014.
50. Magnaghi, A. The Territorialist Approach to Urban Bioregions. In *Bioregional Planning and Design: Volume I*; Fanfani, D., Ruiz, A.M., Eds.; Springer: Cham, Switzerland, 2020; pp. 33–61.
51. Fanfani, D. The urban bioregion as form and project of the coevolution between urban and rural domain. The case of the Florence metropolitan area. *Int. J. Eng. Technol.* **2018**, *7*, 61–68. [CrossRef]
52. Dezio, C. Verso un'infrastruttura materiale ed immateriale per la bioregione. *Territorio* **2020**, *93*, 32–36.
53. Naitza, S.; Sandro, F.; Maddalena, F.; Roberto, P.; Francesco, S. The metallogenic potential of an old European mining region: The case of Sardinia (Italy). In *Life with Ore Deposits on Earth. Proceedings*; Society for Geology Applied to Mineral Deposits: Ginevra, Switzerland, 2019; Volume 4, pp. 1–5.
54. Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Il Progetto di Tutela e Valorizzazione del Patrimonio Minerario. 2006. Available online: https://www.isprambiente.gov.it/files/geoparchi/progetto-tutela-e-valorizzazione-3.pdf (accessed on 1 February 2023).
55. Parco Geominerario Web Site. Available online: http://www.parcogeominerario.eu/ (accessed on 26 January 2023).
56. Cammino Minerario di Santa Barbara Web Site. Available online: https://www.camminominerariodisantabarbara.org/ (accessed on 26 January 2023).
57. Fondazione Cammino di Santa Barbara. Il Cammino Minerario di Santa Barbara: Linee Guida per lo Sviluppo del Prodotto Turistico Territoriale. 2018. Available online: https://www.camminominerariodisantabarbara.org/wp-content/uploads/2020/02/CMSB_Linee-Guida.pdf (accessed on 26 January 2023).

58. Pinna, G. *Il Cammino Minerario di Santa Barbara. A Piedi in Sardegna tra Storia e Natura*; Terre di Mezzo: Milan, Italy, 2017.
59. Corsale, A.; Perelli, C.; Sistu, G. Large Island, big issues. Vulnerability and resilience in Sardinia. In *The anthropocene and Islands: Vulnerability, Adaptation and Resilience to Natural Hazards and Climate Change*; Gelabert, M.G., Micallef, A., Geli, J.R., Eds.; Scientific and Cultural Association "Il Sileno": Lago, Italy, 2020; Volume 3, pp. 59–77.
60. Pau, S.; Contu, G.; Rundeddu, V. From mine industries to a place of culture, tourism, research and higher education: Case study of the great mine Serbariu. *J. Cult. Herit. Manag. Sustain. Dev.* **2022**. [CrossRef]
61. Tanca, M. Sardinia: Inglorious landscapes? In *Surrounded by Water: Landscapes, Seascapes and Cityscapes of Sardinia*; Corsale, A., Sistu, G., Eds.; Franco Angeli: Milano, Italy, 2016; pp. 127–142.
62. Balletto, G.; Borruso, G.; Milesi, A.; Ladu, M.; Mundula, L. Ancient Mining Paths and Slow Tourism. Assessments and Challenges in Sardinia (Italy). In *Computational Science and Its Applications—ICCSA 2021*; Lecture Notes in Computer Science; Springer: Cham, Switzerland, 2021; Volume 12958, pp. 275–287. [CrossRef]
63. Snead, J.E.; Erickson, C.L.; Darling, J.A. (Eds.) *Landscapes of Movement: Trails, Paths, and Roads in Anthropological Perspective*; University of Pennsylvania Press: Philadelphia, PA, USA, 2011.
64. Balletto, G.; Milesi, A.; Ladu, M.; Borruso, G. A dashboard for supporting slow tourism in green infrastructures. A methodological proposal in Sardinia (Italy). *Sustainability* **2020**, *12*, 3579. [CrossRef]
65. Ioppolo, G.; Saija, G.; Salomone, R. From coastal management to environmental management: The sustainable eco-tourism program for the mid-western coast of Sardinia (Italy). *Land Use Policy* **2013**, *31*, 460–471. [CrossRef]
66. Meloni, I.; Saba, C.; Scappini, B. *Improving Regional Accessibility through Planning a Comprehensive Cycle Network*; Federico II Open Access University Press: Napoli, Italy, 2019.
67. Balletto, G.; Borruso, G.; Ladu, M.; Milesi, A. Smart and slow tourism. Evaluation and challenges in Sardinia (Italy). In *Innovation in Urban and Regional Planning, Proceedings of the 11th INPUT Conference-Volume 2, Catania, Italy, 8–10 September 2021*; Springer International Publishing: Cham, Switzerland, 2022; pp. 175–182.
68. Battino, S.; Balletto, G.; Milesi, A.; García, A.A. Rural Tourism and Walkability. Compare Sardinia and Gran Canaria Models. In Proceedings of the Computational Science and Its Applications–ICCSA 2022 Workshops, Malaga, Spain, 4–7 July 2022; Springer International Publishing: Cham, Switzerland, 2022. Part V. p. 211.
69. Burlando, M.; Firpo, M.; Queirolo, C.; Rovere, A.; Vacchi, M. From geoheritage to sustainable development: Strategies and perspectives in the Beigua Geopark (Italy). *Geoheritage* **2011**, *3*, 63–72. [CrossRef]
70. Candia, S.; Pirlone, F.; Spadaro, I. Tourism and Rural Landscape: Sustainable Development and Territorial Enhancement. In *Innovation in Urban and Regional Planning, Proceedings of the 11th INPUT Conference, Catania, Italy, 8–10 September 2021*; Springer International Publishing: Cham, Switzerland, 2021; Volume 1, pp. 531–539.
71. Marchigiani, E.; Cigalotto, P. Along the river Cormor, re-linking landscapes and public facilities in the region Friuli Venezia Giulia. In Proceedings of the AESOP 2019 International Conference Planning for Transition, Venice, Italy, 9–13 July 2019; Book of Papers. IUAV: Venice, Italy, 2019; pp. 3312–3334.
72. Meini, M.; Adducchio, D.; Ciliberti, D.; Di Felice, G. Landscape conservation and valorization by satellite imagery and historic maps. The case of Italian transhumance routes. *Eur. J. Remote Sens.* **2014**, *47*, 375–387. [CrossRef]
73. Rovelli, R.; Senes, G.; Fumagalli, N.; Sacco, J.; De Montis, A. From railways to greenways: A complex index for supporting policymaking and planning. A case study in Piedmont (Italy). *Land Use Policy* **2020**, *99*, 104835. [CrossRef]
74. Mariotti, A.; Dallari, F. Sistemi locali, reti e competitività internazionale: Dai beni agli itinerari culturali. *Almatourism* **2012**, *5*, 81–95.
75. Meloni, I.; Palma, R. *Paesaggio con Biciclette: Piccola Ontologia Illustrata per il Progetto Delle Ciclovie di Lunga Percorrenza*; Accademia University Press: Torino, Italy, 2022.
76. Ippovia Gran Sasso, Homepage. Available online: https://www.ippoviagransasso.eu/category/lippovia-come-natura-e-biodiversita/ (accessed on 1 February 2023).
77. Tolls, C.; Carr, N. The role of nature on horse trail rides: Tourist experience expectations. *Curr. Issues Tour.* **2021**, *24*, 1257–1269. [CrossRef]
78. Bambi, G.; Monti, M.; Barbari, M. New solutions for horse shelters to connect to the equestrian paths. *J. Agric. Eng.* **2013**, *44*, 178–180. [CrossRef]
79. Bambi, G.; Iacobelli, S.; Monti, M.; Barbari, M. Equestrian pilgrim along the Francigena way. Planning, surveying and testing Francigena as an equestrian path in Tuscany. *Eur. Pilgr. Routes Promot. Sustain. Qual. Tour. Rural Area* **2015**, 593–602. Available online: https://flore.unifi.it/retrieve/e398c379-53d6-179a-e053-3705fe0a4cff/EPR%20Equestrian%20Pilgrim.pdf (accessed on 1 February 2023).
80. Franceschinis, C.; Swait, J.; Vij, A.; Thiene, M. Determinants of recreational activities choice in protected areas. *Sustainability* **2022**, *14*, 412. [CrossRef]
81. Hancock, J. *Equestrian Design Guidebook for Trails, Trailheads, and Campgrounds*; USDA, Forest Service, Technology and Development Program: Washington, DC, USA, 2007.
82. ENGEA—Ente Nazionale Guide Equestri Ambientali. Available online: https://www.cavalloecavalli.it/ippovie-italiane-certificate/ (accessed on 1 February 2023).

83. FISE—Federazione Italiana Sport Equestri. Disciplinare per la Progettazione Delle Ippovie Italiane-FISE. Available online: https://www.fise.it/sport/equitazione-di-campagna/documenti/regolamenti-campagna.html?download=1314:disciplinare-ippovie-fise (accessed on 1 February 2023).
84. FITETREC-ANTE—Federazione Italiana Turismo Equestre e Trec—Ante. *Disciplinare per la Progettazione Delle Ippovie Italiane Certificate Dalla FITETREC-ANTE—Turismo Equestre Sostenibile*; 2022. Available online: https://www.fitetrec-ante.it/media/k2/attachments/Disciplinare_Ippovie_2022.pdf (accessed on 1 February 2023).
85. Direzione Regionale per i Beni Culturali e Paesaggistici Della Sardegna e Dipartimento di Architettura dell'Università di Cagliari. Progetto di Ricerca 'Metodologie per la Progettazione Sostenibile del Paesaggio. Rapporto Finale. Linee Guida per il Progetto Sostenibile del Paesaggio Rurale Regionale. Available online: https://sardegna.beniculturali.it/psg/pdf/Consistenza%20del%20paesaggio%20rurale%20in%20Sardegna.pdf (accessed on 1 February 2023).
86. Regional Law No. 16/2017. Art. 35, Registro Delle Ippovie. Available online: https://buras.regione.sardegna.it/custom/frontend/viewInsertion.xhtml?insertionId=95a09e04-8603-460e-8133-7e0830d4671e (accessed on 1 February 2023).
87. Sardinia Region (Sardegna Agricoltura). Available online: https://www.sardegnaagricoltura.it/argomenti/incrementoippico/ (accessed on 1 February 2023).
88. ENGEA. Turismo Equestre Internazionale & Viaggi a Cavallo. 2018. Available online: https://issuu.com/engea/docs/catalogo_ippovie_2017 (accessed on 1 February 2023).
89. Sardinia Region. Ippovia Costa-a-Costa Della Sardegna. Available online: http://www.sardegnadigitallibrary.it/documenti/17_82_20100215171917.pdf (accessed on 1 February 2023).
90. Forestas. Rete Escursionistica della Sardegna (RES) Ipotesi di Sviluppo 2019–2021 come da DGR n. 4/28 del 22 Gennaio 2019. *Rapporto Preliminare.* 2020. Available online: https://portal.sardegnasira.it/documents/21213/262963/01_Rapporto+preliminare_signed.pdf/966671f8-826c-4dfc-9710-34967a5a7746 (accessed on 1 February 2023).
91. Mikhailenko, A.V.; Ruban, D.A.; Ermolaev, V.A. Accessibility of geoheritage sites—A methodological proposal. *Heritage* **2021**, *4*, 1080–1091. [CrossRef]
92. Pontillo, I. Green and artistic routes for slow tourism in the Caserta province. *IJISET-Int. J. Innov. Sci. Eng. Technol.* **2016**, *3*, 319–322.
93. Çoruhlu, Y.E.; Çelik, M.Ö. Protected area geographical management model from design to implementation for specially protected environment area. *Land Use Policy* **2022**, *122*, 106357. [CrossRef]
94. Maggino, F. (Ed.) *Complexity in Society: From Indicators Construction to Their Synthesis*; Springer: Cham, Switzerland, 2017; Volume 70.
95. Sardinia Region Web Site. Available online: http://webgis2.regione.sardegna.it (accessed on 29 January 2023).
96. Ministry of Health (Ministero Della Salute). Codice per la Tutela e la Gestione degli Equidi. 2003. Available online: https://www.anmvioggi.it/files/CODICE%20TUTELA%20E%20GESTIONE%20EQUIDI.pdf (accessed on 1 February 2023).
97. Ministry of Health (Ministero Della Salute). Principi di Tutela e di Gestione Degli Equidi. 2015. Available online: https://www.fise.it/images/okPRINCIPI_DI_TUTELA_E_DI_GESTIONE_DEGLI_EQUIDI_6marzo2015.pdf (accessed on 1 February 2023).
98. Ministry of Health (Ministero della salute). Principi di Tutela e di Gestione Degli Equidi. Centro Stampa del Ministero Della Salute Finito di Stampare: Febbraio 2017 DGSAF—DGCOREI. 2017. Available online: https://www.salute.gov.it/imgs/C_17_opuscoliPoster_292_allegato.pdf (accessed on 1 February 2023).
99. Wheeler, E.F. *Horse Stable and Riding Arena Design*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
100. Bertamini, E.; Minero, M. *Il Paddock*; Federazione Italiana Sport Equestri (FISE), Dipartimento Tutela del Cavallo: Roma, Italy, 2012; pp. 1–4. Available online: https://www.fise.it/images/documenti/Image_Archive/Tutela_del_cavallo/Scheda_n.3_-_Il_Paddock.pdf (accessed on 1 February 2023).
101. Ladu, M.; Balletto, G.; Borruso, G. Sport and smart communities. Assessing the sporting attractiveness and community perceptions of Cagliari (Sardinia, Italy). In *Computational Science and Its Applications–ICCSA 2019, Proceedings of the 19th International Conference, Saint Petersburg, Russia, 1–4 July 2019*; Part VI 19; Springer International Publishing: Cham, Switzerland, 2019; pp. 200–215.
102. Lättman, K.; Olsson, L.E.; Friman, M. Development and test of the perceived accessibility scale (PAC) in public transport. *J. Transp. Geogr.* **2016**, *54*, 257–263. [CrossRef]

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An Operational Model to Downscale Regional Green Infrastructures in Supra-Local Plans: A Case Study in an Italian Alpine Sub-Region

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Abstract: In recent years, green infrastructure (GI) has increasingly become a strategic tool to integrate ecosystem services in spatial planning at different scales. GI has the potential to foster the achievement of environmental targets and landscape enhancement promoted by several planning instruments that act at different territorial scales. Despite this, the combination of the GI strategy with other ordinary plans is poorly investigated and developed due to the difficulty in making planning instruments dialoguing in a transversal approach. This paper presents a case study in an Italian alpine sub-region (Media and Alta Valtellina, Province of Sondrio) focused on a regional GI—defined by a landscape plan—used for testing a replicable methodology to downscale regional strategies by combining them with sub-regional environmental and landscape rules and recommendations derived from planning instruments. The aim is to create an organic connection between GI goals and other sub-regional planning instruments that would otherwise remain siloed within the hierarchical downscaling process of the top-down planning system. The result is the development of a comprehensive matrix that is useful for downscaling the strategies established by a regional landscape plan in sub-regional landscape units that relapse at the local scale; this is also achieved through GI deployment and the promotion of site-specific nature-based solutions.

Keywords: ecosystem services; strategic planning; landscape planning; landscape quality objectives; nature-based solutions

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1. Introduction

Green infrastructures (GIs), as well as green and blue infrastructures (GBI), are increasingly becoming a common tool to provide ecosystem services (ESs) in spatial planning at different scales [1–3].

ESs may be described as "the benefits human populations derive, directly or indirectly, from ecosystem functions" [4]. According to the Millennium Ecosystem Assessment (MA), which was developed by the UN since the start of the XXI century, ESs include provisioning, regulating, supporting and cultural services, whereas the ability of ecosystems to deliver their services can be assessed using a variety of qualitative and quantitative methods [5].

The operational connection between ESs and GIs is clarified in the 2013 Green Infrastructure Strategy by the European Commission. There, GI is defined as "a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings" [6].

GIs are based on the following five main principles: (1) integration, considering the grey–green combination of GI; (2) multifunctionality, which includes the ecological, social and economic/abiotic, biotic and cultural functions of green spaces; (3) connectivity between green spaces; (4) a multi-scale approach taking in all parcels, from the individual to the community, regional and state scales; (5) a multi-object approach including diverse types of (urban) green and blue spaces [7–9].

From a governance process perspective, GIs (1) consider a strategic approach in planning as they aim for longer benefits but remain flexible for changes over time; (2) promote social inclusion, standing for communicative and socially inclusive planning and management; and (3) adopt a transdisciplinary approach based on knowledge from different disciplines, developed in partnership with local authorities and stakeholders [9–11].

In relation to both objectives and spatial structure, GIs are strongly related to ESs as one of their main goals is to deliver and enhance ESs at different scales [12–15]. Hence, mapping and assessing the spatial ES provision has become one of the first stages in designing and implementing a GI or improving existing GIs according to different planning scenarios [16,17].

Therefore, a GI may be considered an environmentally compatible project aiming to promote the integration of ESs into planning processes and instruments [18–20] with considerable potential to advance the adoption of environmental best practices [21]. Moreover, GIs are the backbone of policies that preserve Europe's natural environment, including the EU Biodiversity Strategy for 2030 [22–24].

Despite that, Hansen and Pauleit [8] claimed that GI remains a broad and fuzzy concept when not incorporated in the design process. Studies carried out in recent years [25–27] show that albeit the gaps in operationalising GIs are still significant, there are promising examples and opportunities to transfer ES and GI research into good spatial planning practices [9–11,28,29].

Among the above-mentioned GI principles, the multi-scale approach seems particularly significant for GI spatial design and strategic contents or measures [30,31]. As stated by the European Commission, "Whilst elements of a GI network can operate at different scales, they must normally have a certain critical mass and connectivity potential to be able to contribute effectively to a GI. An individual tree may be an element of the system, but only if it forms part of a larger habitat or ecosystem that provides a wider function" [6], and connecting different planning scales is widely recognised as one of the common features of GIs [32,33]; thus, landscape is considered as "an overall system of ecosystems in which single components interact with each other through a multitude of ecosystems and landscape elements that contribute to create a Green Infrastructure" [34]. The multi-scale approach integrates individual analyses based on different scales in a combined synthesis [35]. An ES-based GI is composed of diverse physical features that are specific to each location and are scale dependent [23,36–38]; this allows for the assessment of ESs at multiple spatial scales and according to the most suitable size specificity of a phenomenon [39].

As defined by Hansen and Pauleit [8], "GI planning can be used for initiatives at different scales, from individual parcels to community, regional, and state. GI should function at multiple scales in concert". Hence, the structure of a GI should be intended as an open framework that is suitable for supporting a multiplicity of implementations at different scales. In a large-scale design, a GI covers a wide range of territories, dealing with a high complexity and variability of landscapes, infrastructures and human settlements [30,40,41] and acting as a framework to guide and connect future implementation at the local scale. The connection between these two dimensions requires a common list of recommendations, prescriptions and planning suggestions [42–44].

In this frame, the GI downscaling process towards local implementation requires addressing the following two major issues, respectively: the scalability of GI strategies concerning their spatial dimension, and the coherence within the different planning levels involved. On the one hand, the translation of broad principles and objectives into site-specific actions and strategies requires detailing and adapting the GI spatial design [45–47] as well as acquiring data required for local spatial knowledge and assessing the coherence between a large-scale spatial design and smaller-scale implementations. A further critical step is choosing proper and suitable solutions (including nature-based solutions—NBSs) to guarantee ecological, environmental, social and mobility benefits to people through ES improvement [21,48]. On the other hand, the operability of the GI at the local scale necessarily requires contextualizing the downscaling process within the regulatory and planning framework in force. This involves both verifying the respondence of the proposed local strategies to supra-local planning objectives and guidelines, and promoting the cooperation among different levels of governance as an application of the subsidiarity principle between the various planning scales [49,50]. In response to such issues, the multi-scale design of a GI combines objectives, spatial design, regulations and tangible solutions that should intertwine and find mutual correspondences to build environmental strategies [51–53]. In turn, strategies should help translate ES-based GIs into feasible land use planning tools and regulations [25,54].

This paper presents a pioneering example of downscaling a regional GI for future possible local implementation, developed within a regional landscape plan framework that identifies different landscape units to facilitate the scaling processes.

The aims of the study are the following: (i) setting a pilot methodology for downscaling the regional GI to a sub-regional scale; (ii) integrating GI principles and spatial design into the complex and fragmented framework of different supra-local planning strategies; (iii) showing how to reach a more detailed implementation of a multi-scale GI by adopting a set of local interventions (including NBSs) to specific landscape typology.

The materials and methods are illustrated in Section 2, with a preamble presenting the Italian planning framework. In Section 3, the main findings are illustrated, and in Section 4, they are discussed, providing possible future applications and defining some limits and critical aspects. Lastly, Section 5 hosts the conclusions.

2. Materials and Methods

2.1. Research Framework

2.1.1. The Italian Planning System and Lombardy Regional Framework

The Italian planning system is organised in four tiers, corresponding to the levels of administrative divisions as follows: (1) national; (2) regional; (3) provincial; (4) local [23].

At the national level, a planning law is in force; furthermore, the government provides guidelines for territorial development, with jurisdiction in the infrastructural system, heritage sites and landscape. The planning law in force was approved in 1942 and, in the following decades, underwent several reforms, shifting spatial planning topics to the local level and assuming the municipal development plan as the central planning instrument.

As for the regional level, Italian regions have the authority to approve regional planning laws. Furthermore, regional administrations are committed to approving the Regional Territorial Plan (RTP) and the Regional Landscape Plan (RLP), in cooperation with the National Ministry of Culture. Actually, regions can choose whether to have two separated plans or a single RTP with landscape value. In the Lombardy region, the RLP is included in the RTP, and it sets out guidelines for the preservation of landscape features and the restoration of historic and natural areas.

Moreover, the Lombardy RTP provides an additional in-depth planning tool, named the Regional Territorial Area Plan (RTAP), that could be applied to selected supra-local contexts involved in major development processes or interventions. It is a medium- to long-term strategic tool that promotes a multi-level governance approach to enhance territorial competitiveness and environmental quality.

At the provincial or metropolitan level, administrations prepare the Provincial Territorial Coordination Plan (PTCP)—or Metropolitan Territorial Plan for the metropolitan cities—which is often focused on environmental and infrastructural topics. Finally, land use decisions at the local level depend on the municipal Territorial Development Plan (TDP). In the Lombardy region, the regional law on urban planning establishes a regional framework for integrated planning and programming at different administrative scales to be implemented through inter-institutional collaboration.

In the recent process for the re-edition of the new RLP of Lombardy, the following two main innovations were introduced: (i) an ES-based approach was used for designing a GI that constitutes the strategic regional landscape spatial structure aimed at promoting and preserving the natural capital while delivering strategic guidelines for landscape enhancement and regeneration; (ii) sub-regional territorial units were introduced to allow for the definition of more site-specific landscape quality objectives [55] within the RLP's general framework.

The goals of the regional GI (RGI) are aligned with the guidelines provided by the European Commission [6]. Specifically, the ES mapping assessment used for RGI deployment included the following: (i) habitat quality, which is considered an overall indicator of environmental health; (ii) rural landscape value, which is based on agricultural productivity and biodiversity in rural land; and (iii) historical, cultural and anthropic heritage value, as a cultural ES, which includes the spatial distribution of protected and historical/identity elements in Lombardy [56]. By integrating the ES assessment, it was possible to determine and identify the areas to be included in the RGI strategic spatial design, which consists of the following three thematic components derived from the ES mapping: natural RGI, rural RGI and historical and cultural RGI. Based on ES values, further sub-articulations of each component were identified to improve the effectiveness of the large-scale GI structure, also considering the huge variety of landscapes in Lombardy, together with the diversity of risk and slow-burn factors affecting the region [57,58]. This operation enables the definition of RGI strategic guidelines that are useful for identifying common priority interventions at the regional scale.

The strategic design of the RGI also includes design proposals to set new landscape connections, to increase existing ones along linear elements (such as rivers or trails) and to improve the landscape integration of infrastructures (highways and railways).

At the same time, the need to target landscape quality objectives, thus fostering the connection between regional and local and supra-local scales, led to the definition of 57 subunits called geographic landscape units (GLUs). GLUs are based on homogeneous geographical, hydrological, geomorphological, environmental, ecological, anthropic, historical and cultural features; they are located within or between Lombardy's various landscapes, as defined by elements like mountains, hills, lakes, rivers, lowlands and metropolitan conurbations.

GLUs represent both analytical tools for identifying territorial qualities and dynamics and operational tools to define quality objectives and strategic priorities to activate multiscale landscape planning and regeneration processes [16].

The most relevant features, the landscape structural elements and the pressure or degradation factors characterising each GLU are identified in descriptive/orientating reports, which detail the list of landscape quality objectives to support local planning. The structural elements of the landscape, with their quality objectives, are organised according to the following four thematic macro-systems: (i) hydrological/geological/morphological systems; (ii) natural ecosystems; (iii) agricultural and rural systems; (iv) urbanised areas and historical and cultural systems.

2.1.2. Case Study Area

To test the validation of our methodological proposal in a highly complex spatial unit, the Media and Alta Valtellina were chosen as a pilot study area. They form a geographical and historical sub-region of the Central Alps, spanning along the river Adda in the northeastern sector of Lombardy, bordering on the north with the Grisons in Switzerland and on the east with South Tyrol in Italy. The area covers an extent of approximately 1348 km^2; it includes GLU 2.1 (Alta Valtellina) and GLU 2.2 (Valtellina di Tirano), characterised by different landscape values but, at the same time, are strictly connected and subject to common dynamics, as they are both involved in the landscape and regional transformations occurring in the Alpine territories [59–61]. In particular, the RTP for Lombardy recognises the need for a joint territorial and landscape development in the area, as testified by the

RTAP Media and Alta Valtellina in force since 2013. An overall strategic vision for the area is becoming even more interesting because of the Milan–Cortina Winter Olympic Games scheduled for 2026 [62]. As competition venues, the event will involve alpine towns like Bormio and Livigno in Alta Valtellina. Besides, Media Valtellina and Valtellina di Tirano will be relevant infrastructural hubs, thus undergoing significant transformations. Studies on past events show that the Winter Olympics partly integrated concepts of sustainable development in their organisation but may still raise concerns about their overall environmental impact [63–65]. Therefore, the choice of the study area was determined by the will to operate a stress test of the research methodology considering a critical context for the reasons set out above.

The national, regional and sub-regional geographical frameworks (i.e., GLU) for the pilot area are displayed in Figure 1.

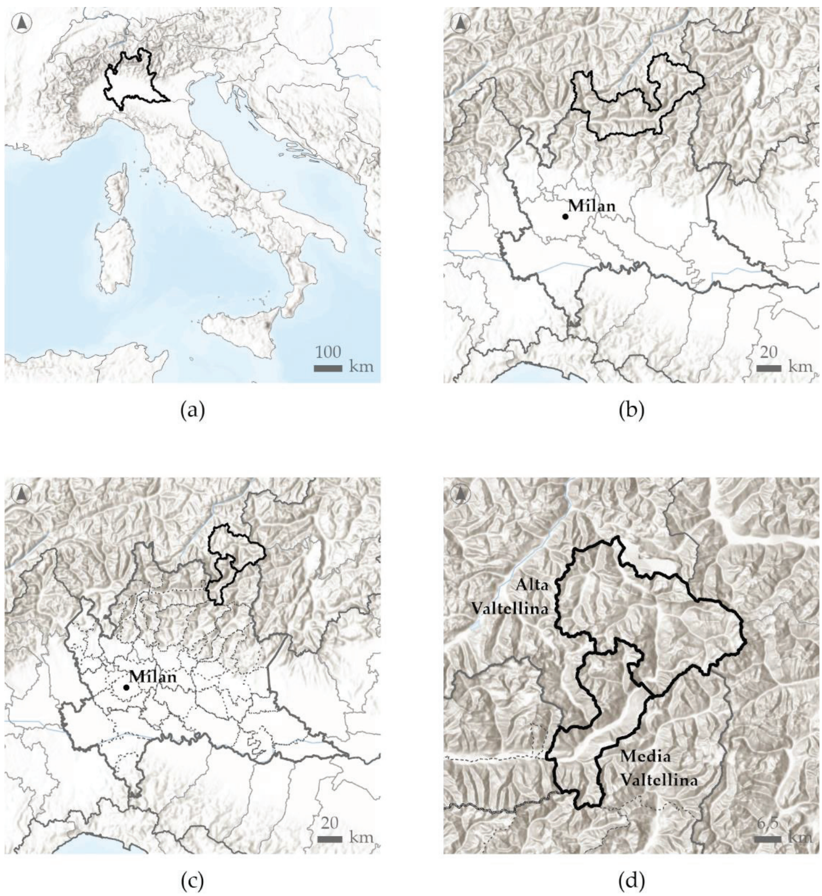

Figure 1. Study area. (**a**) The Lombardy region in Italy; (**b**) location of the province of Sondrio in the Lombardy region; (**c**) GLU subdivision and location of Alta Valtellina and Media Valtellina in the Lombardy region; (**d**) Alta Valtellina and Media Valtellina. (Source: authors' elaboration. World imagery sources: Earthstar Geographics).

2.2. Research Methodology

The working process was articulated into the following two main stages:

(i) Cross-reading and systematization of the extensive set of objectives, prescriptions and strategic guidelines provided by current planning tools (RLP, RTP, RTAP, PTCP) for the study area. Stage one moves from the spatial representation of the structural landscape elements identified by the GLU reports, integrated with the RGI spatial design components. As a result, a structural landscape map for the pilot area was outlined, combining GLU and RGI contents. Then, a cross-reading process of GLU landscape quality objectives, RGI guidelines and strategic orientations or prescriptions deriving from other supra-local planning tools were implemented to organise a Matrix of Planning Objectives. The aim of the matrix is to point out the correlations between each structural landscape element represented in the structural map and the several strategic objectives, guidelines or prescriptions directly affecting it, to allow for a synergic view of the different planning contents referred to spatialised elements.

(ii) Downscaling the RGI spatial design components, from regional scale to GLU scale, as a result of a further cross-reading process applied to the Matrix of Planning Objectives contents. While in the first research stage, the cross-reading process was carried out to point out an exhaustive list of strategic contents selected from different planning tools, the aim of this further step is to provide a synthetic overview of the whole strategic contents listed in the matrix, identifying the main priorities of intervention for the study area, and spatializing them according to the RGI spatial design components. In stage two, cross-reading allows us to identify cross-cutting issues in order to combine the several "Planning Objectives" listed in the matrix into more synthetic "Thematic Objectives". The so-called thematic objectives represent the strategic goals for the study area that can be applied to downscale the RGI, detailing both its spatial structure and the related guidelines, according to site-specific priorities and landscape features. Thematic objectives can be further ascribed to the following three key topics (KTs) identified as crucial issues for the entire Lombardy regional landscape: identity, natural capital, sustainable recreation. As a result of the RGI downscaling process, a pilot strategic operational map, articulated according to the three KTs, was created.

The methodological workflow presented in our study is graphically summarised in the following diagrams (Figures 2 and 3):

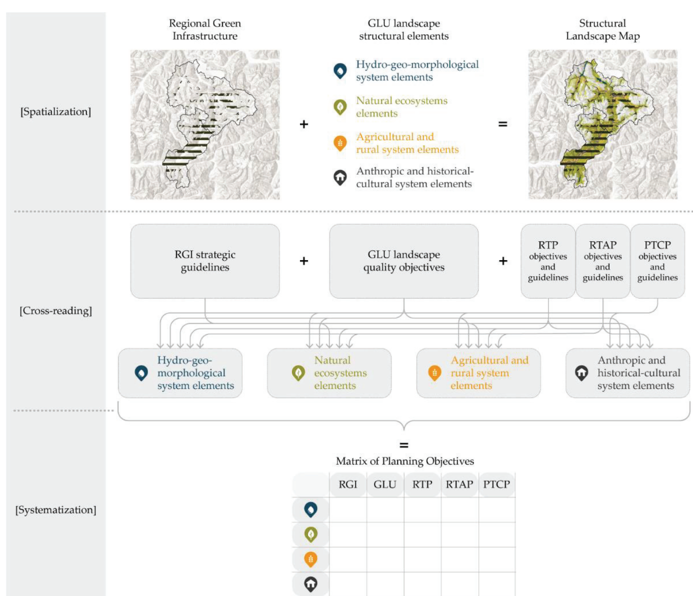

Figure 2. Stage 1 of the proposed methodology. Representation of the workflow performed to create a pilot structural landscape map and a Matrix of Planning Objectives derived by cross-reading of supra-local plans involving structural landscape elements (source: authors' elaboration).

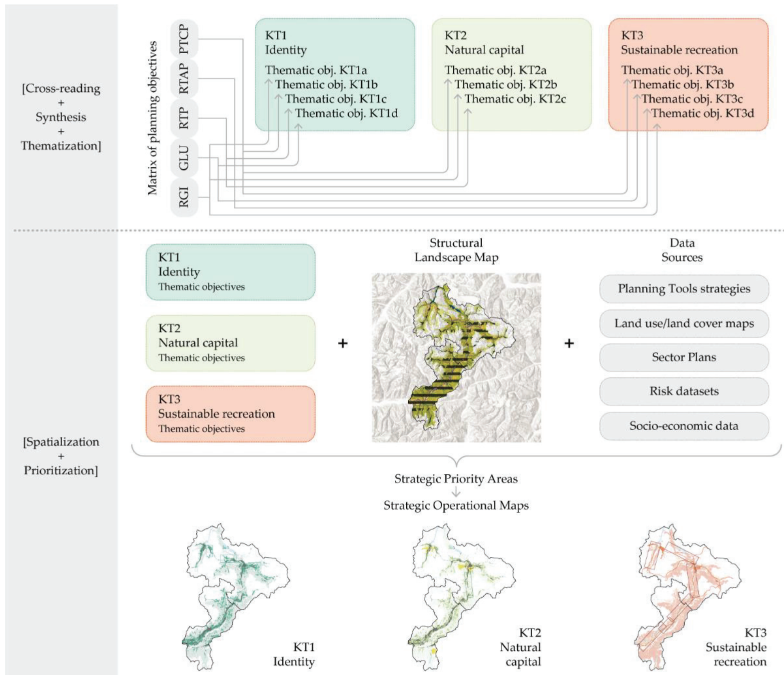

Figure 3. Stage 2 of the proposed methodology. Representation of the workflow performed to create three pilot strategic operational maps as a result of cross-reading, synthesis and thematization of the planning objectives into key topics and thematic objectives, and their spatialization and prioritization to accomplish the RGI downscaling process (source: authors' elaboration).

2.2.1. Assessment of Landscape Structure and Planning Objectives

The pilot structural landscape map was produced by representing all the significant landscape structural elements of the pilot area for each GLU's system (see Section 2.1.1). The hydrogeomorphological system represented, among others, glaciers, lakes, artificial basins, the hydrological network and environmental impact elements like ski resorts and quarries. Elements related to natural ecosystems included woodlands and ecological corridors belonging to the regional ecological network (REN) included in the RTP. Elements represented within the agricultural and rural system encompassed both the main agricultural features of the local rural landscape, e.g., terraced vineyards, chestnut groves, orchards and the higher mountain pastures. Finally, the anthropic and historical–cultural system included urbanised areas, historical settlements, heritage sites scattered along the area of interest and mobility infrastructures like roads and railways.

Then, the map was integrated with the RGI elements included in the pilot area including the three ecosystem-based spatial components—natural, rural and historical and cultural—also named "Enforcement and enhancement areas", and the proposals for new or improved connections and for landscape integration of new infrastructures, jointly named "Priority reinforcement projects"; thus, a close spatial relationship between RGI strategies and site-specific landscape context was created. Moreover, the structural landscape map is strictly related to the Matrix of Planning Objectives, which is an operational tool that aims to provide an overview of planning strategies and guidelines for the pilot area considering regional and supra-local levels of territorial governance. The matrix combines the GLU landscape quality objectives that refer to the landscape structural elements, the strategic guidelines related to the several components of the RGI, and the strategic contents of some of the most relevant supra-local planning tools including the RTP, the RTAP for Media and

Alta Valtellina and the PTCP for the Province of Sondrio, to which the study area belongs (see Figure 1).

Each of these plans is provided with one or more sets of planning objectives or addresses, aimed at guiding their implementation strategies. Each set of objectives was collected and classified by an alphanumeric code allowing us to identify which plan every objective belongs to.

Using the adopted alphanumeric codes, the whole range of planning objectives was classified in the matrix according to their relevance to one or more structural elements of the landscape included in the structural landscape map. Each row of the matrix corresponds to a landscape element, while the columns correspond to the considered supra-local plans. Therefore, an objective belonging to one of the considered plans may have one or more occurrences in the matrix, corresponding to the landscape elements to which it refers. The complete list of objectives used in the matrix, with the correspondence between their extended version and the alphanumeric tracking codes, constitutes an essential consultation tool that integrates the matrix.

The matrix follows the structure of the structural landscape map legend to allow for cross-reading between the map, the synthetic matrix and the comprehensive list of planning objectives.

As the result of an integration of different data, the knowledge and prescriptions that are declined at the GLU scale and are tightly related to the structural landscape map; the Matrix of Planning Objectives enables planners and policymakers to cross-read the objectives related to the local landscape's structural elements to find common themes and synergies to be handled.

The cross-reading and systematisation process also represented a crucial step in providing a synthetic framework for the pilot area to be implemented in the following stage of the research. Some strategic issues emerged during cross-cutting, bringing out possible common fields of action (or KT) to reorganise and merge the several objectives that are separately listed in the matrix.

2.2.2. Definition of Planning Strategies and Scaling GI: Data Sources and Spatialisation Process

Based on the common issues displayed in the Matrix of Planning Objectives, a set of thematic objectives was implemented for the study area. The thematic objectives were articulated into three main KTs to emphasise the strategy's character. KTs are a way to classify landscape planning objectives and strategies into more general and comprehensive issues to facilitate replicability of their implementation. The topics are defined by a short title and condensed into a single keyword to facilitate map reading; they promote a conceptual synthesis of the contents of the matrix, which is articulated and detailed, making it difficult to consult by a non-expert public. The topics are the following:

- Protection and enhancement of the structural elements that provide a substantial contribution in defining the landscape identity of the study area, classified as "identity" (KT1);
- Protection and reinforcement of natural capital and biodiversity, classified as "natural capital" (KT2);
- Promotion of leisure and recreational landscape activities compatible with the preservation of local identity and environmental values, simplified as "sustainable recreation" (KT3).

The topics were set to ideally encompass every possible strategy to be adopted in landscape planning. They can be matched with the fields in which, according to the preamble of the European Landscape Convention, the landscape has a significant public interest role [55]; specifically, "identity" corresponds to cultural values of landscape, "natural capital" represents ecological and environmental values and "sustainable recreation" embodies social values, as well as the definition of landscape as "a resource favourable to economic activity".

Among the three KTs, "identity" refers to what has been defined as "the perceived uniqueness of a place" [66], which means the combined result of multiple elements like physical features, spatial morphology, presence of cultural heritage and socio-economic image of a landscape [67].

"Natural capital" is a term that was introduced based on a definition of capital as "a stock that yields a flow of valuable goods or services into the future"; considering natural assets, their sustainable flow is "natural income", and the stock that yields the sustainable flow is "natural capital" [68]. For our purposes, it concerns ecological and environmental perspectives on landscape and strategies to integrate the preservation and enhancement of natural values in landscape management to create sustainable landscapes [69,70].

"Sustainable recreation" covers issues related to leisure activities in which visitors enjoy an experience involving morphological, ecological and cultural landscape features, and sets strategies both for promoting recreational uses of landscape and for tackling potential environmental or social threats linked to heavy tourist flows [71,72].

The definition of thematic objectives is the fruit of a cross-reading of the objectives classified in the Matrix of Planning Objectives; starting from the detection of thematic contents of each planning objective, a conceptual abstraction was performed to identify their thematic cores, to cluster them as subsets of the main strategic framework and express them in a synthetic formulation, to identify priorities of intervention in the study area and to promote the integration between the several planning levels. In this stage, GLU-scale landscape quality objectives from RLP were chosen as a baseline and looked for thematic correspondences in objectives derived from other planning tools. This allows for inner coherence, considering that the whole research process was framed into the RLP tools. Therefore, for example, thematic objective KT2a, which is "Promoting maintenance, reinforcement or reinstatement of ecological connectivity and high habitat quality" (see Supplementary File S1, KT2), is defined based on indications from GLU quality objectives for ecosystems, environment and nature, connectivity objectives from RGI and REN, territorial resilience objectives for the mountain territorial system from RTP and objectives for well-being and environment from RTAP.

Then, to achieve the RGI downscaling process, thematic objectives were spatially translated into one or more strategic priority areas, identified by specific mapping criteria and provided with a set of design solutions.

Priority areas coincide with those spatial extents, landscape elements or spatial landscape strategies that require a special focus based on scrutinised planning objectives. They allow us to detail or to integrate the RGI spatial design at the local scale. The whole list of priority areas and their correspondence to thematic objectives and key topics are illustrated in Figure 4.

Locating and mapping each priority area was a complex and challenging phase of the research, requiring a wide array of spatial data sources and different GIS processing. Different data were combined with RGI spatial components to accomplish the RGI downscaling process, i.e., (i) data from regional and supra-local plans (RTP, RTAP, PTCP) identifying core areas or elements involved in spatialised strategies or projects (e.g., natural protected areas and protected cultural heritage; regional ecological network corridors or core areas; planned mobility infrastructures; planned soft mobility networks; main viewpoints and scenic routes; other elements or areas specifically addressed by surveyed territorial planning tools); (ii) spatial data from land use/land cover maps; (iii) data from sector plans spatializing specific phenomena (e.g., forestry management data; quarries management data); (iv) data from ministerial or recognised scientific databases spatializing risk phenomena or occurred damages affecting landscape (e.g., landslide danger or hydrogeological instability maps; data on damaged or degraded natural areas); (v) socio-economic datasets provided by recognised national or regional research institutes or organizations (e.g., production sites of agricultural and food products protected by geographical indications; tourism data).

Key topics	Thematic objectives	Strategic priority areas
KT1_Identity	**KT1a**_*Preserving unity and perceivability of hydro-geo-morphological elements*	Glaciers to be supervised and protected in order to tackle climate change impacts
		Priority areas to tackle structural modifications and prevent risks on hydrographic network: 1. areas to safeguard of the river morphology and increase of the naturalistic values; 2. areas to prevent hydrological risk prevention and increase naturalistic values in urbanized context; 3. priority areas to prevent hydrological risk on minor hydrographic network
		Priority areas to prevent hydrogeological risk on mountain woodlands
		Peculiar hydro-geo-morphological features to be preserved
		High visibility mountain landscapes to be preserved
	KT1b_*Preserving landscape values of natural elements*	Priority areas to tackle vegetation diversity loss
	KT1c_*Preserving constitutive features of rural landscape*	Traditional and historical rural landscapes to be maintained, preserved and enhanced
		Priority areas where to tackle forest regrowth
		Priority areas where to tackle abandon and degradation of croplands
		Alpine rural buildings to be restored, enhanced or preserved
	KT1d_*Preserving features representing the identity of the anthropic landscape*	Valley floor historical urban settlements to be restored, enhanced or preserved
		Slope historical urban settlements to be restored, enhanced or preserved
		Historical and cultural heritage sites to be preserved
		Historical and cultural heritage clusters to be preserved
		Aggregations of buildings and areas with significant landscape quality
		UNESCO World Heritage Sites
KT2_Natural Capital	**KT2a**_*Promoting maintenance, reinforcement or reinstatement of ecological connectivity and high habitat quality*	Regional Ecological Network (REN) primary corridors
		REN passages
		Landscape enhancement connections from RGI with mainly environmental purposes
		Priority revitalization areas for damaged woodland ecosystems: 1. revitalization areas of woodland ecosystem damaged by windstorms; 2. revitalization areas of woodland ecosystem damaged by wildfires; 3. revitalization areas of woodland ecosystem damaged by beetle outbreaks
	KT2b_*Promoting reorganization and defragmentation of peri-urban landscapes tackling loss of biodiversity*	Peri-urban rural areas to be preserved: 1. areas with high environmental values; 2. areas with high historical and cultural values; 3. areas with high environmental, historical and cultural values
		Priority areas where to tackle linear conurbation trends
	KT2c_*Limiting, containing and mitigating impacts of anthropic activities*	Areas involved in mining activities whose impacts should be limited and mitigated
		Hydroelectric power plants and electrical power lines whose impacts should be limited and mitigated
		Industrial or commercial settlements and accommodation facilities whose landscape and environmental suitability should be increased
		Ski resorts to be involved in integrated redevelopment strategies
		Landscape mitigation and integration buffers for new infrastructures from RGI
KT3_Sustainable recreation	**KT3a**_*Promoting sustainable recreation in natural heritage, also through soft mobility networks and landscape connections*	Local trail network sections to be improved and enhanced
		Landscape enhancement connections from RGI with mainly recreational purposes
		Landscape connection projects from RGI with mainly recreational purposes
		Sustainable recreational enhancement of "Landscapes of Silence"
		Environmental systems to be enhanced, redeveloped and restored
	KT3b_*Supporting traditional and quality supply chains in farming, forestry and dairy products as multifunctional activities*	Priority multi-function enhancement areas: mountain pastures
		Priority multi-function enhancement areas: wine production
		Priority multi-function enhancement areas: typical dairy production
		Priority multi-function enhancement areas: apple orchards
		Priority multi-function enhancement areas: historical cereal production
	KT3c_*Promoting and enhancing recreation in historical and cultural heritage*	Structural soft mobility elements whose connections with local cycle path network should be increased
		Historical and cultural systems to be enhanced, redeveloped and restored
	KT3d_*Exploring and promoting alternative tourism and recreation*	Attention and mitigation areas linked to possible functionality loss of low altitude ski resorts
		Attention and mitigation areas linked to overtourism impacts
		Areas substantially depending on winter tourism

Figure 4. Key topics, thematic objectives and priority areas (source: authors' elaboration).

Selection and representation criteria adopted for strategic priority areas and the related data sources are reported in a table of strategies and criteria connected to the operational maps (see Supplementary File S2). Criteria can be subdivided into the following four main categories:

a. Representation of landscape elements in their spatial conformation: Natural, rural or anthropic landscape elements recognised as deserving specific strategies (e.g., glaciers, historical and cultural heritage, quarries, hydroelectric power plants, etc.) were represented, with geometric simplifications in some cases. They could be already included in the RGI spatial components, or they could interact with them. (Spatial data sources: regional and provincial geographic datasets, local socio-economic maps.)
b. Representation of planned spatial strategies: Strategies set by supra-local plans (e.g., corridors or passages from regional ecological network, RGI buffer zones mitigating planned infrastructures, focus areas to implement landscape or environmental strategies, etc.), provided with inherent values and allocated to proper KTs, were represented without modifications. They could allow us to better detail the RGI spatial components or to integrate RGI design at local scale. (Spatial data sources: strategic datasets derived from planning tools in force, such as RLP; RTP; RTAP.)
c. Elaborations by the authors combining RGI spatial components with datasets or elements involved in spatialised strategies: Starting from a group of territorial elements or spatial representations set by supra-local plans, the location of strategic areas descends from aggregation, filter and, in some cases, classification procedures (e.g., clip via RGI extent or risk areas, selection via contact with RGI, classification via landscape subtypes). They could allow us to better detail the RGI spatial components and the related strategic guidelines, or to integrate RGI design at local scale. (Spatial data sources: regional and provincial geographic datasets, national maps of hydrological instability areas, strategic datasets derived from the following plans: provincial forestry management plan; RGI; regional wildfire prevention plan; provincial quarries management plan.)
d. Elaboration by authors combining several datasets to spatialise and prioritise strategic actions facing ongoing territorial phenomena: With various degrees of complexity, strategic areas are identified by authors' elaborations consisting of, e.g., spatial analysis based on transformations in land use/land cover; selection of high visibility areas derived from GIS-based analysis; classification and interpretation of local socio-economic data. (Spatial data sources: regional and provincial geographic datasets, socio-economic data from the national institute for statistics, strategic datasets derived from RGI.)

The latter category includes complex elaborations aimed at identifying site-specific strategic solutions to the following four priority issues identified as crucial for a mountain context: the prevention of hydrogeological risk; the protection of the mountain landscape features; the limitation of agricultural soil sealing in the valley floor; the management of winter tourism impacts and criticalities. Therefore, the corresponding procedures require a broader methodological explanation than the synthetic one provided in the table of strategies and criteria available in Supplementary File S2. The following are extended descriptions of the articulated procedure to locate strategic areas:

- Priority areas to tackle structural modifications and prevent risks on the hydrographic network (KT1a): The regional land use/land cover (LULC) of Lombardy was resized on high hydrological instability areas provided at a national scale by ISPRA (Italian Institute for Environmental Protection and Research acting under the vigilance and policy guidance of the Italian Ministry for the environment and energy security), locating areas next to rivers and streams that are at risk of flooding. Then, the selection was classified by predominant LULC types to diversify strategic actions. Selected areas that were primarily permeable (rural or natural LULC) were classified as "areas of safeguard of the river morphology and increase of the naturalistic values", linking actions of increasing vegetation cover, supervised flooding or restoration of the natural river course. When waterways penetrated urban areas, priority areas were classified as "areas of hydrological risk prevention and increase of naturalistic values in urbanised context", with actions of desealing or creation of retention basins. Priority areas along minor hydrographic networks were classified regardless of LULC type; for those areas, strategic actions include maintaining riparian vegetation and increasing morphological diversity of riverbeds.

- High mountain landscapes visibility to be preserved (KT1a): With the aim of considering the perceptual characters of landscapes for preservation and enhancement purposes, a procedure to select high visibility reliefs in the pilot area was implemented, starting from a GIS-based visibility analysis. Using a digital terrain model (DTM) with a spatial resolution of 5 m, viewsheds from the main panoramic viewpoints, paths and routes were separately calculated. The procedure was integrated by calculating viewsheds from a selection of the most photographed points in the pilot area based on the visitation, recreation and tourism model of the free open-source suite of software models InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) [73], developed through a collaboration between different universities and international research and conservation centres for ES mapping and assessment. In particular, the visitation, recreation and tourism model aims to display the rate of visitation across landscapes using geotagged photos posted on the website Flickr as a proxy for the presence of visitors [74]. Raster viewsheds calculated from each layer of observation points were clipped to exclude valley floors and focus on mountains and slopes and then classified by visibility values adopting the natural breaks (Jenks) classification method to provide a consistent classification among the different viewsheds [75]. Finally, cells belonging to higher visibility classes were selected and aggregated, thus generating an overall map of high visibility areas in mountain landscapes, subject to specific preservation and enhancement actions.
- Peri-urban rural areas to be preserved (KT2b): Chosen with the aim of detecting rural areas along urban fringes, which can be considered at risk of being enclosed by anthropic elements. A GIS-based selection by share of contact was performed. Rural plots from the regional LULC map were selected as priority areas if more than 50% of their perimeter was in contact with urban fabric or infrastructures. Then, to diversify strategic actions, RGI values were used as a filter to classify rural plots. Most of the selected areas, in fact, were included in the rural component of RGI and provided significant environmental and/or historical and cultural values. This led to a three-sided classification where RGI values' co-presences are considered as vocations to guide strategic actions. In areas with high environmental values, local actions included the creation of allotments to be managed according to agroecology principles and increasing vegetation equipment for ecological restoration; in areas with high historical and cultural values, actions may also involve their reuse as public gardens or the refurbishment of abandoned rural buildings to support recreational uses. Areas with high values for both environmental and historical and cultural components are suitable to host actions related to both vocations.
- Priority areas to tackle linear conurbation trends (KT2b): Firstly, LULC transitions from rural or natural land uses to urbanised areas that occurred in the past two decades were detected by clipping urbanised areas from current regional LULC maps on areas that were rural or natural in 1999, according to a former regional LULC map; then, a visual analysis was performed to identify conurbation trends, considering the spatial distribution of new urbanised areas, their linear aggregation along mobility infrastructures and the presence of neighbouring urban settlements subject to conjoining trends at the expense of rural or natural open spaces. Linear conurbation trends were represented as two collinear lines with converging arrows, indicating the direction of urban expansion. Strategic actions to tackle such trends include green buffer zones, hedgerows or tree rows along peri-urban rural areas and incentives to reuse abandoned buildings or complexes to avoid land take.
- Attention and mitigation areas linked to possible functionality loss of low altitude ski resorts (KT3d): Present and future impacts of decreasing snowfalls on mountain activities are a risk factor for ski resorts, with increasing use of artificial snowmak-

ing [76,77]. Ski resorts that can be more affected by the snowfall reduction were identified, suggesting alternative recreation strategies. Because climate in mountain areas may substantially vary depending on local factors, a recognised and potentially replicable criterion was chosen, known as the line of snow reliability (LSR), defined as the altitude that allows for a snow cover that is sufficient for at least 100 skiing days per season in a ski resort. OECD [78] estimates an LSR rise of 150 m per 1 °C of warming, starting from an LSR of 1500 m in alpine areas. Based on a supposed future scenario where LSR is set at 1650 m, percentages of each ski resort in the pilot area located below this altitude were calculated. Looking at the results, resorts whose future functionality may be considered at risk were selected by adopting a threshold corresponding to 40% or more of ski resort area below 1650 m. Priority areas descending from this procedure include a ski resort next to the town of Aprica (GLU 2.1) and some cross-country tracks generally located at lower altitudes than alpine skiing tracks.

- Attention and mitigation areas linked to over-tourism impacts (KT3d): Since Media and Alta Valtellina territory relies considerably on tourism, issues related to tourist flows in fragile mountain contexts were highlighted, suggesting possible tackling strategies. In this case, tourism intensity—defined as the ratio of total overnight stays to total resident population [79]—was mapped at a municipality scale using data from Istat (the Italian National Institute of Statistics). The towns of Bormio and Livigno (GLU 2.1) show values remarkably higher than the other municipalities in the pilot area. They are, therefore, identified as attention and mitigation areas, where planning decisions that are able to combine the positive economic effects of tourism with environmental and landscape preservation must be adopted.
- Areas substantially depending on winter tourism (KT3d): These priority areas represent municipalities where the local economy is tied to winter tourism activities—a condition that, combined with vulnerability to decreasing snowfalls, shall be considered a risk factor for the economy. To select such areas, municipal Istat data were analysed, including variance between tourist flows in the high season (winter and summer) and in the low season; the variance between winter and summer tourist flows; share of tourist facilities on overall local businesses. As a result of this combination of factors, Aprica municipality stands out as the most dependent on winter tourism and may take future advantage of diversifying recreation strategies.

3. Results

3.1. Strategic Operational Maps for the Pilot Area

The outcomes of the described procedure are the strategic operational maps for the pilot area. During the design phase, the downscaling process of the RGI contents from the regional scale to the context of the study area was pivotal. In fact, several priority areas were identified by intersecting the RGI extent with the local landscape elements mentioned by the objectives in the matrix. In other cases, the RGI connection projects were classified according to their recreational or environmental primary purpose and added to the corresponding KT.

Three operational maps related to the major KT for the pilot area were produced. Their content frameworks are traceable by reading the Matrix of Planning Objectives.

Below, a combined representation of the operational maps is presented (Figure 5). A high resolution version of each map, including excerpts of a significant sub-area (municipality of Bormio in Alta Valtellina and its surroundings) and the legend of thematic objectives and priority areas, is available as Supplementary File S1.

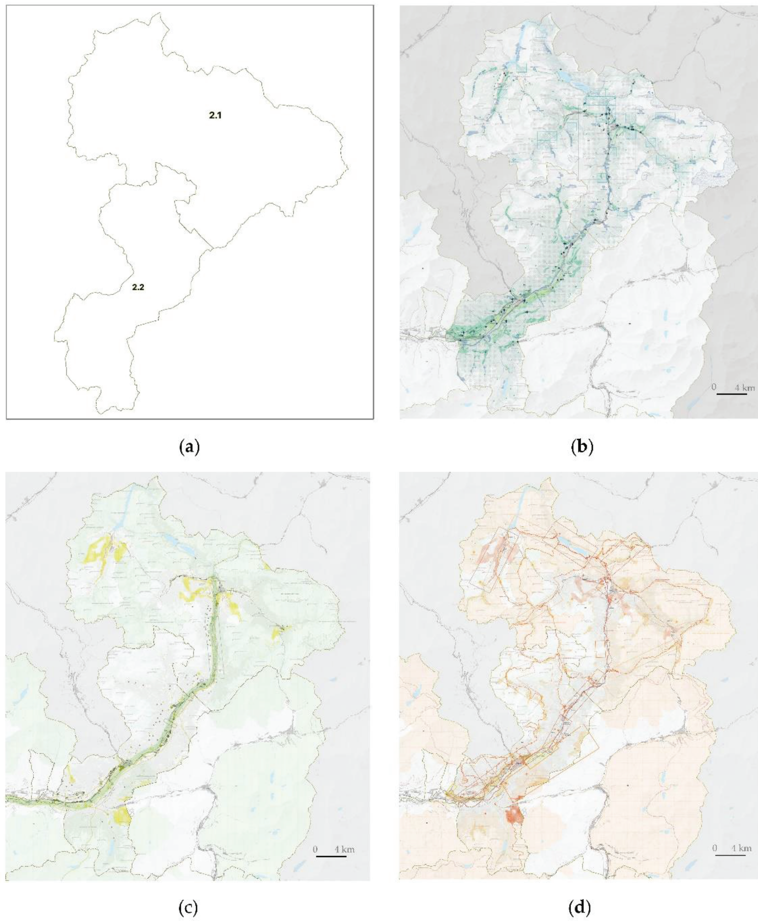

Figure 5. Combined representation of the strategic operational maps, with the location of strategic priority areas identified to achieve the RGI downscaling process: (**a**) Identification of involved GLU (2.1 Alta Valtellina; 2.2 Media Valtellina); (**b**) KT1: identity; (**c**) KT2: natural capital; (**d**) KT3: sustainable recreation. High resolution versions of each strategic operational map, with related legends, are available as Supplementary File S1. (Source: authors' elaboration.)

The layout and contents of each KT are described hereinafter.

3.1.1. KT1: Identity

The first strategic operational map (Figure 5b) is designed to set and locate strategies for preserving and enhancing the elements of the landscape that assume relevance in defining the identity of the pilot areas. Since this KT mostly recalls landscape preservation and protection actions, referring to the maintenance of both the physical and perceptive features of landscape structural elements, the thematic objectives included in KT1 are the following:

KT1a. To preserve unity and perceptions of hydrogeomorphological elements;
KT1b. To preserve landscape values of natural elements;
KT1c. To preserve constitutive features of the rural landscape;
KT1d. To preserve the features representing the identity of the anthropic landscape.

Within this KT, the RGI—particularly its rural component with a co-presence of high historical and cultural values—defines the priority areas for preserving and enhancing the historically valuable agricultural landscape.

Moreover, the features representing the identity of the anthropic landscape coincide with the historical and cultural components of the RGI. At the same time, the panoramic paths identified as primary connective elements of the RGI are selected as strategic viewpoint sources to determine the high-visibility mountain landscapes to be preserved.

3.1.2. KT2: Natural Capital

The second strategic operational map (Figure 5c) promotes environmental preservation and reinforcement of biodiversity, including strategies to cope with anthropic impacts.

The priority areas belonging to this KT can be synthesised into the following three main thematic units: the first one is the preservation of natural or rural areas provided with relevant ecological/environmental values; the second one includes hybrid peri-urban landscapes distinguished by suitable biodiversity hotspots and/or corridors; the last one focuses on detecting anthropic elements and activities producing high impacts and threats on nature and biodiversity. In that case, the actions aim at tackling, limiting and mitigating potential impacts for natural capital conservation. Hence, the thematic objectives defined for KT2 are the following:

KT2a. Promoting maintenance, reinforcement or reinstatement of ecological connectivity and high habitat quality;
KT2b. Promoting reorganisation and defragmentation of peri-urban landscapes tackling loss of biodiversity;
KT2c. Limiting, containing and mitigating impacts of anthropic activities.

The RGI is widely used to define priority areas related to these strategies; RGI reinforcement connections and new connection projects that are primarily meant to increase ecological values are represented as a component of the KT2a objectives. In KT2b, fragmented rural areas scattered along urban fringes are selected based on their inclusion in the RGI rural component and then classified via vocation according to the co-presence of natural and/or historical–cultural values. In KT2c, the priority areas to contain the impact of quarries are identified by selecting those that are surrounded by the RGI; likewise, industrial, commercial and accommodation facilities are identified as priority elements to activate mitigation strategies when their area is larger than 50,000 m^2 and they are next to the RGI. Lastly, buffer zones for the mitigation and landscape integration of projected new mobility infrastructures become a further priority area for containing anthropic impacts.

3.1.3. KT3: Sustainable Recreation

This operational map (Figure 5d) collects strategies to harmonise the promotion of leisure and recreational values of local landscapes with the preservation of ecological and social values, fostering soft mobility connections and enhancing the quality of food and agricultural supply chains. Since Media and Alta Valtellina highly rely on winter tourism, which has multiple effects on landscape and risks related to temperature and precipitation patterns, strategies for alternative tourism solutions were added. The thematic objectives for KT3 are the following:

KT3a. Promoting sustainable recreation in natural heritage through soft mobility networks and landscape connections;
KT3b. Supporting traditional and quality supply chains in farming, forestry and dairy products as multi-functional activities;
KT3c. Promoting and enhancing recreation in historical and cultural heritage;
KT3d. Exploring and promoting alternative tourism and recreation.

Within this KT, as in KT2, a selection of RGI reinforcement connections and new connection projects is represented; here, the RGI connections that are mainly related to recreation and soft mobility are a component of KT3a. Moreover, mountain pastures with a high recreation potential are identified by selecting pastures within the RGI extent, according to the sustainable recreation purposes of the RGI of Lombardy.

As stated in Section 2, in addition to the strategic operational maps, a table of strategies and criteria was implemented, including KTs and thematic objectives, strategic priority areas, spatial data sources, descriptions of spatial selection and representation criteria adopted, and local NBSs or other design solutions related to each priority area. The table is available as Supplementary File S2.

3.2. From GI to NBS: A Set of Actions for Local Implementation

As already introduced, one of the most significant challenges in downscaling GI is transitioning from general/specific objectives to site-specific planning recommendations. This process has the following two main obstacles: selecting the contents represented in the tables, whose edits are traceable in the Matrix of Planning Objectives, and the cartographic representation for implementing planning strategies through local spatial design actions.

Since GIs are planning tools that aim to deliver and increase ESs, one of the most effective strategies to fulfil their goals at a local scale and to operationalise that strategy is to adopt design solutions based on the use of natural elements and/or principles, i.e., NBSs. NBSs "are designed to address various environmental challenges in an efficient and adaptable manner, while simultaneously providing economic, social, and environmental benefits" [80,81]. So, NBSs are greening design actions that can contribute to developing GIs in urban areas [21].

In the pilot area, design solutions, including NBSs, were selected to implement the thematic objectives and the related actions and strategies identified by the three strategic operational maps. By considering each priority area, a selection of possible alternative design solutions were identified to specifically respond to its objective, defining a framework for future projects. The design process at the local level is therefore not rigorously defined in advance but will be developed, for instance, based on available financial resources and by considering local peculiarities. The set of actions is structured as an implementable tool that can support local planning and design processes in identifying possible operational solutions.

NBSs and other solutions are strictly related to the purposes of the thematic objectives on which they are based (e.g., risk management, natural/cultural heritage conservation, ecological/landscape reconnection) and to the landscape elements involved. Examples of suggested solutions include creating tree rows along the border of rural areas, increasing riparian vegetation to prevent runoff, preserving or defragmenting ecological passages threatened by land take process through natural buffer zones, enhancing peri-urban rural plots by creating allotments or public green spaces and improving the energy efficiency of industrial or commercial sites and accommodation facilities.

The complete list of actions linked to each priority area is available in the table of strategies and criteria (Supplementary File S2).

4. Discussion

4.1. Main Findings of the RGI Downscaling Process

As stated in the introduction, the methodological approach developed for the Media and Alta Valtellina pilot area aims to enhance the GI's role as a multi-scale and multi-functional strategic planning tool. In this frame, the RGI downscaling process meets different purposes.

Firstly, it promotes a more integrated approach to territorial planning by implementing cross-reading procedures within different plans or components of the same plan. Specifically referring to the case study, the RGI guidelines and GLU landscape quality objectives were intended to be used as a framework to guide the systematisation of the contents provided by several supra-local plans that were analysed. As a result, the structural landscape map combined with the Matrix of Planning Objectives represents an operational tool that is able to emphasise the correlations and possible integrations between the different levels of the planning system that affect the pilot area. At the same time, the structural landscape map provides a connection between the physical landscape elements to which the planning objectives relate and the spatial dimension of the RGI. Identifying possible correlations and synergies at different scales could contribute to implementing the RGI guidelines at the local scale, both from an operational and an institutional point of view.

Secondly, the RGI downscaling process allows us to spatialise the several planning objectives within the priority intervention areas identified at the local scale through a selective and site-specific approach. The methodology aims to overcome some critical issues of the downscaling approach by proposing a step-by-step workflow. The spatial and multi-functional dimensions of the RGI played a crucial role in the process, combined with the elaborations of the datasets related to the KT that inform the three strategic operational maps. On the one hand, the spatial structure of the RGI was considered a strategic tool aimed to localise and select the priority areas of intervention within homogeneous territorial contexts deriving from the analysis of the dataset. On the other hand, several combinations of RGI values were considered to determine site-specific actions and strategies within the priority areas. Furthermore, while each strategic operational map is selective in the representation according to the priorities of its respective key issue, some priority areas are included in multiple strategies because of their multi-functional value.

Finally, the proposed methodology allows for regional spatial and landscape strategies to be operationalised, integrating NBSs and other design solutions in the planning process, and providing an effective cross-scale approach. The RGI downscaling process moves from a regional strategic overview to defining local priorities and actions. The three KTs and the respective thematic objectives define a common framework that allows for the achievement of both a site-specific approach to identify possible actions to implement at the local scale and a replicable approach that can even be adopted for other GLUs. In general, the research outcomes introduce some innovative elements that can be applied even to other planning processes.

The relevance of our findings for policy makers and practitioners may be highlighted from at least three points of view.

Firstly, the Matrix of Planning Objectives sets a punctual correspondence between landscape systems and elements, and supra-local planning objectives. Thus, at a local scale, it can be used as a consultation tool to verify the coherence between the objectives set by supra-local plans and the objectives defined during the local planning process.

Secondly, the strategic operational maps and RGI downscaling process aim to set specific intervention areas and planning priorities, whose extent and related strategies may be confirmed, detailed or modified according to further analysis in support of local planning. In particular, downscaling the RGI to provide more site-specific indications and to intersect local land uses or strategic areas may support the local design of GIs to be implemented in local plans and, at the same time, preserve a broader spatial design continuity given by the supra-local scale.

Lastly, the variety of design solutions linked to each priority area is an important catalogue that allows for policy makers and practitioners to choose the most suitable solutions based on local spatial contexts and issues.

4.2. Replicability and Further Implementation

The described workflow is conceived to be replicable in each GLU of the Lombardy region and, in a more general way, in each planning tool that requires a synthesis of different strategies for their implementation by local authorities.

Within the Lombardy region, the three KTs identified for the pilot area can deal with issues and planning needs coming from remarkably different spatial units. In particular, comparisons with GLUs provided with different landscape structures and features show that most of the thematic objectives identified for Media and Alta Valtellina are also suitable for driving strategic interventions while maintaining their structure. More significant differences may be expected when it comes to the criteria for selecting and identifying strategic priority areas, which are more dependent on geographic context, land use change dynamics and socio-economical characteristics.

Within the Italian national context, the most recent regional landscape plans [82] show several elements that are in common with the LRP and some differences in the approach. For instance, the landscape plans drawn up by the Tuscany, Apulia, Piedmont and Friuli Venezia Giulia regions identified quality objectives related to strategic guidelines that can be referred to homogeneous landscape contexts through descriptive/guiding reports. Except for the Piedmont plan, the reports present thematic maps that are representative of specific issues that detail the analysis carried out by the plan for the regional territory at the scale of the landscape unit, generally proposing some synthetic maps of landscape criticalities and structural elements. On the other hand, only the Piedmont plan has developed a proper regional "Landscape Connection Network", comparable to the multifunctional Lombardy RGI, to identify the relationships between ecological, historical and cultural or recreational territorial components [83]. In contrast, the other plans mentioned above mainly consider them separately. Finally, the plans are composed of several regulative and strategic tools or guidelines with different purposes and objectives that need to be related.

In this framework, the methodological approach developed for the Media and Alta Valtellina pilot area appears to be replicable to enhance the contents of the mentioned landscape plans, to achieve the following different goals: (i) to promote a more integrated approach to territorial planning, implementing cross-reading and systematisation processes within different plans or different components of the same plan (e.g., the Friuli Venezia Giulia plan); (ii) to spatialise the quality objectives according to the main regional strategic priorities (e.g., the Piedmont plan); (iii) to prioritise areas of intervention at the local scale, detailing the quality objectives identified for the whole landscape unit (e.g., the Tuscany plan); (iv) to operationalise regional landscape strategies integrating NBSs and other design solutions in the planning process, providing an effective cross-scale approach (all the mentioned plans).

In addition, it may be noticed that the proposed approach is applicable both in Italian regions with the RTP and RLP as different plans, and in regions with a single regional territorial and landscape plan, since both frameworks are supposed to have one or more sets of planning-related objectives to survey and classify in the Matrix of Planning Objectives.

At the same time, possible implementations of the proposed methodology are not limited to regional landscape planning and can be extended both to other forms of spatial planning in the Italian context and to other European planning systems that adopt GI strategies.

With regard to contextualisation and comparisons at the European scale, firstly, we focus on the European national planning frameworks, reporting data from the ESPON Compass project [84]. The project set the goal of conducting an integrated study of planning frameworks in Europe and their changes since the year 2000. According to the final report, in 21 of the considered countries, there are three administrative levels responsible for planning; in nine states, there are two competence levels; in three states, including Italy, there are four levels, while only Portugal reaches five levels. The relationships between the types of planning tools and the administrative levels show a mainly strategic or framework-setting character at the national level, a mainly regulatory character at the local level and a substantial variability at the sub-national, supra-local level. Except for some small-sized countries, where national-level plans can interact directly with the local level, all countries have one or more intermediate-scale instruments, which relate to the local scale. Despite the diversity of the planning principles and practices, it can therefore be assumed in the first instance that our methodological approach can be replicated in other European states. The same report also highlights how the EU legislation and guidelines have had a growing influence in guiding the planning activities of member states in recent decades.

As for the GI policies, Slätmo et al. [42] state that as of 2017, 11 of the 32 European states considered in their study (EU members plus Iceland, Liechtenstein, Norway and Switzerland) had adopted or were adopting national policies for GI and, moreover, that the perceived scope of GI covers, in particular, the sectors of land use and spatial development planning, water management, agriculture, forestry and fisheries, climate change mitigation and adaptation, environmental protection and rural development.

Within this framework, the ES approach adopted to develop the Lombardy RGI appears to be widely integrated in spatial and landscape planning [28,85].

With respect to the integration of GIs at different scales in planning, especially landscape-oriented planning, the study conducted by Hersperger et al. [86] shows how landscape-related contents of strategic plans are frequently linked to the concept of a GI as an operational tool to enhance the landscape setting, to support the creation of "landscape corridors", to increase landscape structural functions and to facilitate recreational activities. This widespread orientation of supra-local planning tends to confirm the opportunities for a GI downscaling towards the local level, within a broader strategic framework.

Finally, we report two European case studies dealing with the relationship between ES mapping, supra-local planning levels and GI implementation.

The first one [30] concerns the Barcelona Metropolitan Region in Catalonia, Spain. The area is regulated by the General Territorial Plan of Catalonia, under whose guidelines the Territorial Metropolitan Plan of Barcelona was developed. The authors map the supply and demand of two ESs (outdoor recreation and air purification) at the metropolitan scale and compare their results with the preservation and enhancement strategies envisaged by the metropolitan plan; they highlight the mismatches between the analysis and current planning strategies suggesting, among other things, how the Barcelona Green Infrastructure and Biodiversity Plan approved by the City Council in 2020 may offer a relevant opportunity to improve outdoor recreation.

The second study [87] describes the uneven development process of the French Green and Blue Network policy, a GI project with mainly environmental purposes. The policy was developed by national regulations and guidelines but shall be applied through the interaction with regional and sub-regional administrative levels, up to the transposition of supra-local strategic guidelines into local requirements and regulations (the authors show, as a good practice, the case of the Local Urban Plan of the Le Cheylas municipality, Grenoble urban area, Auvergne-Rhône-Alpes).

The cited analyses and examples show how, although planning frameworks in the European context may display remarkable diversities, testing the backbone of our methodological approach appears to be feasible in most European countries.

4.3. Methodological Limitations

In this frame, the methodology developed for the Media and Alta Valtellina pilot area shows some possible limitations in replicability, partly depending on the availability of data and information. One issue is related to performing analogous spatial processing to identify akin priority areas because of differences in spatial data sources for selection. For example, identifying woodlands with high landscape values is the output of the classification adopted by the forestry management plan for Alta Valtellina. In other areas of Lombardy, forestry management plans may have different classification layouts, leading to the adoption of different selection parameters. Furthermore, strategic plans like an RTAP do not always cover all the regional extent; therefore, in GLUs that are not provided with an RTAP, its contribution in identifying objectives and priority areas should be replaced with other sources.

Another critical issue is the need to set an operational threshold in comparing and matching objectives derived from involved tools to create a common Matrix of Planning Objectives. In other words, not all the hierarchical subsets of the objectives of each plan can be considered to avoid their excessive proliferation when composing the matrix. However, when the objectives matrix is properly used as a guide to manage a further consultation of planning tools, their in-depth contents can be recovered and employed in the strategy definition stage.

Considering other national or international territorial contexts, the above-mentioned issues related to data sources and spatialisation processes may be even more relevant. It is important to notice that such a process is inevitably partly based on a combination of data sources and analysis related to specific landscapes or spatial units; nevertheless, the general framework of the procedure—which consists of the recognition of structural landscape elements, the synthesis of relevant supra-local planning tools, the identification of common objectives and the spatialisation of planning strategies—may be tested and possibly adopted in remarkably different spatial contexts, using adequate planning contents and proper local data sources for spatial processing.

Regarding the systematisation of planning objectives and their transposition into strategies and design solutions, it may be useful to note that a common path to guide similar processes in a European context may be, once again, the European Landscape Convention [55]; in fact, its Article 6 urges the parties to undertake the definition of landscape quality objectives for landscapes that are identified and assessed. Multi-scale landscape-oriented planning procedures are therefore able to consider such objectives, recognised within national planning frameworks, as a cornerstone upon which to build strategies.

4.4. Future Development and Perspectives

The workflow integrates tools designed at different scales within an intermediate supra-local geographic unit to support local administrators and planners in operationalising large-scale goals and objectives.

Once GLU-based strategic priority areas and design solutions are defined at the pilot area scale, surveys and checks should be conducted to test the aptness of the outcomes and, if needed, they should be modified. Given the extent of the pilot area, it was impossible to fulfil this further task during the research stages conducted so far; however, in a long-lasting perspective, this may be considered a future workflow development.

Then, to implement the research outcomes and integrate them into local planning strategies, they should be discussed and further developed through round tables involving local authorities and public participation forums open to citizens and stakeholders. Thus, strategies and actions defined during the research stage will be validated, modified or integrated considering local knowledge and requests. This fine-tuning phase should be incorporated into the overall downscaling procedure for each GLU, or other territorial units where the described workflow should be adopted.

In this context, regional administration would have a coordinating role, with the task of managing and balancing local requirements within a large-scale planning framework, thus fulfilling an actual multi-scale approach.

Regarding NBSs and other local design solutions, it would be useful to classify them from a replication perspective, concerning their suitability in different landscapes. For this purpose, a development of the pilot research should include a targeted replication in GLUs representing diverse landscapes; for Lombardy, in addition to alpine landscapes addressed in the pilot area, hilly landscapes, plain landscapes, river landscapes and highly urbanised landscapes should be considered. In this way, NBSs and local actions defined in the different pilot areas can be assembled and linked to landscape types to create a global catalogue of landscape-specific design solutions to be used as a source to choose the proper local actions for each geographic unit.

5. Conclusions

Starting from raising the awareness of existing gaps in operationalising a landscape-oriented GI within actual planning tools, our research aims at setting a pilot, replicable methodology to downscale a regional GI into a sub-regional landscape unit; to integrate GI principles and designs into a complex framework of supra-local planning strategies, thus obtaining a spatialised set of common strategies; and to further detail their implementation by adopting site-specific design solutions, including NBSs. Media and Alta Valtellina, a mountainous sub-region in Lombardy, Italy, was chosen as a test area because of its geographical and environmental relevance and was also stress tested for the use of the methodological framework in a multi-layered fragile spatial unit.

Our methodological approach consisted in identifying and mapping the main territorial and landscape elements of the pilot area; assessing existing supra-local planning tools to match their objectives with landscape structural elements; and in combining them into strategic operational maps, in which the regional GI serves as the main spatial filter, together with other spatial data sources, to identify strategic priority areas.

The results show that the pursued methodology can provide effective operative outcomes; moreover, unlike other experimentations where a GI is integrated into a single planning tool, the novelty of the approach lies in the downscaling process of a regional GI as a strategic key to simultaneously implement multiple wider planning strategies towards a local size.

The whole process is designed to be replicable in other comparable landscape units, but its methodological principles may also be adopted at wider or smaller scales. The main critical issues and limitations affecting replicability are the potential dissimilarities in the planning and territorial data sources to be employed in the spatialising strategies, due to differences in the sub-regional planning frameworks or in the spatial data organisation, and the need to summarise the contents of each planning tool involved in the process by extracting comparable sets of planning objectives to be combined into common strategies, thus reducing their complexity.

As for comparisons with the international context, replicability is partly dependent on national planning frameworks and involves the overall methodology rather than specific strategic outcomes; the planning approaches and case studies comparable to our effort can be found in the literature. Moreover, the growing influence of EU regulations and guidelines could help with the integration and standardization of planning frameworks and practices.

Future development perspectives include the use of local surveys to test the aptness of the identified strategic priority areas and to properly select specific design solutions as the final operational level of the process, and discussing the research outcomes through round tables and participation processes involving local authorities, citizens and stakeholders.

Finally, the inherent and more general value of the adopted methodology lies in the opportunity to organise the implementation of supra-local planning tools from an ES-based planning standpoint, ensuring ES provision by integrating multiple plans with a GI acting as a strategic spatial key.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su151511542/s1, Supplementary File S1: Strategic operational maps for the pilot area; Supplementary File S2: Table of strategies and criteria for the pilot area.

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References

1. Dorst, H.; van der Jagt, S.; Raven, R.; Runhaar, H. Urban Greening through Nature-Based Solutions—Key Characteristics of an Emerging Concept. *Sustain. Cities Soc.* **2019**, *49*, 101620. [CrossRef]
2. Albert, C.; Schröter, B.; Haase, D.; Brillinger, M.; Henze, J.; Herrmann, S.; Gottwald, S.; Guerrero, P.; Nicolas, C.; Matzdorf, B. Addressing Societal Challenges through Nature-Based Solutions: How Can Landscape Planning and Governance Research Contribute? *Landsc. Urban Plan.* **2019**, *182*, 12–21. [CrossRef]
3. Meerow, S.; Newell, J.P. Spatial Planning for Multifunctional Green Infrastructure: Growing Resilience in Detroit. *Landsc. Urban Plan.* **2017**, *159*, 62–75. [CrossRef]
4. Costanza, R.; D'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; et al. The Value of the World's Ecosystem Services and Natural Capital. *Nature* **1997**, *387*, 253–260.
5. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: A Framework for Assessment*; Island Press: Washington, DC, USA, 2003; ISBN 9780128096659.
6. European Commission. *Building a Green Infrastructure for Europe*; Publications Office of the European Union: Luxembourg, 2013; ISBN 9789279334283.
7. Benedict, M.A.; McMahon, E.T. Green Infrastructure: Smart Conservation for the 21st Century. *Renew. Resour. J.* **2001**, *20*, 12–17.
8. Hansen, R.; Pauleit, S. From Multifunctionality to Multiple Ecosystem Services? A Conceptual Framework for Multifunctionality in Green Infrastructure Planning for Urban Areas. *Ambio* **2014**, *43*, 516–529. [CrossRef]
9. Kambites, C.; Owen, S. Renewed Prospects for Green Infrastructure Planning in the UK. *Plan. Pract. Res.* **2006**, *21*, 483–496. [CrossRef]
10. Benedict, M.E.; Mcmahon, E.T. *Green Infrastructure. Linking Landscapes and Communities*; Island Press: Washington, DC, USA, 2006; ISBN 9781597267649.
11. Pauleit, S.; Liu, L.; Ahern, J.; Kazmierczak, A. Multifunctional Green Infrastructure Planning to Promote Ecological Services in the City. In *Urban Ecology: Patterns, Processes, and Applications*; Niemelä, J., Breuste, J.H., Elmqvist, T., Guntenspergen, G., James, P., McIntyre, N.E., Eds.; Oxford Scholarship Online: Oxford, UK, 2011; pp. 272–285.
12. Fisher, B.; Turner, R.K.; Morling, P. Defining and Classifying Ecosystem Services for Decision Making. *Ecol. Econ.* **2009**, *68*, 643–653. [CrossRef]
13. Langemeyer, J.; Gómez-Baggethun, E.; Haase, D.; Scheuer, S.; Elmqvist, T. Bridging the Gap between Ecosystem Service Assessments and Land-Use Planning through Multi-Criteria Decision Analysis (MCDA). *Environ. Sci. Policy* **2016**, *62*, 45–56. [CrossRef]
14. Ersoy Mirici, M. The Ecosystem Services and Green Infrastructure: A Systematic Review and the Gap of Economic Valuation. *Sustainability* **2022**, *14*, 517. [CrossRef]
15. European Commission. *Mapping and Assessment of Ecosystems and Their Services. Urban Ecosystems 4th Report*; Office for Official Publications of the European Communities: Luxembourg, 2016; ISBN 9789279361616.
16. Arcidiacono, A.; Ronchi, S.; Salata, S. Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. *Procedia Eng.* **2016**, *161*, 2297–2303.
17. Cortinovis, C.; Geneletti, D. Mapping and Assessing Ecosystem Services to Support Urban Planning: A Case Study on Brownfield Regeneration in Trento, Italy. *One Ecosyst.* **2018**, *3*, e25477. [CrossRef]
18. Maes, J.; Zulian, G.; Günther, S.; Thijssen, M.; Reynal, J. *Enhancing Resilience of Urban Ecosystems through Green Infrastructure (EnRoute) Final Report*; Publications Office of the European Union: Luxembourg, 2019; ISBN 978-92-79-98984-1.
19. Van Oijstaeijen, W.; Van Passel, S.; Cools, J. Urban Green Infrastructure: A Review on Valuation Toolkits from an Urban Planning Perspective. *J. Environ. Manag.* **2020**, *267*, 110603. [CrossRef]
20. Gómez-Baggethun, E.; Barton, D.N. Classifying and Valuing Ecosystem Services for Urban Planning. *Ecol. Econ.* **2013**, *86*, 235–245. [CrossRef]
21. Ronchi, S.; Arcidiacono, A.; Pogliani, L. Integrating Green Infrastructure into Spatial Planning Regulations to Improve the Performance of Urban Ecosystems. Insights from an Italian Case Study. *Sustain. Cities Soc.* **2020**, *53*, 101907. [CrossRef]
22. European Commission. *EU Biodiversity Strategy for 2030: Bringing Nature Back into Our Lives. COM(2020) 380 Final*; European Commission: Brussels, Belgium, 2020.
23. Zulian, G.; Ronchi, S.; La Notte, A.; Vallecillo, S.; Maes, J. Adopting a Cross-Scale Approach for the Deployment of a Green Infrastructure. *One Ecosyst.* **2021**, *6*, 1–29.

24. Hermoso, V.; Carvalho, S.B.; Giakoumi, S.; Goldsborough, D.; Katsanevakis, S.; Leontiou, S.; Markantonatou, V.; Rumes, B.; Vogiatzakis, I.N.; Yates, K.L. The EU Biodiversity Strategy for 2030: Opportunities and Challenges on the Path towards Biodiversity Recovery. *Environ. Sci. Policy* **2022**, *127*, 263–271. [CrossRef]
25. Cortinovis, C.; Geneletti, D. Ecosystem Services in Urban Plans: What Is There, and What Is Still Needed for Better Decisions. *Land Use Policy* **2018**, *70*, 298–312. [CrossRef]
26. Cortinovis, C.; Geneletti, D. A Framework to Explore the Effects of Urban Planning Decisions on Regulating Ecosystem Services in Cities. *Ecosyst. Serv.* **2019**, *38*, 100946. [CrossRef]
27. Di Marino, M.; Tiitu, M.; Lapintie, K.; Viinikka, A.; Kopperoinen, L. Integrating Green Infrastructure and Ecosystem Services in Land Use Planning. Results from Two Finnish Case Studies. *Land Use Policy* **2019**, *82*, 643–656. [CrossRef]
28. de Groot, R.; Alkemade, R.; Braat, L.; Hein, L.; Willemen, L. Challenges in Integrating the Concept of Ecosystem Services and Values in Landscape Planning, Management and Decision Making. *Ecol. Complex.* **2010**, *7*, 260–272. [CrossRef]
29. Mascarenhas, A.; Ramos, T.B.; Haase, D.; Santos, R. Ecosystem Services in Spatial Planning and Strategic Environmental Assessment-A European and Portuguese Profile. *Land Use Policy* **2015**, *48*, 158–169. [CrossRef]
30. Baró, F.; Palomo, I.; Zulian, G.; Vizcaino, P.; Haase, D.; Gómez-Baggethun, E. Mapping Ecosystem Service Capacity, Flow and Demand for Landscape and Urban Planning: A Case Study in the Barcelona Metropolitan Region. *Land Use Policy* **2016**, *57*, 405–417. [CrossRef]
31. Grêt-Regamey, A.; Altwegg, J.; Sirén, E.A.; van Strien, M.J.; Weibel, B. Integrating Ecosystem Services into Spatial Planning—A Spatial Decision Support Tool. *Landsc. Urban Plan.* **2017**, *165*, 206–219. [CrossRef]
32. Seiwert, A.; Rößler, S. Understanding the Term Green Infrastructure: Origins, Rationales, Semantic Content and Purposes as Well as Its Relevance for Application in Spatial Planning. *Land Use Policy* **2020**, *97*, 104785. [CrossRef]
33. Grădinaru, S.R.; Hersperger, A.M. Green Infrastructure in Strategic Spatial Plans: Evidence from European Urban Regions. *Urban For. Urban Green.* **2019**, *40*, 17–28. [CrossRef]
34. Lafortezza, R.; Davies, C.; Sanesi, G.; Konijnendijk, C.C.C. Green Infrastructure as a Tool to Support Spatial Planning in European Urban Regions. *iForest-Biogeosci. For.* **2013**, *6*, 102–108. [CrossRef]
35. Scholes, R.; Reyers, B.; Biggs, R.; Spierenburg, M.; Duriappah, A. Multi-Scale and Cross-Scale Assessments of Social–Ecological Systems and Their Ecosystem Services. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 16–25. [CrossRef]
36. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Green Infrastructure (GI)—Enhancing Europe's Natural Capital {SWD(2013) 155 Final}*; European Commission: Bruxelles, Belgium, 2013; Volume 51.
37. European Commission. *Review of Progress on Implementation of the EU Green Infrastructure Strategy. COM(2019) 236 Final*; European Commission: Brussels, Belgium, 2019.
38. European Commission. *The European Green Deal. COM(2019) 640 Final*; European Commission: Bruxelles, Belgium, 2019.
39. Ronchi, S. *Ecosystem Services for Spatial Planning. Innovative Approaches and Challenges for Practical Applications*; Green Ener; Springer: Cham, Switzerland, 2018; ISBN 9783319901848.
40. Kopperoinen, L.; Itkonen, P.; Niemelä, J. Using Expert Knowledge in Combining Green Infrastructure and Ecosystem Services in Land Use Planning: An Insight into a New Place-Based Methodology. *Landsc. Ecol.* **2014**, *29*, 1361–1375. [CrossRef]
41. Staccione, A.; Candiago, S.; Mysiak, J. Mapping a Green Infrastructure Network: A Framework for Spatial Connectivity Applied in Northern Italy. *Environ. Sci. Policy* **2022**, *131*, 57–67. [CrossRef]
42. Slätmo, E.; Nilsson, K.; Turunen, E. Implementing Green Infrastructure in Spatial Planning in Europe. *Land* **2019**, *8*, 62. [CrossRef]
43. Donati, G.F.A.; Bolliger, J.; Psomas, A.; Maurer, M.; Bach, P.M. Reconciling Cities with Nature: Identifying Local Blue-Green Infrastructure Interventions for Regional Biodiversity Enhancement. *J. Environ. Manag.* **2022**, *316*, 115254. [CrossRef]
44. Isola, F.; Lai, S.; Leone, F.; Zoppi, C. Strengthening a Regional Green Infrastructure through Improved Multifunctionality and Connectedness: Policy Suggestions from Sardinia, Italy. *Sustainability* **2022**, *14*, 9788. [CrossRef]
45. Herreros-Cantis, P.; McPhearson, T. Mapping Supply of and Demand for Ecosystem Services to Assess Environmental Justice in New York City. *Ecol. Appl.* **2021**, *31*, e02390. [CrossRef]
46. Kremer, P.; Hamstead, Z.A.; McPhearson, T. The Value of Urban Ecosystem Services in New York City: A Spatially Explicit Multicriteria Analysis of Landscape Scale Valuation Scenarios. *Environ. Sci. Policy* **2015**, *62*, 57–68. [CrossRef]
47. Salata, S.; Özkavaf-Şenalp, S.; Velibeyoğlu, K. Integrating Ecosystem Vulnerability in the Environmental Regulation Plan of Izmir (Turkey)—What Are the Limits and Potentialities? *Urban Sci.* **2022**, *6*, 19. [CrossRef]
48. Pauleit, S.; Ambrose-Oji, B.; Andersson, E.; Anton, B.; Buijs, A.; Haase, D.; Elands, B.; Hansen, R.; Kowarik, I.; Kronenberg, J.; et al. Advancing Urban Green Infrastructure in Europe: Outcomes and Reflections from the GREEN SURGE Project. *Urban For. Urban Green.* **2019**, *40*, 4–16. [CrossRef]
49. Minoia, P.; Zanetto, G. An Assessment of the Principle of Subsidiarity in Urban Planning to Face Climate Change The Case of Martellago, Venice Province. *Int. J. Clim. Chang. Strateg. Manag.* **2009**, *1*, 63–74. [CrossRef]
50. Cattivelli, V. Land Use Policy Planning Peri-Urban Areas at Regional Level: The Experience of Lombardy. *Land Use Policy* **2021**, *103*, 105282. [CrossRef]
51. Lennon, M.; Scott, M. Delivering Ecosystems Services via Spatial Planning: Reviewing the Possibilities and Implications of a Green Infrastructure Approach. *Town Plan. Rev.* **2014**, *85*, 563–587. [CrossRef]

52. Demuzere, M.; Orru, K.; Heidrich, O.; Olazabal, E.; Geneletti, D.; Orru, H.; Bhave, A.G.; Mittal, N.; Feliu, E.; Faehnle, M. Mitigating and Adapting to Climate Change: Multi-Functional and Multi-Scale Assessment of Green Urban Infrastructure. *J. Environ. Manag.* **2014**, *146*, 107–115. [CrossRef]
53. Arthur, N.; Hack, J. A Multiple Scale, Function, and Type Approach to Determine and Improve Green Infrastructure of Urban Watersheds. *Urban For. Urban Green.* **2022**, *68*, 127459. [CrossRef]
54. Zardo, L.; Geneletti, D.; Pérez-Soba, M.; Van Eupen, M. Estimating the Cooling Capacity of Green Infrastructures to Support Urban Planning. *Ecosyst. Serv.* **2017**, *26*, 225–235. [CrossRef]
55. Council of Europe. *European Landscape Convention*; Council of Europe Publishing Division: Strasbourg, France, 2000; Available online: https://rm.coe.int/16807b6bc7 (accessed on 13 July 2023).
56. Arcidiacono, A.; Ronchi, S. *Ecosystem Services and Green Infrastructure. Perspectives from Spatial Planning in Italy*; Springer International Publishing: Berlin/Heidelberg, Germany, 2020; ISBN 9783030543440.
57. Agnoletti, M.; Santoro, A. The Lombard Forest Landscape. A Historical Summary. In *Land Cover Changes in Lombardy over the Last 50 Years*; ERSAF Regione Lombardia: Milan, Italy, 2012; pp. 131–156.
58. Oppio, A.; Corsi, S.; Mattia, S.; Tosini, A. Exploring the Relationship among Local Conflicts and Territorial Vulnerability: The Case Study of Lombardy Region. *Land Use Policy* **2015**, *43*, 239–247. [CrossRef]
59. Schirpke, U.; Leitinger, G.; Tasser, E.; Schermer, M.; Steinbacher, M.; Tappeiner, U. Multiple Ecosystem Services of a Changing Alpine Landscape: Past, Present and Future. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2013**, *9*, 123–135. [CrossRef]
60. Campagnaro, T.; Frate, L.; Carranza, M.L.; Sitzia, T. Multi-Scale Analysis of Alpine Landscapes with Different Intensities of Abandonment Reveals Similar Spatial Pattern Changes: Implications for Habitat Conservation. *Ecol. Indic.* **2017**, *74*, 147–159. [CrossRef]
61. Jiménez-Olivencia, Y.; Ibáñez-Jiménez, Á.; Porcel-Rodríguez, L.; Zimmerer, K. Land Use Change Dynamics in Euro-Mediterranean Mountain Regions: Driving Forces and Consequences for the Landscape. *Land Use Policy* **2021**, *109*, 105721. [CrossRef]
62. Bazzanella, F.; Bichler, B.F.; Schnitzer, M. Collaboration and Meta-Organisation in Event Tourism—Effects of the Olympic Agenda 2020 on Planning the 2026 Winter Olympics. *Tour. Manag. Perspect.* **2022**, *41*, 100939. [CrossRef]
63. Chappelet, J.-L. Olympic Environmental Concerns as a Legacy of the Winter Games. *Int. J. Hist. Sport* **2008**, *25*, 1884–1902. [CrossRef]
64. Song, S.; Zhang, S.; Wang, T.; Meng, J.; Zhou, Y.; Zhang, H. Balancing Conservation and Development in Winter Olympic Construction: Evidence from a Multi-Scale Ecological Suitability Assessment. *Sci. Rep.* **2018**, *8*, 14083. [CrossRef]
65. Zhang, H.; Yu, Y.; Zha, T.; Rodrigo-Comino, J. Assessing Previous Land-Vegetation Productivity Relationships on Mountainous Areas Hosting Coming Winter Olympics Games in 2022. *Sci. Total Environ.* **2021**, *788*, 147870. [CrossRef] [PubMed]
66. Stobbelaar, D.J.; Pedroli, B. Perspectives on Landscape Identity: A Conceptual Challenge Perspectives on Landscape Identity: A Conceptual Challenge. *Landsc. Res.* **2011**, *36*, 321–339. [CrossRef]
67. Kaligarič, M.; Ivajnšič, D. Vanishing Landscape of the "Classic" Karst: Changed Landscape Identity and Projections for the Future. *Landsc. Urban Plan.* **2014**, *132*, 148–158. [CrossRef]
68. Costanza, R.; Daly, H.E. Natural Capital and Sustainable Development. *Conserv. Biol.* **1992**, *6*, 37–46.
69. Vardon, M.; Bass, S. (Eds.) Natural Capital Accounting for Better Policy Decisions: Measuring and Valuing Natural Capital to Improve Landscape Management and Governance. In Proceedings of the 4th Forum on Natural Capital Accounting for Better Policy Decisions, Kampala, Uganda, 18–19 November 2019.
70. Blaschke, T. The Role of the Spatial Dimension within the Framework of Sustainable Landscapes and Natural Capital. *Landsc. Urban Plan.* **2006**, *75*, 198–226. [CrossRef]
71. Kulczyk, S.; Woźniak, E.; Derek, M. Landscape, Facilities and Visitors: An Integrated Model of Recreational Ecosystem Services. *Ecosyst. Serv.* **2018**, *31*, 491–501. [CrossRef]
72. De Valck, J.; Landuyt, D.; Broekx, S.; Liekens, I.; De Nocker, L.; Vranken, L. Outdoor Recreation in Various Landscapes: Which Site Characteristics Really Matter? *Land Use Policy* **2017**, *65*, 186–197. [CrossRef]
73. Nelson, E.; Ennaanay, D.; Wolny, S.; Olwero, N.; Pennington, D.; Mendoza, G.; Aukema, J.; Foster, J.; Forrest, J.; Cameron, D.; et al. *InVEST 2.0 Beta User's Guide: Integrated Valuation of Ecosystem Services and Tradeoffs*; Woods Institute for the Environment, Stanford University: California, CA, USA, 2011; Available online: http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/ (accessed on 13 July 2023).
74. Keeler, B.L.; Wood, S.A.; Polasky, S.; Kling, C.; Filstrup, C.T.; Downing, J.A. Recreational Demand for Clean Water: Evidence from Geotagged Photographs by Visitors to Lakes. *Front. Ecol. Environ.* **2015**, *13*, 76–81. [CrossRef]
75. North, M.A.; College, J. A Method for Implementing a Statistically Significant Number of Data Classes in the Jenks Algorithm. In Proceedings of the 2009 Sixth International Conference on Fuzzy Systems and Knowledge Discovery, Tianjin, China, 14–16 August 2009; Volume 1, pp. 35–38. [CrossRef]
76. Steiger, R.; Scott, D.; Abegg, B.; Pons, M.; Aall, C. A Critical Review of Climate Change Risk for Ski Tourism. *Curr. Issues Tour.* **2019**, *22*, 1343–1379. [CrossRef]
77. Vorkauf, M.; Steiger, R.; Abegg, B.; Hiltbrunner, E. Snowmaking in a Warmer Climate: An in-Depth Analysis of Future Water Demands for the Ski Resort Andermatt-Sedrun-Disentis (Switzerland) in the Twenty-First Century. *Int. J. Biometeorol.* **2022**. [CrossRef] [PubMed]

78. Abegg, B.; Agrawala, C.; Crick, F.; de Montfalcon, A. *Climate Change in the European Alps*; Agrawala, S., Ed.; OECD: Paris, France, 2006; ISBN 9264031685.
79. Batista e Silva, F.; Marín Herrera, M.A.; Rosina, K.; Ribeiro Barranco, R.; Freire, S.; Schiavina, M. Analysing Spatiotemporal Patterns of Tourism in Europe at High-Resolution with Conventional and Big Data Sources. *Tour. Manag.* **2018**, *68*, 101–115. [CrossRef]
80. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank "A Framework Strategy for a Resilient Energy Union with a Forward-Looking*; European Commission: Bruxelles, Belgium, 2015.
81. Maes, J.; Jacobs, S. Nature-Based Solutions for Europe's Sustainable Development. *Conserv. Lett.* **2017**, *10*, 121–124. [CrossRef]
82. Colavitti, A.M.; Serra, S. Regional Landscape Planning and Local Planning. Insights from the Italian Context. *J. Settl. Spat. Plan.* **2021**, *2021*, 81–91. [CrossRef]
83. Argenziano, M.; Deffacis, J.; Gamalero, B.; Paludi, G. La Struttura. *Atti Rass. Tec. Soc. Ing. Archit. Torino* **2018**, *3*, 27–33.
84. Nadin, V.; Fernández, M.; Maldonado, A.; Zonneveld, W.; Stead, D.; Dąbrowski, M.; Piskorek, K.; Sarkar, A.; Schmitt, P.; Smas, L.; et al. *COMPASS Final Report*; ESPON & TU Delft: Luxembourg, 2018; ISBN 978-99959-55-55-7.
85. Galler, C.; Albert, C.; von Haaren, C. From Regional Environmental Planning to Implementation: Paths and Challenges of Integrating Ecosystem Services. *Ecosyst. Serv.* **2016**, *18*, 118–129. [CrossRef]
86. Hersperger, A.M.; Bürgi, M.; Wende, W.; Bacău, S.; Grădinaru, S.R. Does Landscape Play a Role in Strategic Spatial Planning of European Urban Regions? *Landsc. Urban Plan.* **2020**, *194*, 103702. [CrossRef]
87. Perrin, M.; Bertrand, N.; Vanpeene, S. Ecological Connectivity in Spatial Planning: From the EU Framework to Its Territorial Implementation in the French Context. *Environ. Sci. Policy* **2022**, *129*, 118–125. [CrossRef]

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Strengthening a Regional Green Infrastructure through Improved Multifunctionality and Connectedness: Policy Suggestions from Sardinia, Italy

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Abstract: A wide body of research in recent years has studied either green infrastructures as providers of multiple ecosystem services, especially at the urban level, or ecological corridors and the issue of connectivity between landscape patches in the face of growing fragmentation. However, not many studies have analyzed how the two concepts can be combined to ground evidence-based policy and planning recommendations. In this study, a methodological approach for such a combination is proposed: after mapping a regional green infrastructure building upon the assessment of multiple ecosystem services and a network of ecological corridors through the resistance to movement of species, the two spatial layouts are combined so as to analyze correlations between the potential provision of ecosystem services and the resistance to movement. The methodology is applied in the case of the island of Sardinia, whose self-containment makes it possible to discard potential effects from surrounding areas, hence facilitating the implementation of the model. The outcomes of the regression model point out three ecosystem services as the most important factors that should be targeted by appropriate spatial policies if connectivity is to be increased: regulation of micro and local climate, forestry productivity, and cultural identity and heritage values.

Keywords: ecological corridors; green infrastructure; ecosystem services; spatial planning; environmental planning; Sardinia

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1. Introduction

Two common and recurring themes that encompass different definitions of Green Infrastructures (GIs) are multifunctionality and connectedness [1,2]. The European Commission [3] has, for almost a decade, promoted GIs as networks of green spaces that are simultaneously multifunctional because they deliver multiple functions that result in the provision of goods and services to people and are interconnected, meaning that smaller and larger patches are interlinked within a single, planned, and managed system that comprises natural, semi-natural, or even artificial green areas.

Within the planning domain and literature [4–6], GIs are considered a means for simultaneously delivering, in an integrated way, several policy objectives. This entails that a wide range of different goals are pursued, particularly as far as urban settlements are concerned [7], where environmental goals can clash with social and economic ones. Such different and sometimes contrasting objectives are delivered through the functions performed by GIs; these, in turn, translate into the supply of multiple ecosystem services (ESs) [8], although the semantic ambiguity of the term "function", which takes different meanings in the ES lexicon and in the GI lexicon, can lead to imprecision or even confusion [9].

A typical characteristic of GIs is, therefore, multifunctionality, here considered as the landscape's capacity to provide, through properly functioning ecosystems, a number of benefits that are sought after and valued by human beings; that is, a number of ESs [10,11], notwithstanding the fact that at the very local level, and especially in urban areas, the conception, design, and implementation of GIs is usually monofunctional [12,13], for instance, driven by the need to regulate floods or to mitigate the heat island effect. For them to be an effective planning tool to improve sustainability, resilience, and wellbeing within a landscape or even within urban spaces, GIs must, therefore, be properly designed, planned, and managed with a view to multifunctionality. This entails operationalizing the ES approach in spatial planning and moving away from traditional planning and mindsets that pursue monofunctionality, for instance, through zoning schemes and segregated land-use allocations [1,8].

The second outstanding feature, connectivity, points to the concept of ecological corridors (ECs). As a matter of fact, GIs can be conceived of as a system of core areas or nodes, i.e., the most significant areas in terms of the potential supply of ESs, which are interlinked through branches, i.e., through ECs, hence allowing for the movement of species and for fostering spontaneous biological exchanges across core areas. The effectiveness of ECs in improving the operational capacity of GIs is based on decreasing the effects on biological and species flows generated by forestry and agricultural production, urbanization and related infrastructure, and pollutant emissions to air and water, whose degradation or even depletion of natural ecosystems result in negative impacts on ECs and, in turn, on GIs [14].

However, some landscape elements can prevent ECs from effectively contributing to supporting biological flows and exchanges within a GI. The most prominent are physical obstacles, be they natural (such as water courses, which can act as barriers to movement for some species) or human-made (such as boundary walls or roads, railroads, and linear infrastructure in general); also worthy of note is the presence or absence of areas that provide key contributions to support species' life cycles, such as suitable habitats and nourishment [14–16]. Therefore, the absence of such physical obstacles is a prerequisite for putting GI's potential to good use, as ensuring connectivity through ECs is key to allowing for species' movement along suitable linear branches that connect core areas within a GI [17].

According to the European Commission, a GI is identified as a spatial network that provides a set of ESs since a GI is "[A] strategically planned network of natural and semi–natural areas with other environmental features designed and managed to deliver a wide range of ESs. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings" [3] p. 3, and "The work done over the last 25 years to establish and consolidate the network means that the backbone of the EU's GI is already in place. It is a reservoir of biodiversity that can be drawn upon to repopulate and revitalize degraded environments and catalyze the development of GI. This will also help reduce the fragmentation of the ecosystems, improving the connectivity between sites in the Natura 2000 network and thus achieving the objectives of Article 10 of the Habitats Directive" [3] p. 7. This entails that planning policies aimed at increasing and enhancing the provision of services supplied by nature and natural resources should target GIs as networks providing a large set of ESs while protecting their environmental features [2].

The operational definition by the European Commission entails that GIs are relevant systems with reference to conservation and the improvement of biodiversity, increase in ecosystem continuity, and the enhancement of ESs provision [18].

It also implies that the increase in the supply of ESs, and the conservation and enhancement of biodiversity, must be prioritized as management objectives for the implementation of GIs [2,19].

In this study, we regard GIs as both providers of ESs and networks of core areas interconnected through ECs, and we contribute to the current academic debates on the relationship between ES supply and connectivity [20,21], not only by quantitatively investigating such relationship but also by identifying evidence-based policy recommendations aimed at strengthening its significance. The second section provides the reader with some background information on the study area, as well as on methodological approaches that can be used to map an RGI based on patches' suitability both to simultaneously provide several ESs and to belong to linear ECs that connect core areas. In the third section, the results from the implementation of the models in the study area are presented: by overlaying the spatial configuration of ECs upon the map of potential provision of ESs, a regression model is implemented to analyze correlations between the two key characteristics of the GI. Next, the fourth section discusses, in light of the current literature, some highlights from the regression model, which concern those ESs that contribute the most to increasing an area's suitability to belong to an EC. Finally, the fifth and concluding section provides suggestions for policymakers and planning practitioners, with a view to improving the environmental characteristics of an RGI in order to enhance its capacity to supply ESs; moreover, the exportability of the adopted methodological approaches to other Italian and European Union (EU) regional contexts is also discussed.

2. Materials and Methods

2.1. Study Area

Sardinia is a Mediterranean island with a land mass of about twenty-four thousand square kilometers and a coastline of approximately 1850 km; from an administrative point of view, it is an autonomous region with a population of nearly 1.6 million residents. Because it is an island, its GI can be regarded as self-contained and not affected by factors concerning proximal or contiguous areas; therefore, it constitutes an ideal context to investigate a regional GI (RGI) and its characteristics in terms of both provision of ESs and layout of terrestrial ECs.

A GI is here regarded as a network whose branches are linear ECs that enable connectivity among core areas. In Sardinia, core areas are taken as those that are protected under national or regional laws (Protected Areas, henceforth PAs) for their natural characteristics, and that can be listed as follows (Figure 1), following Lai et al. [22].

- The four natural regional parks established under the provisions of Regional Law no. 31/1989.
- Public woods managed by the Regional Agency for Forests and the "permanent oases of faunal protection", identified by Regional Law no. 23/1998, whose maps are available from the Geoportal of the Autonomous Region of Sardinia [23].
- The Ramsar sites designated by the Ramsar Convention, signed in 1971; nine Sardinian Ramsar sites have been established since 1977.
- The Natura 2000 sites, broadly classed into two groups: Sites of Community Interest (SCIs) and Special Areas of Conservation (SACs), designated under the Habitats Directive [24], and Special Protection Areas (SPAs), designated under the Birds Directive [25]; in Sardinia 128 sites have been established under the provisions of such Directives: 31 SPAs, 97 SCIs, and 10 that have been designated both as SPAs and as SCIs; 84 former SCIs have recently been designated as SACs [26].

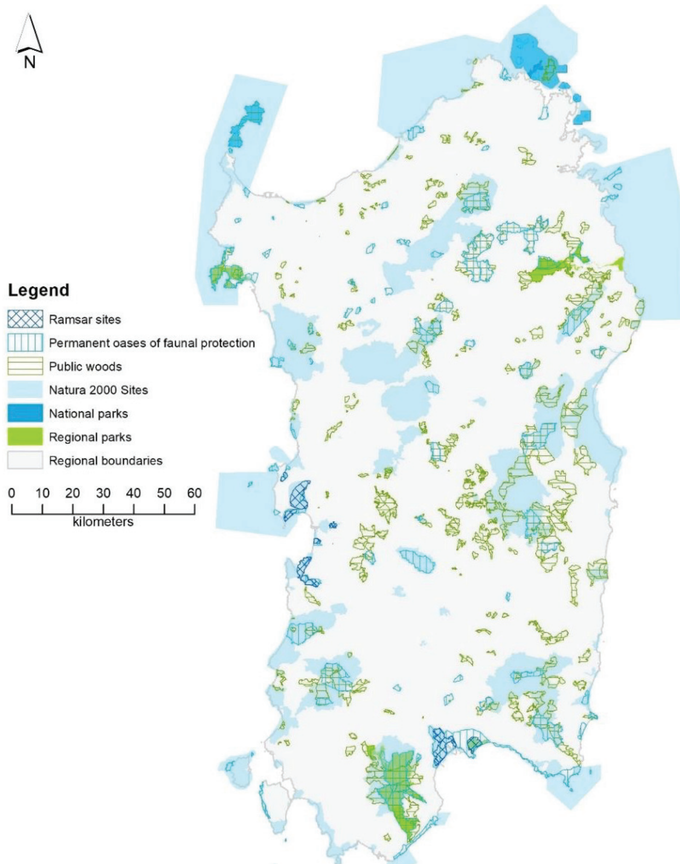

Figure 1. Map of the Sardinian natural protected areas (PAs).

2.2. Data

Seven ESs were selected to spatially assess multifunctionality, i.e., the potential and simultaneous delivery of a number of ESs. The choice of which ESs was to be included was made in such a way to comprise at least one ES for each of the three sections identified within the hierarchical taxonomy offered by the Common International Classification of Ecosystem Services (CICES) [27], as follows.

1. Regulating and maintenance section, "Regulation of physical, chemical, biological conditions" division.
    - Preserving levels of habitat quality that are suitable to support the life cycles of wild plants and animals that can be useful to people (HAB_QUAL), within the class "Maintaining nursery populations and habitats (Including gene pool protection)", group "Lifecycle maintenance, habitat and gene pool protection".
    - Micro and regional climate regulation through the mitigation of land surface temperature (REG_LST), within the class "Regulation of temperature and humidity, including ventilation and transpiration", group "Atmospheric composition and conditions". Carbon sequestration and storage in soils and vegetation (CARB_SEQ), within the class "Regulation of chemical composition of atmosphere and oceans", group "Atmospheric composition and conditions".
2. Provisioning section, "Biomass" division.

- Value of agricultural and forest land, taken as a proxy for agricultural crop production and harvested wood (CROP_WOOD), encompassing three classes ("Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes", "Fibers and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)", "Cultivated plants (including fungi, algae) grown as a source of energy") within the group "Cultivated terrestrial plants for nutrition, materials or energy".

3. Cultural section.
    - Endangered species or habitats and areas that are relevant for conservation purposes (CONSERV), within the class "Characteristics or features of living systems that have an existence, option or bequest value" class, "Other biotic characteristics that have a non-use value" group, "Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting" division.
    - Ecosystems' capacity to support nature-based recreation (RECREAT), within the class "Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions", "Physical and experiential interactions with natural environment", "Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting" division.
    - Landscape features that support local identity, cultural heritage, and tourism (CULT_HER), within the class "Characteristics of living systems that are resonant in terms of culture or heritage", group "Intellectual and representative interactions with natural environment", "Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting" division.

2.3. Methodological Approach

This section presents, in three subsections, the steps of the methodological approach. The first subsection is devoted to the analysis and mapping of the seven chosen ESs, on whose basis the multifunctionality of the RGI is assessed. The second subsection presents an approach that relies upon resistance maps to spatially identify the layout of ECs. For both of the first two subsections, the reader can refer to Isola et al. [28], chapters 2 and 3, respectively, for more details on the methodological approaches implemented to model the ESs and the ECs. Finally, the third subsection explains how the regression model was used here to unveil correlations between the RGI and the ECs was implemented.

A graphic representation of the methodological approach adopted in this study is provided in Figure 2.

2.3.1. Assessing GI's Multifunctionality

For each selected ES, Table 1 lists the variable abbreviation and provides an overview of input data requirements, data sources, and available tools or conceptual models. An off-the-shelf set of tools developed by the Natural Capital Project is InVEST [29], which makes it possible to map both HAB_QUAL and CARB_SEQ by means of two tools, termed "Habitat quality" and "Carbon Storage and Sequestration". Another ready-to-use tool used to assess REG_LST is a QGIS plugin [30] that makes it possible to map land surface temperature by using free and worldwide available satellite imagery as the only input data. A conceptual model to be tailored to the scope, aim, and scale of the assessment is ESTIMAP [31,32], one of whose outputs provides the spatial layout of areas showing different levels of potential suitability for nature-based recreation and is used here to map RECREAT. Concerning the other three ESs, the approach developed by Lai and Leone [33] was implemented to map both CONSERV and CULT_HER: as for CONSERV, its spatial assessment is grounded on qualitative and quantitative data concerning the Natura 2000 Sardinian network contained within the Standard Data Forms, i.e., on descriptive forms that are compulsory and standardized across the European Union [34] and within a monitoring report commissioned by the Sardinian Regional Government; as for CULT_HER, its assessment relies on the spatial dataset of landscape features protected under the Regional Landscape Plan (RLP) and on a qualitative score that reflects the protection level to which each feature is subject, under the assumption that the stricter planning provisions and restrictions correlate with higher supply of this ES. Finally, in the absence of detailed regional data (either biomass or market values) on agricultural crops and harvested wood production, CROP_WOOD was assessed based on the land value of agricultural and forestry areas, under the assumption that land values correlate with productivity [35].

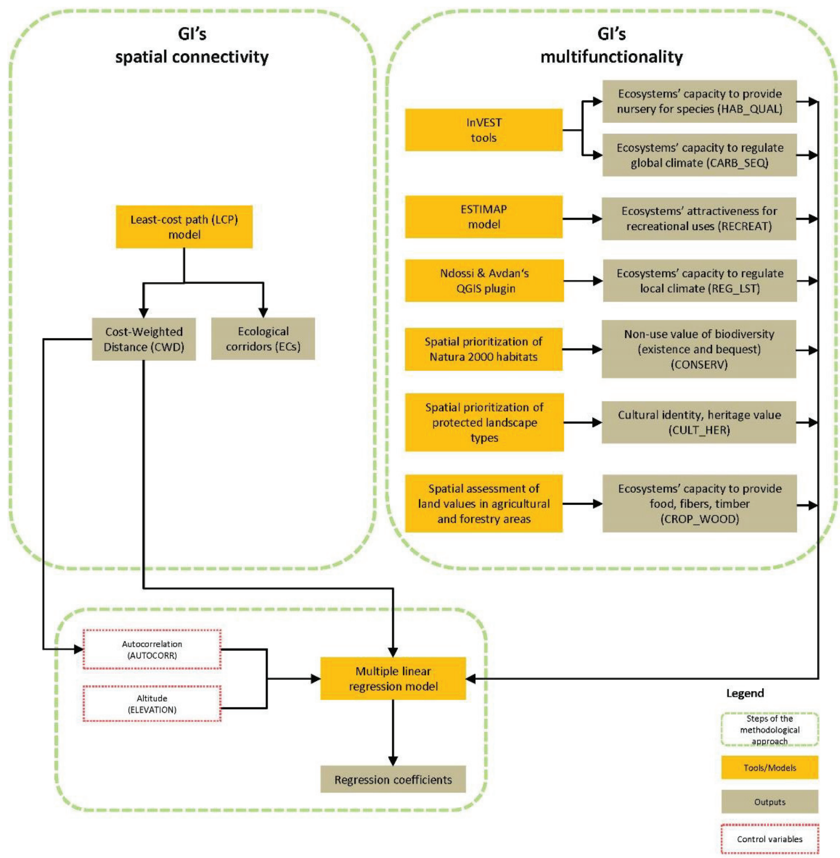

Figure 2. Graphical overview of the three-step methodological approach.

Table 1. Spatial datasets developed to assess multifunctionality: ESs, input data, sources, tools.

ES	Variable	Input Data	Input Data Source(s)	Tool/Model
Non-use value of biodiversity (existence and bequest)	CONSERV	Habitats of Community interest Regional monitoring report	Regional administration dataset	
		Natura 2000 standard data forms	Environmental ministry's website	
Ecosystems' capacity to provide nursery for species	HAB_QUAL	Regional land cover map Protected areas map Threats to biodiversity (spatial data only)	Sardinian regional geoportal	InVEST (Habitat quality model)
		Expert judgments	Questionnaires	
Ecosystems' attractiveness for recreational uses	RECREAT	2018 Corine land cover map	Copernicus Land monitoring service	ESTIMAP (Ecosystem-based recreation potential model)
		Potential vegetation series	Potential distribution of vegetation series and geoseries by Bacchetta et al. [36]	
		Nitrogen inputs	National Census	
		Livestock density	National Zootechnical Register	
		Natural protected areas and landscapes	Sardinian regional geoportal	
		Distance from the coastline	Sardinian regional geoportal	
		Coastal geomorphology	EEA website, EUROSION project	
		Bathing water quality	European Environment Agency website	
Cultural identity, heritage value	CULT_HER	Regional landscape plan (RLP) dataset	Sardinian regional geoportal	
Ecosystems' capacity to provide food, fibers, timber	CROP_WOOD	2018 Corine land cover map	Copernicus Land monitoring service	
		Land value (Agricultural areas)	CREA website	
		Land value (Forestry areas)	National Revenue Agency's website	
Ecosystems' capacity to regulate local climate	REG_LST	Landsat 8 TIRS and OLI satellite imagery	USGS's Earth Resources Observation and Science's website	REG_LST QGIS plugin by Ndossi & Avdan [30]
Ecosystems' capacity to regulate global climate	CARB_SEQ	Regional land cover map	Regional geoportal	InVEST (Carbon Storage and Sequestration model)
		Carbon pool data	2005 National Inventory of Italian Forests Regional pilot project on land units and soil capacity in Sardinia	

For each selected ES, a raster map was produced with a spatial resolution of 300 m. Since each ES had its own unit of measurement and scale, unity-based normalization was performed to bring the values into the [0, 1] range to ensure homogeneity and comparability, where zero corresponds to the absence of ES provision, while 1 means that the

ES is provided at the maximum level in Sardinia. For this reason, inversion of the scale was required in the case of REG_LST so that zero would correspond to the maximum temperature and one to the minimum.

2.3.2. The Spatial Layout of the ECs

Widely used models to spatially assess connectivity between patches of land are those that map resistance, which "represents the willingness of an organism to cross a particular environment, the physiological cost of moving through a particular environment, the reduction in survival for the organism moving through a particular environment, or an integration of all these factors" [37] p. 778. Among these models, those based on the circuit theory [38] and on individual behavior [39] are the most complex because of the amount of required data and accuracy in their selection [40]. Therefore, least-cost-path (LCP) models are most often used to analyze spatial connectivity and to map ECs [41,42] as linear strips of patches having low resistance to the movement of animal species. The general axiom of the LCP approaches is that animals own an intrinsic comprehensive perception of the environment they live in, which allows them to choose the best way when moving [40].

The methodology implemented in this study to retrieve a connectivity map builds upon Cannas et al.'s approach [43–46] and develops through the following stages.

- Identification of the regional spatial taxonomy of the habitat suitability.
- Identification of the regional spatial taxonomy of the ecological integrity.
- Identification of the regional spatial taxonomy of the resistance.
- Identification of the ECs connecting the regional PAs.

In the first stage, a habitat suitability vector map is produced for the study area based on the probability that organisms use selected habitats located in the land parcels where they live and move. This map takes, as input data, the regional land cover map [47] together with a lookup table where each land cover is assigned, for each considered species, a score ranging in the 0–3 interval that represents its suitability to provide a suitable habitat for the species. Such scores are provided in a report [48] that is part of a regional biodiversity monitoring project assessing the conservation status of habitats and species located in Natura 2000 sites. The scores of the habitat suitability concerning the land cover classes belonging to the Natura 2000 network, reported in the study, are extended to the same classes located outside the network, and, in doing so, a vector spatial taxonomy of the habitat suitability is identified for the whole regional land.

In the second stage, Burkhard et al.'s method [49,50], where the landscape capacity to deliver various ESs is assessed through qualitative judgments from experts in the [0, 5] range, is applied to develop a vector map of ecological integrity. The basic connection between ecological integrity and spatial connectivity is that ecological integrity is positively correlated with an organism's attitude to movement.

In the third stage, a resistance map is obtained following LaRue and Nielsen's approach [51], which comprises four steps. First, the two vector maps representing habitat suitability and ecological integrity indices are converted into raster ones. Next, the two indices are inverted, and two inverted raster maps are produced. Afterward, the two inverted raster maps are rescaled in the [1–100] interval, following an approach proposed by the European Environment Agency [19], where the higher the value, the higher the resistance. Finally, the newly produced (i.e., inverted and rescaled) raster maps are summed through raster algebra to develop a total resistance map.

The total resistance map, together with the vector map of the regional PAs, feeds into the model to map ECs through the "Linkage Pathways" tool, part of the ArcMAP "Linkage Mapper" toolbox [52], which implements an LCP-related model whereby the Cost-Weighted Distance (CWD) is mapped [53]. The CWD between two elements of the PAs vector map is calculated as follows: (i) the average values of the resistance of couples of adjacent areal units along the connecting path are calculated; (ii) these values are multiplied times the Euclidean distance between their centers [54]; and (iii) such results are summed up across the patches of the path. The Linkage Pathways tool returns, as final outputs, a raster map representing the CWD and the spatial and linear configuration of the ECs.

2.3.3. A multiple Linear Regression to Identify How the ECs Relate to the ESs Provided by the RGI

The ECs detected through the Linkage Pathways tool overlay the RGI spatial layout, which builds on the seven ES typologies earlier defined. ECs include spatial units whose CWDs are lower than the second decile. The CWD of a spatial unit j, included in an EC, which connects two PAs labeled M and N, is identified as follows:

$$CWD_j = CWD_{jM} + CWD_{jN}, \quad (1)$$

where CWD_{jM} and CWD_{jN} are the CWDs from spatial unit j to PAs M and N.

A regression model is implemented that estimates the marginal effects of variables representing the supply of ESs on the CWD of the spatial units overlaying ECs, i.e., whose CWDs feature values are lower than the second decile. These spatial units are considered the core patches of the RGI. The model takes the following form:

$$CWD = \gamma_0 + \gamma_1\ CONSERV + \gamma_2\ HAB\_QUAL + \gamma_3\ RECREAT + \gamma_4\ CULT\_HER + \gamma_5\ CROP\_WOOD + \gamma_6\ REG\_LST + \gamma_7\ CARB\_SEQ + \gamma_8\ ELEVATION + \gamma_9\ AUTOCORR, \quad (2)$$

where dependent and independent variables come from the intersections of spatial units supplying ESs and the ECs, as follows.

- CWD represents the cost-weighted distance of a spatial unit overlaying an EC.
- CONSERV, HAB_QUAL, RECREAT, CULT_HER, CROP_WOOD, REG_LST, and CARB_SEQ are variables that lay in the [0, 1] interval, and that represent the potential provision of the ESs described in Section 2.
- ELEVATION is a covariate that controls for the altitude of the spatial units overlaying the ECs, whose values are detected from a digital elevation model retrieved from the geoportal of the Sardinian region.
- AUTOCORR is a control variable related to the spatial autocorrelation phenomenon.

The model provides the estimates of the marginal impacts of the explanatory variables on the CWD of the spatial units overlaying the ECs. The use of the regression model is motivated by the fact that no priors are identified with reference to the marginal effects on CWD of the covariates that represent the ESs, which feature the RGI [55–58]; that being so, the n-dimensional hypersurface that stands for the phenomenon at stake can be locally represented by its linear approximation, expressed by model (2) [59,60].

The covariate representing the elevation of patches identifies systematic differences in marginal effects related to altitude. The *p*-value related to the elevation coefficient allows to detect if its estimate is significant; if this is so, altitude is an important determinant of the size of the contribution of ESs provided by the spatial units of the RGI to the ECs detection.

The AUTOCORR variable controls for autocorrelation as a spatially lagged covariate; its identification is based on Anselin's studies [61,62], as implemented by Zoppi and Lai [63], and computed through GeoDa [64].

Finally, the estimated coefficients of the explanatory variables allow to detect, through their *p*-values, if their estimates are significant, for instance, at 5%.

3. Results

This section provides the reader with the results of this study, structured into three subsections. First, the spatial taxonomies of the supply of the seven ESs are described as a basis for the Sardinian RGI, and their outstanding features are highlighted. Next, the ECs are identified as connections between the Sardinian PAs. Finally, the results of the estimates of model (2) are reported; these identify a hierarchy in the relevance of different ESs as regards their contribution to the inclusion of patches in the ECs' spatial system.

3.1. The Spatial Assessment of the Potential Delivery of Ecosystem Services

Figure 3 shows the spatial distribution of the seven values listed in Section 2.2 (i.e., CONSERV, HAB_QUAL, RECREAT, CULT_HER, CROP_WOOD, REG_LST, CARB_SEQ) and modeled as per Section 2.3.1. A further map, obtained by summing up the seven values, is also provided.

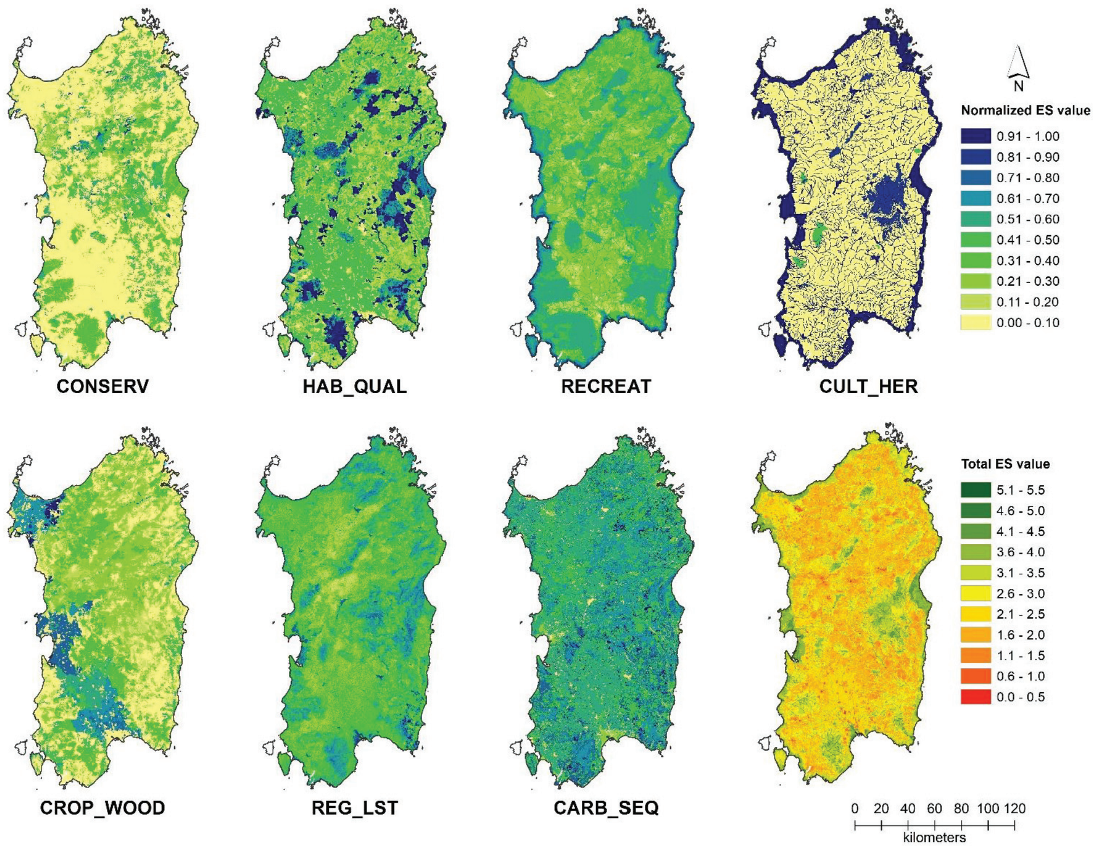

Figure 3. Mapping multifunctionality: the spatial layout of the seven selected ecosystem services, normalized in the [0, 1] range, and of their sum.

CONSERV takes null values in almost two-thirds of the regional land, while the highest values are mostly clustered within areas belonging to the regional Natura 2000 network and in their proximity. This is consistent with expectations since CONSERV accounts for endangered habitats and areas that are relevant for conservation purposes, including habitats of community interest and Natura 2000 sites. Only a small percentage of the island (0.90%) has values higher than 0.75; 4.95% have values between 0.50 and 0.75, and 27.80% have values below 0.50.

HAB_QUAL equals zero in only 3.44% of the island land mass; 35.51% hosts low-quality habitats (HAB_QUAL $\leq$ 0.33), 62.45% middle-quality habitats (0.33 < HAB_QUAL $\leq$ 0.66), while 13.8% hosts high-quality habitats (0.66 < HAB_QUAL $\leq$ 1). The highest values can be found either within national or regional PAs or in areas occupied by forests and woodlands.

As for RECREAT, around 49.5% of the island takes low values (RECREAT $\leq$ 0.33), and around 44.75% takes mid values (0.33 < RECREAT $\leq$ 0.66), while only the remaining 5.75% takes very high values (0.66 < RECREAT $\leq$ 1). Null values concern only a tiny fraction of the regional land mass. As for its spatial layout, RECREAT shares some common traits with HAB_QUAL, but, contrary to the latter, it is characterized by its distinctively large values across coastal areas.

CULT_HER is null in over 60% of the island's land mass. The highest values are usually associated with the following three landscape goods, protected against land transformation and development under the provisions of the landscaper plan in force: "Coastal strip" (clearly visible along the coastline in Figure 3), "Lakes, reservoirs, wetlands and their 300-m buffers", and "(listed) Rivers, creeks and their 150-m buffers" (also clearly visible in Figure 3).

CROP_WOOD equals zero in approximately a third of the region; low values (lower than 0.33) dominate in nearly a half of the island, with less than 5% taking high values, i.e., over 0.66. As Figure 3 shows, the latter is remarkably clustered along the two main plains: Nurra to the north, and Campidano, which stretches from the mid-west to the south.

REG_LST takes low values (lower than 0.33) in nearly 40% of the island; because REG_LST is a value that represents the ecosystems' capacity to regulate micro and regional climate through the mitigation of land surface temperature, low values of REG_LST are associated with hot land surface temperatures. Less than 2% of the regional land mass takes high values of REG_LST, while mid-normalized values concern nearly 60% of the island. No real clusters emerge, here: the small, dark blue spots on the map generally correspond to lakes and wetlands, while lighter shades of blue in general correspond to mountain chains and peaks.

As for CARB_SEQ, a mere 4.8% have low values ($0 < \text{CARB\_SEQ} \leq 0.33$), while the large majority, i.e., about 74.4%, have mid values ($0.33 < \text{CARB\_SEQ} \leq 0.66$), and around 18.6% have high values ($0.66 < \text{CARB\_SEQ} \leq 1$), which leaves the remaining 2.2% with null values. Low values are usually found either in artificial land covers or in water courses.

A basic assessment of multifunctionality can be carried out by calculating the multiple ecosystem services landscape index (MESLI) [65,66], whose spatial distribution is provided in the eightieth map in Figure 3. This index is simply calculated as the sum of the seven selected values; since each value varies between zero and one, the MESLI can, in principle, range in the [0, 7] interval. The underlying assumption here is that the higher the index, the higher the ES multifunctionality; this is actually a simplification since large values of the index could be due to either the high supply of a few ESs or to the low supply of a larger number of ESs. However, the map can provide an expeditive tool to highlight the areas that, in principle, are more multifunctional and should, therefore, deserve to be included in a GI.

3.2. The Spatial Layout of the Network of Ecological Corridors

The taxonomy of CWD and the spatial plot of the ECs that connect the Sardinian regional PAs are the outcomes generated by the methodology implemented in the previous section.

Such outcomes show 240 ECs, detected through spatial units identified by CWDs lower than the second decile, whose length is included in the 0.07–27.34-km interval (Figure 4).

3.3. The Regression Outcomes

The results of the implemented regression model display the marginal impacts of the provision of the seven types of ESs on the CWD of the spatial units overlaying the ECs (Table 2), and, in so doing, an ESs hierarchy is identified on the basis of the size of their contribution to boost the connection capacity within the ECs regional network.

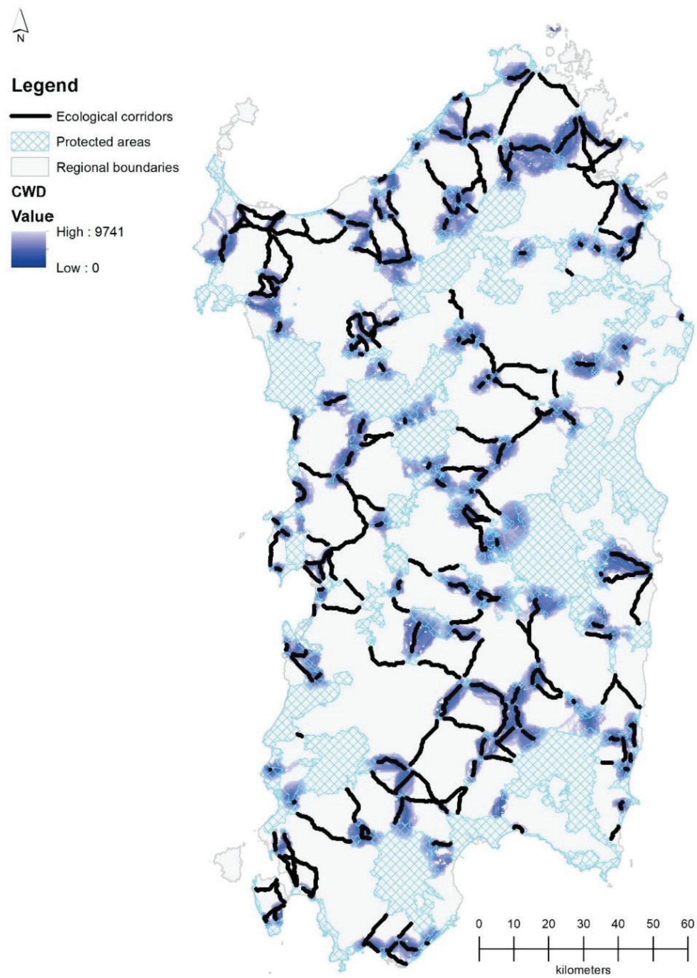

Figure 4. Spatial representation of PAs, ECs, and spatial units whose CWDs are lower than the second decile.

Table 2. Regression outcomes.

Explanatory Variable	Coefficient	Standard Deviation	*t*-Statistic	*p*-Value	Mean of the Explanatory Variable
CONSERV	378.9043	46.0212	8.233	0.000	0.1357
HAB_QUAL	844.6393	35.8077	23.588	0.000	0.4134
RECREAT	345.0859	67.1934	5.136	0.031	0.4210
CULT_HER	−180.8370	22.4312	−8.062	0.000	0.3078
CROP_WOOD	−157.3472	45.2657	−3.476	0.000	0.2128
REG_LST	−773.2409	74.6302	−10.361	0.000	0.4485
CARB_SEQ	516.6964	57.6843	8.957	0.000	0.5606
ELEVATION	0.9055	0.0361	25.059	0.000	356.8034
AUTOCORR	0.5340	0.0022	241.749	0.000	5597.6660

Dependent variable: CWD: Mean: 4925.448 km; Standard deviation: 2866.052 km; Adjusted R-squared: 0.523.

The estimate of the coefficient of the elevation-related variable is significant in terms of the *p*-value, and it shows a positive marginal effect. Therefore, it can be stated that the higher the elevation, the higher the CWD of patches belonging to ECs. On average, an increase of 100 m in altitude implies an increase of about 1% in CWD.

The spatially lagged variable AUTOCORR, which accounts for the spatial autocorrelation phenomenon, shows a positive and significant value as well, which indicates that CWD is positively influenced by autocorrelation or that autocorrelation has a negative impact on the performance of patches in terms of their eligibility to be included in ECs.

All in all, the estimates of the two control variables' coefficients are significant, and they highlight negative effects on the patches' performance.

That being so, the analysis of the estimated coefficients concerning the other covariates can be straightforwardly enacted, and, therefore, the size of the impact of each of the seven types of ESs on the CWD of spatial units included in the ECs' regional network was easily identified. Moreover, the *p*-values of the estimated coefficients are always significant at 5%, which gives strength to the assessment of the model estimates.

Three ES types show negative effects, i.e., their increase is associated with a decrease in CWD and, thus, with an increase in the connection potential of ECs. The corresponding variables are REG_LST, CROP_WOOD, and CULT_HER. REG_LST reveals the largest effect, with an average decline in CWD of 7.7‰ related to a 10% increase in REG_LST, while the corresponding increases in CROP_WOOD and CULT_HER are associated with a 1.6‰ and a 1.8‰ decline in CWD, respectively.

Furthermore, CONSERV, HAB_QUAL, RECREAT, and CARB_SEQ reveal positive impacts since a 10% growth in the covariates is correlated to 3.8‰, 8.4‰, 3.5‰, and 5.2‰ increases, respectively.

As a consequence, the estimated model shows that the ESs, whose provision is associated with their capacity to host plants and wildlife (CONSERV and HAB_QUAL), of supplying recreational and leisure time-related infrastructure and services (RECREAT) and of capturing and storing carbon dioxide (CARB_SEQ), are the most challenging when dealing with the identification of ECs within the Sardinian regional context, whereas mitigation of land surface temperature (REG_LST), crop and forest production (CROP_WOOD), and landscape heritage (CULT_HER) are the most functional ESs to drive connections within the spatial network of the Sardinian PAs.

4. Discussion

The results from the regression models point to three values, i.e., REG_LST, CROP_WOOD, and CULT_HER, as the prominent factors that affect the suitability of a parcel of land to be included within an EC.

As for the first, i.e., REG_LST, lower values correlate with diminishing CWD, which can be explained by looking at farmland areas. Agricultural land uses can hamper species' movement across ECs, hence hindering connectivity [67], mainly because of the widespread use of boundary walls and artificial fences [68], but also due to farming techniques that are neither soil-friendly nor species-friendly, such as tillage, which alters the physical characteristics of soils [69], or the use of fire to clean the fields once the crop is yielded [70], or improper application of chemicals, including biocides and fertilizers [67,71]. Furthermore, as argued by Lai et al. [72], REG_LST can be negatively affected by farming activities as these can hamper the cooling effect generated by air circulation and evapotranspiration in the case of dense and thick low vegetation [73].

As with REG_LST, CROP_WOOD is also affected by agricultural uses and farming practices, which, again, can hinder species' movement. It is pretty intuitive that connectivity decreases when agricultural potential productivity (which depends both on locational characteristics, first and foremost, elevation and soil type, and on crop type) increases, for the very same reasons highlighted with reference to the relationship between CWD and REG_LST. On the contrary, connectivity is positively influenced by forests and woodlands, as shown by lower CWD in wooded land covers. Following Santos et al. [74], land cover changes in forest areas are prominent drivers of habitat loss for a number of species due to reduction in patch sizes and increase in landscape fragmentation, which result in lower variety and population numbers of species that can survive [75]. Moreover, small forest-covered patches may seem irrelevant in terms of connectivity; however, they do play a key role in connecting remote and isolated patches [76], and additionally, small forest-covered patches can work as stepping stones to foster species movement [77] and as fundamental habitats for some species [76], as shown in the case of the Stołowe Mountains National Park, where a staggering 40% of epiphytic bryophytes are hosted by broadleaved forest-covered patches, although these account for less than 5% of the area [78].

Concerning CULT_HER, the outcomes of the regression model revealed that the higher the CULT_HER, the lower the CWD. It is worth underlining that CULT_HER is assessed based upon landscape assets protected under the provisions of the Sardinian RLP, and the values of the corresponding covariate are identified with reference to the restrictions in force, in such a way that the stricter the rules, the higher the CULT_HER values are. The Italian Code on cultural heritage and landscape (Law enacted by decree no. 2004/42) defines landscape assets as buildings and areas that are expressions of the historical, cultural, natural, morphological, and aesthetic values of a spatial context. In relation to environmental assets, which are a type of landscape assets, the highest values are associated with water courses and their 150-m buffers, as well as with natural lakes, artificial water basins, and wetlands together with their 300-m buffers. According to article no. 20 of the RLP implementation code, any transformation is generally precluded in non-urbanized areas within the coastal strips. According to article no. 25 of the RLP implementation code, within the spatial system that includes rivers and their surroundings, the following operations are prohibited: (i) anthropic interventions on riverbeds and banks, including riparian vegetation removal; (ii) reforestation with non-native species; and (iii) river sand sampling and substitution in the absence of specific projects that demonstrate the compatibility of regeneration. Furthermore, the connectivity function performed by water courses, one of the most common types of landscape assets across the island, is well established in the literature: though riparian vegetation, an umbrella term for several plant species that grow along the riverbanks and stretch into the floodplain, water courses offer shelter and suitable reproduction habitats for many species [79], as well as nourishment and water [80]. Riparian vegetation, therefore, represents, per se, a suitable EC for many species, among which are not only fish but also birds, amphibians, and reptiles [79]. On the other hand, the role of riparian formations in terms of species movement can be hindered by human-induced activities and geomorphological conditions [81].

By shedding light on how the potential supply of ESs impacts the suitability of land patches to belong to EC, taken as the branches of a GI, this study contributes to the recent academic debates on the relationship between connectivity and multifunctionality of a GI with a novel perspective. Thus far, studies have investigated such interaction using two broad approaches. The first takes connectivity as a driver of direct or indirect impacts on the supply of ES, and it focuses on investigating how fragmentation and decreased connectivity degrade natural capital, in turn, affecting ES provision [20,21,82]. This group of studies posits that ES provision depends on the spatial interaction between patches [83] and that such dependency is complex when looking at multiple ESs, not only because of the synergies and trade-offs among the services but also because, rather counterintuitively, fragmentation and patch interspersion can positively affect the flow of some ESs by making nature more accessible to ES beneficiaries; that is, human beings; this holds especially as far as recreational, and provisioning services are concerned [82]. The second approach attempts to integrate the concept of multifunctionality within either circuit models or LCP models in two different ways: either by considering patches that simultaneously provide multiple ESs as nodes of the graphs [84,85] or by regarding areas rich in wildlife as nodes and identifying branches, hence corridors, as linear aggregations of patches that simultaneously provide multiple ESs [86–88]. The approach taken in this study is, in our view, novel because, although it assumes that a causal relationship exists between connectivity and multifunctionality, as the first approach does, it changes the direction of the relationship by regarding connectivity as a function of variables that represent multifunctionality to explain the causal relationship. Moreover, and differently to the second approach, the identification of the ecological corridors and the spatial assessment of selected ESs are carried out independently of each other, which is a prerequisite if causal relationships are to be analyzed through the regression model.

5. Conclusions

In this section, some suggestions for planners and policymakers are offered, drawing upon the outcomes of the model and their discussion through the lens of the extant literature. Such suggestions aim to improve the suitability of land parcels to be included within a GI by focusing on the three aspects discussed in the previous section (i.e., mitigating land surface temperature, increasing forest and woodland in size, improving the protection regime of landscape assets), which have been found to be key to strengthening the EC network.

Following Lai et al. [89], whose study concerns the Sardinian region, land surface temperature can be lowered, and, therefore, the REG_LST variable used in this study can be increased in value through regional afforestation policies.

Moreover, since heat waves and islands characterize urbanized areas, especially the consolidated fabrics of urban centers, policies aimed at decreasing air temperature should be based on targeting urban contexts at the micro-scale level. Urban greening measures, aimed at increasing existing green areas and setting up new ones, planting rows of trees and urban woodland, are the most successful in order to mitigate climate change impacts related to LST on urban areas [90–92].

An outstanding paragon of the implementation of such policies is offered by the London Green Grid, which counters a 3 °C increase in average temperature in the London area [93], which drives sensible decreases in the urban life quality and health conditions and water supply, and increases in focuses of insect- and vermin-related infections, and drought-affected open-spaces and urban parks. Green grids, facades, and walls are the most effective planning measures that characterize the implementation of the London Green Grid conceptual approach into the East London Green Grid, which entails a dense tissue of blue and green paths that feature city landscapes where densely-built areas, sealed land, and hub centers used by commuters are intertwined with the Green Belt and Thames green and blue infrastructures [94].

The increased supply of ecosystem services that mitigate heat island and wave phenomena improves the quality of urban life [95]. These measures implement a number of planning policies that may boost virtuous approaches on behalf of urban communities, organized citizen groups, building enterprises, and public administrations [96]. An important issue is connected to the narrow relation between the price of the urban land and the buildable volume size, be it for new houses or service buildings. That being so, since targeting urban areas for greening-oriented interventions, be they enlarged existing ones or newly vegetated, implies a significant decline in their property values, the implementation of such planning policies should entail the establishment of compensatory measures concerning the landowners' loss of value generated by the local administration pursuing sustainability-oriented goals concerning urban heat waves and islands. Steady building rules should state that newly-built settlements or existing ones should be endowed with an appropriate amount of green spaces, which may possibly be complemented with green facades and roofs or with blue and green lanes, as has happened as regards the Green Grid of East London [97,98]. Moreover, due to the outstanding relevance of the availability of financial resources, a scheme of allowances should be designed aimed at increasing the number of green elevations and rooftops and blue and green lanes in new and existing developments, which would make such settlements more interesting to building enterprises [99,100]. Such incentives could consist of discounts on impact fees, and taxes on property and value-added, and allowances granted to building entrepreneurs to enhance the quality of the local environment [101,102]. Lastly, the implementation of infrastructures such as blue and green lanes, green roofs and facades, etc., would drive attention and consensus, on behalf of the local communities, to the local administrations' positive attitude towards environmental quality and landscape protection [103,104].

Afforestation policies should target not only urban areas but also non-artificial ones; in Sardinia, where agriculture is generally associated with the highest temperature values in non-urbanized areas; this entails targeting rural, farmland areas. Moreover, the implementation of afforestation policies in rural areas would also be beneficial as far as CROP_WOOD is concerned, as shown by the coefficient of the regression model related to this variable. Therefore, implementing afforestation actions would feed two birds with one scone, as it can significantly improve an RGI by contributing to both the regulation of micro and regional climate and providing wood, fibers, and other materials retrievable from sustainably managed forests.

In rural areas, this would entail supporting land cover transition processes from agriculture to forestry, which have been studied by Ryan and O'Donoghue [105], who analyze the social and economic factors that feature such processes. From this perspective, a relevant opposite role is played by the social and cultural ties between farmers and their agricultural land [106]. Such a relationship is grounded on their familiarity with the flexible and low-pressure practices that characterize crop production [107] and with their historically consolidated farming know-how, which often acts as a substitute for the increase in income that can come from transitioning towards forestry production [105]. Moreover, land-cover change from agriculture to forestry is feasible in the case it concerns extensive, low-rent cropland, while afforestation is almost unfeasible with reference to intensively cultivated, highly profitable arable land [108]. In the case of processes related to extensive agriculture, afforestation should be encouraged by financial resources made available in order to cover transition and retraining costs [109].

When dealing with transition policies concerning afforestation related to cropland, the issue of the weakening of rural areas should be carefully assessed since afforestation implies a net decrease in the presence of farmers and, as a consequence, a potential social and cultural deterioration of rural environments [110]. Another relevant question is represented by the need for a careful assessment of the affordability of the public investment entailed by the implementation of afforestation policies in order to identify the optimal land-cover change size [111].

Although not as important as low land surface temperature and high forestry activities, a third factor that has been found to be relevant in this study to improve an RGI by strengthening ECs that connect core areas is the endowment of landscape-protected goods and assets. In the Sardinian case, such goods and assets can be natural features (such as the coastal strip or the riverine network) or artifacts (such as archaeological sites); for both, the RLP mandates that transformations be restricted, if not totally forbidden. Thus, decision-makers have two main tools at their disposal to increase the value of CULT_HER: one possibility would rely on making landscape protection policies even stricter than they currently are by increasing the levels of restrictions for those landscape features and goods that are already protected within the RLP; a second possibility would, instead, entail increasing the protection scope of the RLP by including further categories of landscape features to be protected, in the future, through the RLP provisions. This second direction can, in principle, be very powerful if linear landscape elements can effectively act as corridors, and are treated as landscape assets and goods to be protected. For instance, vegetated edges along agricultural plots or tree lines along linear infrastructures can foster connectivity [112], as well as enable landscape heterogeneity and, as a consequence, can support larger varieties of species [113–115], and facilitate their movement, especially as far as small animals are concerned [116]. Policymakers are, therefore, recommended to include such landscape elements, widely treated as cultural and identity features [117,118], among the goods and assets to be protected against land transformation and to encourage their inclusion in new developments.

In this study, we have implemented an integrated and flexible methodology that can be readily applied and tailored to other local contexts. Elements that can be adjusted to account for data availability and scholars' expertise, or even for local needs and legal frameworks, include but are not limited to, the scores that were here used the build the resistance map or the taxonomy of core areas to be connected through the ECs, or the choice of ESs to be considered to assess multifunctionality, or the selection of models that were implemented here to map the selected ESs.

Finally, the limitations of this study that should be taken into account in directions for future research concern the validation of the data in relation to both REG_LST and REC-REAT. The spatial layout of LST could not be compared with real data. Therefore, direct and in situ observations would be needed to validate the baseline dataset concerning LST. On the one hand, in relation to the in situ observations, continuous and effective monitoring of LST values is unattainable due to the inhomogeneity in the spatial distribution of the measurement sites and the inaccuracy of the model simulations [119]. On the other hand, remote sensing approaches are characterized by significant uncertainty due to atmospheric effects in terms of attenuation and emissions and the inhomogeneity of land surface emissivity [120]. The absence of a validated dataset risks jeopardizing the possibility of implementing planning policies aimed at influencing LST values. In relation to the RECREAT variable, the model estimates the potential supply of natural recreational services; therefore, as with REG_LST, a comparison with direct and in situ observations would be worthwhile to validate the dataset by looking at the effective use of recreational services. Moreover, the methodological approach used to identify ECs does not take into consideration physical (either artificial or natural) barriers to movement, such as roads, railways, and rivers. Further research is hence needed to evaluate and adjust the ECs; in this regard, a possible approach is that by Wu et al. [41], who use remote sensing to adjust the EC layout by overlaying the potential ecological corridors with fragmenting elements, such as roads and human settlements.

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References

1. Lennon, M.; Scott, M. Delivering ecosystems services via spatial planning: Reviewing the possibilities and implications of a green infrastructure approach. *Town Plann. Rev.* **2014**, *85*, 563–587. [CrossRef]
2. Liquete, C.; Kleeschulte, S.; Dige, G.; Maes, J.; Grizzetti, B.; Olah, B.; Zulian, G. Mapping green infrastructure based on ecosystem services and ecological networks: A Pan–European case study. *Environ. Sci. Policy* **2015**, *54*, 268–280. [CrossRef]
3. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. *Green Infrastructure—Enhancing Europe's Natural Capital. SWD (2013) 155 Final.* 2013. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC_1&format=PDF (accessed on 30 June 2022).
4. Benedict, M.A.; McMahon, E.T. Green infrastructure: Smart conservation for the 21st century. *Renew. Resour. J.* **2002**, *20*, 12–17.

5. Tzoulas, K.; Korpela, K.; Venn, S.; Yli-Pelkonen, V.; Kaźmierczak, A.; Niemela, J.; James, P. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape Urban Plan.* **2007**, *81*, 167–178. [CrossRef]
6. Maes, J.; Barbosa, A.; Baranzelli, C.; Zulian, G.; Batista e Silva, F.; Vandecasteele, I.; Hiederer, R.; Liquete, C.; Paracchini, M.L.; Mubareka, S.; et al. More green infrastructure is required to maintain ecosystem services under current trends in land-use change in Europe. *Landscape Ecol.* **2015**, *30*, 517–534. [CrossRef] [PubMed]
7. Madureira, H.; Andresen, T. Planning for multifunctional urban green infrastructures: Promises and challenges. *Urban Des. Int.* **2014**, *19*, 38–49. [CrossRef]
8. Selman, P. Planning for landscape multifunctionality. *Sustain. Sci. Pract. Policy* **2009**, *5*, 45–52. [CrossRef]
9. Hansen, R.; Stahl Olafsson, A.; van der Jagt, A.P.N.; Rall, E.; Pauleit, S. Planning multifunctional green infrastructure for compact cities: What is the state of practice? *Ecol. Indic.* **2019**, *96*, 99–110. [CrossRef]
10. Hansen, R.; Pauleit, S. From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for urban areas. *AMBIO* **2014**, *43*, 516–529. [CrossRef]
11. Wang, Y.; Chang, Q.; Fan, P. A framework to integrate multifunctionality analyses into green infrastructure planning. *Landscape Ecol.* **2021**, *36*, 1951–1969. [CrossRef]
12. Meerow, S.; Newell, J.P. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landsc. Urban Plan.* **2017**, *159*, 62–75. [CrossRef]
13. Meerow, S. The politics of multifunctional green infrastructure planning in New York City. *Cities* **2020**, *100*, 102621. [CrossRef]
14. D'Ambrogi, S.; Gori, M.; Guccione, M.; Nazzini, L. Implementazione della connettività ecologica sul territorio: Il monitoraggio ISPRA 2014 [Ecological connectivity implementation in practice: ISPRA's 2014 monitoring]. *Reticula* **2015**, *9*, 1–7.
15. Battisti, C. *Frammentazione Ambientale, Connettività, Reti Ecologiche. Un Contributo Teorico e Metodologico con Particolare Riferimento alla Fauna Selvatica [Environmental Fragmentation, Connectivity, Ecological Networks. A Technical and Methodological Contribution with Particolar Reference to Wildlife Species]*; Provincia Di Roma, Assessorato Delle Politiche Ambientali; Agricoltura e Protezione Civile [Province of Rome, Board of Environmental Policy, Agriculture and Civil Protection]: Rome, Italy, 2004.
16. D'Ambrogi, S.; Nazzini, L. Monitoraggio ISPRA 2012: La rete ecologica nella pianificazione territoriale [The ecological network in spatial planning]. *Reticula* **2013**, *3*, 1–5.
17. Baudry, J.; Merriam, H.G. Connectivity and connectedness: Functional versus structural patterns in landscapes. In Proceedings of the 2nd IALE Seminar "Connectivity in Landscape Ecology", Münster, Germany, 19–24 July 1987; Münsterche Geographische Arbeiten: Münster, Germany, 1988; Volume 29, pp. 23–28.
18. Directorate–General Environment, European Commission. The Multifunctionality of Green Infrastructure, Science for Environment Policy, DG News Alert Service, In–Depth Report. 2012. Available online: https://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf (accessed on 30 June 2022).
19. European Environment Agency. *Spatial Analysis of Green Infrastructure in Europe*; EEA Technical Report no. 2/2014; Publications Office of the European Union: Luxembourg, 2014. [CrossRef]
20. Mitchell, M.G.E.; Bennett, E.M.; Gonzalez, A. Linking landscape connectivity and ecosystem service provision: Current knowledge and research gaps. *Ecosystems* **2013**, *16*, 894–908. [CrossRef]
21. Correa Ayram, C.A.; Mendoza, M.E.; Etter, A.; Salicrup, D.R.P. Habitat connectivity in biodiversity conservation: A review of recent studies and applications. *Prog. Phys. Geogr. Earth Environ.* **2016**, *40*, 7–37. [CrossRef]
22. Lai, S.; Leone, F.; Zoppi, C. Land cover changes and environmental protection: A study based on transition matrices concerning Sardinia (Italy). *Land Use Policy* **2017**, *67*, 126–150. [CrossRef]
23. SardegnaGeoportale. Available online: http://www.sardegnageoportale.it (accessed on 30 June 2022).
24. European Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043 (accessed on 30 June 2022).
25. European Parliament and Council Directive 2009/147/EC of 30 November 2009 on the Conservation of Wild Birds. Available online: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0147 (accessed on 30 June 2022).
26. SIC, ZSC e ZPS in Italia [SCIs, SACs, and SPAs in Italy]. Available online: https://www.mite.gov.it/pagina/sic-zsc-e-zps-italia (accessed on 30 June 2022).
27. Common International Classification of Ecosystem Services. Available online: https://cices.eu/ (accessed on 30 June 2022).
28. Isola, F.; Lai, S.; Leone, F.; Zoppi, C. *Green Infrastructure and Regional Planning: An Operational Framework*; FrancoAngeli: Milan, Italy, 2022.
29. InVEST. Available online: https://naturalcapitalproject.stanford.edu/software/invest (accessed on 30 June 2022).
30. Ndossi, M.I.; Avdan, U. Application of open source coding technologies in the production of Land Surface Temperature (REG_LST) maps from Landsat: A PyQGIS Plugin. *Remote Sens.* **2016**, *8*, 413. [CrossRef]
31. Zulian, G.; Paracchini, M.L.; Maes, J.; Liquete, C. *ESTIMAP: Ecosystem Services Mapping at European Scale*; JRC Technical Report EUR 26474 ENG; Publications Office of the European Union: Luxembourg, 2013. [CrossRef]
32. Vallecillo, S.; La Notte, A.; Polce, C.; Zulian, G.; Alexandris, N.; Ferrini, S.; Maes, J. *Ecosystem Services Accounting: Part I-Outdoor Recreation and Crop Pollination*; EUR 29024 EN; Publications Office of the European Union: Luxembourg, 2018. [CrossRef]
33. Lai, S.; Leone, F. Bridging biodiversity conservation objectives with landscape planning through green infrastructures: A case study from Sardinia, Italy. In Proceedings of the 17th International Conference on Computational Science and Its Applications (ICCSA 2017), Trieste, Italy, 3–6 July 2017; Lecture Notes in Computer Sciences Series. Gervasi, O., Murgante, B., Misra, S., Borruso,

G., Torre, C., Rocha, A.M.A.C., Taniar, D., Apduhan, B.O., Stankova, E., Cuzzocrea, A., Eds.; Springer: Cham, Switzerland, 2017; Volume 10409, pp. 456–472. [CrossRef]
34. Decision of the EU Commission of 11 July 2011 Concerning a Site Information Format for Natura 2000 Sites. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011D0484&from=EN (accessed on 30 June 2022).
35. Lai, S.; Isola, F.; Leone, F.; Zoppi, C. Assessing the potential of green infrastructure to mitigate hydro-geological hazard. Evidence-based policy suggestions from a Sardinian study area. *TeMA J. Land Use Mobil. Environ.* **2021**, *2021*, 109–133. [CrossRef]
36. Bacchetta, G.; Bagella, S.; Biondi, E.; Farris, E.; Filigheddu, R.; Mossa, L. Vegetazione forestale e serie di vegetazione della Sardegna (con rappresentazione cartografica alla scala 1: 350.000) [Forest vegetation and serial vegetation of Sardinia (with map at the scale 1:350,000)]. *Fitosociologia* **2009**, *46*, 3–82.
37. Zeller, K.A.; McGarigal, K.; Whiteley, A.R. Estimating landscape resistance to movement: A review. *Landscape Ecol.* **2012**, *27*, 777–797. [CrossRef]
38. McRae, B.H.; Dickson, B.G.; Keitt, T.H.; Shah, V.B. Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology* **2008**, *89*, 2712–2724. [CrossRef]
39. Palmer, S.C.F.; Coulon, A.; Travis, J.M.J. Introducing a 'stochastic movement simulator' for estimating habitat connectivity. *Methods Ecol. Evol.* **2011**, *2*, 258–268. [CrossRef]
40. Balbi, M.; Petit, E.J.; Corci, S.; Nabucet, J.; Georges, R.; Madec, L.; Ernoult, A. Ecological relevance of least cost path analysis: An easy implementation method for landscape urban planning. *J. Environ. Manag.* **2019**, *244*, 61–68. [CrossRef]
41. Wu, J.; Delang, C.O.; Li, Y.; Ye, Q.; Zhou, J.; Liu, H.; He, H.; He, W. Application of a combined model simulation to determine ecological corridors for western black-crested gibbons in the Hengduan Mountains, China. *Ecol. Indic.* **2021**, *128*, 107826. [CrossRef]
42. Guo, X.; Zhang, X.; Du, S.; Li, C.; Siu, Y.L.; Rong, Y.; Yang, H. The impact of on-shore wind power projects on ecological corridors and landscape connectivity in Shanxi, China. *J. Clean. Prod.* **2020**, *254*, 120075. [CrossRef]
43. Cannas, I.; Zoppi, C. Ecosystem Services and the Natura 2000 Network: A Study concerning a green infrastructure based on ecological corridors in the metropolitan city of Cagliari. In Proceedings of the 17th International Conference on Computational Science and Its Applications (IC-CSA 2017), Trieste, Italy, 3–6 July 2017; Lecture Notes in Computer Sciences Series. Gervasi, O., Murgante, B., Misra, S., Borruso, G., Torre, C., Rocha, A.M.A.C., Taniar, D., Apduhan, B.O., Stankova, E., Cuzzocrea, A., Eds.; Springer: Cham, Switzerland, 2017; Volume 10409, pp. 379–400. [CrossRef]
44. Cannas, I.; Zoppi, C. Un'infrastruttura verde nell'area metropolitana di Cagliari: Corridoi ecologici come connessioni tra i Siti della Rete Natura 2000 [A Green Infrastructure in the Metropolitan Area of Cagliari: Ecological Corridors as Connections between the Sites of the Natura 2000 Network]. In *Atti Della XX Conferenza Nazionale SIU. Urbanistica E/È Azione Pubblica [Proceedings of the 20th National Conference of SIU. Spatial Planning And/Is Public Action]*; AA.VV.; Planum Publisher: Rome, Italy; Milan, France, 2017; pp. 1373–1386.
45. Cannas, I.; Lai, S.; Leone, F.; Zoppi, C. Green infrastructure and ecological corridors: A regional study concerning Sardinia. *Sustainability* **2018**, *10*, 1265. [CrossRef]
46. Cannas, I.; Lai, S.; Leone, F.; Zoppi, C. Integrating green infrastructure and ecological corridors: A Study concerning the Metropolitan Area of Cagliari (Italy). In *Smart Planning: Sustainability and Mobility in the Age of Change*; Papa, R., Fistola, R., Gargiulo, C., Eds.; Springer International Publishing: Basel, Switzerland, 2018; pp. 127–145. [CrossRef]
47. CORINE Land Cover. Available online: https://www.eea.europa.eu/publications/COR0-landcover (accessed on 30 June 2022).
48. AGRISTUDIO; CRITERIA; TEMI. Realizzazione del Sistema di Monitoraggio dello Stato di Conservazione degli Habitat e delle Specie di Interesse Comunitario della Regione Autonoma della Sardegna. Relazione Generale, Allegato 1b: Carta dell'Idoneità Faunistica [Implementation of the Monitoring System Concerning the Conservation Status of Habitats and Species of Community Interest of the Autonomous Region of Sardinia. General Report, Attachment 1b: Habitat Suitability Map]. Unpublished work. 2011.
49. Burkhard, B.; Kroll, F.; Müller, F.; Windhorst, W. Landscapes' capacities to provide ecosystem services–A concept for land-cover based assessments. *Landsc. Online* **2009**, *15*, 1–22. [CrossRef]
50. Burkhard, B.; Kroll, F.; Nedkov, S.; Müller, F. Mapping ecosystem service supply, demand and budgets. *Ecol. Indic.* **2012**, *2*, 17–29. [CrossRef]
51. LaRue, M.A.; Nielsen, C.K. Modelling potential dispersal corridors for cougars in Midwestern North America using least-cost path methods. *Ecol. Model.* **2008**, *212*, 372–381. [CrossRef]
52. Linkage Mapper. Available online: https://linkagemapper.org/ (accessed on 30 June 2022).
53. McRae, B.H.; Kavanagh, D.M. User Guide: Linkage Pathways Tool of the Linkage Mapper Toolbox—Version 2.0—Updated October 2017. Available online: https://github.com/linkagescape/linkage-mapper/files/2204107/Linkage_Mapper_2_0_0.zip (accessed on 30 June 2022).
54. Shirabe, T. Buffered or bundled, least-cost paths are not least-cost corridors: Computational experiments on path-based and wide-path-based models to conservation corridor design and effective distance estimation. *Ecol. Inform.* **2018**, *44*, 109–116. [CrossRef]
55. Zoppi, C.; Argiolas, M.; Lai, S. Factors influencing the value of houses: Estimates for the City of Cagliari, Italy. *Land Use Policy* **2015**, *42*, 367–380. [CrossRef]

56. Sklenicka, P.; Molnarova, K.; Pixova, K.C.; Salek, M.E. Factors affecting farmlands in the Czech Republic. *Land Use Policy* **2013**, *30*, 130–136. [CrossRef]
57. Stewart, P.A.; Libby, L.W. Determinants of farmland value: The case of DeKalb County, Illinois. *Rev. Agric. Econ.* **1998**, *20*, 80–95. [CrossRef]
58. Cheshire, P.; Sheppard, S. On the price of land and the value of amenities. *Economica* **1995**, *62*, 247–267. [CrossRef]
59. Wolman, A.L.; Couper, E. Potential consequences of linear approximation in economics. *Fed. Reserve Bank Econ. Q.* **2003**, *11*, 51–67.
60. Bera, A.K.; Byron, R.P. Linearized estimation of nonlinear single equation functions. *Int. Econ. Rev.* **1983**, *24*, 237–248. [CrossRef]
61. Anselin, L. *Spatial Econometrics: Methods and Models*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1988.
62. Anselin, L. Spatial econometrics. In *A Companion to Theoretical Econometrics*; Baltagi, B.H., Ed.; Blackwell Publishing: Oxford, UK, 2003; pp. 310–330.
63. Zoppi, C.; Lai, S. Land-taking processes: An interpretive study concerning an Italian region. *Land Use Policy* **2014**, *36*, 369–380. [CrossRef]
64. GeoDa-An Introduction to Spatial Data Science. Available online: https://geodacenter.github.io (accessed on 30 June 2022).
65. Rodríguez-Loinaz, G.; Alday, J.G.; Onaindia, M. Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation. *J. Environ. Manag.* **2015**, *147*, 152–163. [CrossRef]
66. Pilogallo, A.; Scorza, F. Ecosystem services multifunctionality: An analytical framework to support sustainable spatial planning in Italy. *Sustainability* **2022**, *14*, 3346. [CrossRef]
67. Gregory, A.; Spence, E.; Beier, P.; Garding, E. Toward best management practices for ecological corridors. *Land* **2021**, *10*, 140. [CrossRef]
68. Hilty, J.; Worboys, G.L.; Keeley, A.; Woodley, S.; Lausche, B.; Locke, H.; Carr, M.; Pulsford, I.; Pittock, J.; White, J.W.; et al. *Guidelines for Conserving Connectivity through Ecological Networks and Corridors*; Best Practice Protected Area Guidelines Series no. 30; IUCN: Gland, Switzerland, 2020. [CrossRef]
69. McLaughlin, A.; Mineau, P. The impact of agricultural practices on biodiversity. *Agric. Ecosyst. Environ.* **1995**, *55*, 201–212. [CrossRef]
70. Peirce, K.N.; vanDaele, L.J. Use of a garbage dump by brown bears in Dillingham, Alaska. *Ursus* **2006**, *17*, 165–177. [CrossRef]
71. Robbins, C.S.; Bystrak, D.; Geissler, P.H. *The Breeding Bird Survey: Its First Fifteen Years, 1965–1979*; Resource Publication, Series no.157; U.S. Fish and Wildlife Service: Washington, DC, USA, 1986. Available online: https://pubs.er.usgs.gov/publication/5230189 (accessed on 30 June 2022).
72. Lai, S.; Leone, F.; Zoppi, C. Policies to decrease land surface temperature based on land cover change: An assessment related to Sardinia, Italy. In *Innovation in Urban and Regional Planning–Proceedings of the 11th INPUT Conference, Lecture Notes in Civil Engineering*; La Rosa, D., Privitera, R., Eds.; Springer: Cham, Switzerland, 2021; Volume 146, pp. 101–109. [CrossRef]
73. Oke, T.R. The urban energy balance. *Prog. Phys. Geog.* **1988**, *12*, 471–508. [CrossRef]
74. Santos, J.S.; Leite, C.C.C.; Viana, J.C.C.; dos Santos, A.R.; Milton Marques Fernandes, M.M.; de Souza Abreu, V.; do Nascimento, T.P.; dos Santos, L.S.; de Moura Fernandes, M.R.; Gilson Fernandes da Silva, G.F.; et al. Delimitation of ecological corridors in the Brazilian Atlantic Forest. *Ecol. Indic.* **2018**, *88*, 414–424. [CrossRef]
75. Hidalgo, P.J.; Hernández, H.; Sánchez-Almendro, A.J.; López-Tirado, J.; Vessella, F.; Porras, R. Fragmentation and connectivity of island forests in agricultural Mediterranean environments: A comparative study between the Guadalquivir Valley (Spain) and the Apulia Region (Italy). *Forests* **2021**, *12*, 1201. [CrossRef]
76. Wang, Z.; Yang, Z.; Shi, H.; Han, L. Effect of forest connectivity on the dispersal of species: A case study in the Bogda World Natural Heritage Site, Xinjiang, China. *Ecol. Indic.* **2021**, *125*, 107576. [CrossRef]
77. Fischer, J.; Lindenmayer, D.B. Landscape modification and habitat fragmentation: A synthesis. *Global Ecol. Biogeogr.* **2007**, *16*, 265–280. [CrossRef]
78. Wierzcholska, S.; Dyderski, M.K.; Pielech, R.; Gazda, A.; Smoczyk, M.; Malicki, M.; Horodecki, P.; Kamczyc, J.; Skorupski, M.; Hachułka, M.; et al. Natural forest remnants as refugia for bryophyte diversity in a transformed mountain river valley landscape. *Sci. Total Environ.* **2018**, *640–641*, 954–964. [CrossRef]
79. Sánchez-Montoya, M.M.; Moleón, M.; Sánchez-Zapata, J.A.; Tockner, K. Dry riverbeds: Corridors for terrestrial vertebrates. *Ecosphere* **2016**, *7*, e01508. [CrossRef]
80. Allen, A.M.; Singh, N.J. Linking movement ecology with wildlife management and conservation. *Front. Ecol. Evol.* **2016**, *3*, 155. [CrossRef]
81. Sabo, J.L.; Sponseller, R.; Dixon, M.; Gade, K.; Harms, T.; Heffernan, J.; Jani, A.; Katz, G.; Soykan, C.; Watts, J.; et al. Riparian zones increase regional richness by harboring different, not more species. *Ecology* **2005**, *86*, 56–62. [CrossRef]
82. Mitchell, M.G.E.; Suarez-Castro, A.F.; Martinez-Harms, M.; Maron, M.; McAlpine, C.; Gaston, K.J.; Johansen, K.; Rhodes, J.R. Reframing landscape fragmentation's effects on ecosystem services. *Trends Ecol. Evol.* **2015**, *30*, 190–198. [CrossRef]
83. Ng, C.N.; Xie, Y.J.; Yu, X.J. Integrating landscape connectivity into the evaluation of ecosystem services for biodiversity conservation and its implications for landscape planning. *Appl. Geogr.* **2013**, *42*, 1–12. [CrossRef]
84. Peng, J.; Yang, Y.; Liu, Y.; Hu, Y.; Du, Y.; Meersmans, J.; Qiu, S. Linking ecosystem services and circuit theory to identify ecological security patterns. *Sci. Total Environ.* **2018**, *644*, 781–790. [CrossRef]
85. Shi, X.; Qin, M.; Li, B.; Zhang, D. A framework for optimizing green infrastructure networks based on landscape connectivity and ecosystem services. *Sustainability* **2021**, *13*, 10053. [CrossRef]

86. Lee, J.A.; Chon, J.; Ahn, C. Planning landscape corridors in ecological infrastructure using least-cost path methods based on the value of ecosystem services. *Sustainability* **2014**, *6*, 7564–7585. [CrossRef]
87. Fňukalová, E.; Zýka, V.; Romportl, D. The network of green infrastructure based on ecosystem services supply in Central Europe. *Land* **2021**, *10*, 592. [CrossRef]
88. Field, R.D.; Parrott, L. Mapping the functional connectivity of ecosystem services supply across a regional landscape. *eLife* **2022**, *11*, e69395. [CrossRef]
89. Lai, S.; Leone, F.; Zoppi, C. Land surface temperature and land cover dynamics. A study related to Sardinia, Italy. *TeMA J. Land Use Mobil. Environ.* **2020**, *13*, 329–351. [CrossRef]
90. Geneletti, D.; Cortinovis, C.; Zardo, L.; Blam Adel, E. *Planning for Ecosystem Services in Cities*; Springer: Dordrecht, Germany, 2019. [CrossRef]
91. Ustaoglu, E.; Aydınoglu, A. Land suitability assessment of green infrastructure development. A case study of Pendik District (Turkey). *TeMA-J. Land Use Mobil. Environ.* **2019**, *12*, 165–178. [CrossRef]
92. Lai, S.; Leone, F.; Zoppi, C. Spatial distribution of surface temperature and land cover: A study concerning Sardinia, Italy. *Sustainability* **2020**, *12*, 3186. [CrossRef]
93. Mayor of London. *London's Urban Heat Island: A Summary for Decision Makers*; Greater London Authority, City Hall: London, UK, 2006.
94. Pötz, H.; Sjauw En Wa-Windhorst, A.; van Someren, H. *Urban Green-Blue Grids Manual for Resilient Cities*; Atelier Groenblauw: Delft, The Netherlands, 2016.
95. Gómez-Baggethun, E.; Barton, D.N. Classifying and valuing ecosystem services for urban planning. *Ecol. Econ.* **2013**, *86*, 235–245. [CrossRef]
96. Mazzeo, G.; Zucaro, F.; Morosini, R. Green is the colour. Standards, equipment and public spaces as paradigm for the Italian sustainable city. *TeMA-J. Land Use Mobil. Environ.* **2019**, *12*, 31–52. [CrossRef]
97. Mathey, J.; Rößler, S.; Lehmann, I.; Bräuer, A. Urban green spaces: Potentials and constraints for urban adaptation to climate change. In *Resilient Cities. Cities and Adaptation to Climate Change. Proceedings of the Global Forum 2010, Munich, Germany, 19–20 May 2010*; Otto-Zimmermann, K., Ed.; Springer: Dordrecht, Germany, 2011; Volume 1, pp. 479–485. [CrossRef]
98. Jenning, V.; Larson, L.; Yun, J. Advancing sustainability through urban green space: Cultural ecosystem services, equity and social determinants of health. *Int. J. Environ. Res. Public Health* **2016**, *13*, 196. [CrossRef] [PubMed]
99. Webster, C. The new institutional economics and the evolution of modern urban planning: Insights, issues and lessons. *Town Plan. Rev.* **2005**, *76*, 455–502. [CrossRef]
100. Bramley, G.; Watkins, D.G. 'Measure twice, cut once'—Revisiting the strength and impact of local planning regulation of housing development in England. *Environ. Plan. B* **2014**, *41*, 863–884. [CrossRef]
101. Buijs, A.; Hansen, R.; Van der Jagt, S.; Ambrose-Oji, B.; Elands, B.; Lorance Rall, E.; Mattijssen, T.; Pauleit, S.; Runhaar, H.; Stahl Olafsson, A.; et al. Mosaic governance for urban green infrastructure: Upscaling active citizenship from a local government perspective. *Urban For. Urban Green.* **2019**, *40*, 53–62. [CrossRef]
102. Slätmo, E.; Nilsson, K.; Turunen, E. Implementing green infrastructure in spatial planning in Europe. *Land* **2019**, *8*, 62. [CrossRef]
103. Fors, H.; Frøik Molin, J.; Murphy, M.A.; Konijnendijk van den Boschab, C. User participation in urban green spaces—For the people or the parks? *Urban. For. Urban. Green.* **2015**, *14*, 722–734. [CrossRef]
104. Pérez-Urrestarazu, L.; Fernández-Cañero, R.; Franco-Salas, A.; Egea, G. Vertical greening systems and sustainable cities. *J. Urban. Technol.* **2015**, *22*, 65–85. [CrossRef]
105. Ryan, M.; O'Donoghue, C. Socio-economic drivers of farm afforestation decision-making. *Ir. For. J.* **2016**, *73*, 96–121.
106. Howley, P.; Buckley, C.; O'Donoghue, C.; Ryan, M. Explaining the economic 'irrationality' of farmers' land use behaviour: The role of productivist attitudes and non-pecuniary benefits. *Ecol. Econ.* **2015**, *109*, 186–193. [CrossRef]
107. Duesberg, S.; Ní Dhubháin, A.; O'Connor, D. Assessing policy tools for encouraging farm afforestation in Ireland. *Land Use Policy* **2014**, *38*, 194–203. [CrossRef]
108. Kumm, K.-I.; Hessle, A. Economic comparison between pasture-based beef production and afforestation of abandoned land in Swedish forest districts. *Land* **2020**, *9*, 42. [CrossRef]
109. Hyytiainen, K.; Leppanen, J.; Pahkasalo, T. Economic analysis of field afforestation and forest clearance for cultivation in Finland. In Proceedings of the International Congress of European Association of Agricultural Economists, Ghent, Belgium, 26–29 August 2008. [CrossRef]
110. Behan, J.; McQuinn, K.; Roche, M.J. Rural land use: Traditional agriculture or forestry? *Land Econ.* **2006**, *82*, 112–123. [CrossRef]
111. Zavalloni, M.; D'Alberto, R.; Raggi, M.; Viaggi, D. Farmland abandonment, public goods and the CAP in a marginal area of Italy. *Land Use Policy* **2021**, *107*, 104365. [CrossRef]
112. Kollányi, L.; Máté, K. Connectivity analysis for green infrastructure restoration planning on national level. In Proceedings of the Fábos Conference on Landscape and Greenway Planning 2016, Budapest, Hungary, 30 June–3 July 2016; Available online: https://scholarworks.umass.edu/fabos/vol5/iss1/30 (accessed on 30 June 2022).
113. Penko Seidl, M.; Golobič, M. Quantitative assessment of agricultural landscape heterogeneity. *Ecol. Indic.* **2020**, *112*, 106115. [CrossRef]
114. Ernoult, A.; Alard, D. Species richness of hedgerow habitats in changing agricultural landscapes: Are α and γ diversity shaped by the same factors? *Landscape Ecol.* **2011**, *26*, 683–696. [CrossRef]

115. Lenoir, J.; Decocq, G.; Spicher, F.; Gallet-Moron, E.; Buridant, J.; Closset-Kopp, D. Historical continuity and spatial connectivity ensure hedgerows are effective corridors for forest plants: Evidence from the species–time–area relationship. *J. Veg. Sci.* **2021**, *32*, e12845. [CrossRef]
116. Lai, S.; Leone, F.; Zoppi, C. Assessment of municipal masterplans aimed at identifying and fostering green infrastructure: A study concerning three towns of the metropolitan area of Cagliari, Italy. *Sustainability* **2019**, *11*, 1470. [CrossRef]
117. Oreszczyn, S.; Lane, A. The meaning of hedgerows in the English landscape: Different stakeholder perspectives and the implications for future hedge management. *J. Environ. Manag.* **2000**, *60*, 101–118. [CrossRef]
118. Gravsholt Busck, A. Hedgerow planting analysed as a social system—Interaction between farmers and other actors in Denmark. *J. Environ. Manag.* **2003**, *68*, 161–171. [CrossRef]
119. Cheng, J.; Meng, X.; Dong, S.; Liang, S. Generating the 30-m land surface temperature product over continental China and USA from Landsat 5/7/8 data. *Sci. Remote Sens.* **2021**, *4*, 100032. [CrossRef]
120. Li, J.; Wu, H.; Li, Z.-L. An optimal sampling method for multi-temporal land surface temperature validation over heterogeneous surfaces. *ISPRS J. Photogramm.* **2020**, *169*, 29–43. [CrossRef]

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Mapping of Ecological Corridors as Connections between Protected Areas: A Study Concerning Sardinia, Italy

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Abstract: According to the European Commission, green infrastructure and spatial connectivity concerning the provision of ecosystem services are strictly related to the conceptual category of ecological networks. In particular, regional and urban planning processes should adequately manage, improve and monitor the effectiveness of green infrastructures as ecological networks which provide ecosystem services and the spatial connectivity of such systems. Building on a methodological approach defined in previous studies, this article aims at identifying ecological corridors through a least-cost path model with reference to the spatial layout of a set of protected areas. Moreover, such a methodological approach is implemented in the context of the Sardinian region to map ecological corridors, which form, together with protected areas, a network representing the spatial framework of regional green infrastructure. Finally, the study discusses the relation between ecological corridors and the spatial taxonomy of the landscape components featured by environmental relevance, identified by the Regional Landscape Plan, through multiple linear regression analysis, in order to assess if, and to what extent, the present regional spatial zoning code can be used as a basis to implement regulations aimed at protecting ecological corridors. This methodological approach is relevant to defining planning policies and measures to strengthen the operational capacity and effectiveness of regional networks of protected areas through the protection and the improvement of the spatial framework of ecological corridors.

Keywords: ecological corridors; protected areas; landscape components; least-cost path model; multiple linear regression analysis

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1. Introduction

This study aims at defining and implementing a methodology to identify ecological corridors (ECs) as edges of spatial networks whose nodes are represented by areal units which provide a wide range of ecosystem services (ESs). This methodology detects ECs as important spatial structures aimed at improving the effectiveness of ecological networks by supporting their connection capacity for migration of wild species, their spatial layout and their potential in terms of genetic exchange. EC connection capacity can manifest through minimizing impacts on wild species and genetic flows coming from pressures generated by human activities, such as agriculture and forestry, air and water pollution, gray infrastructure and urban expansion. These threats could cause negative environmental effects as a consequence of the break–up of ecosystem matrices [1].

This study identifies a methodological approach to map ECs and implements such an approach with reference to a network of protected areas located in the spatial context of Sardinia, an Italian insular region. ECs form, together with protected areas, a network representing the spatial framework of regional green infrastructure (GI). Finally, the relation between the ECs and the spatial taxonomy of the landscape components featured by environmental relevance (LCFERs), identified by the Regional Landscape Plan (RLP), is analyzed, in order to assess if, and to what extent, the present regional spatial zoning code can be used as a basis to implement regulations aimed at protecting ECs.

The conceptual category of connectivity expresses more precisely than that of connection the capacity of connecting ESs, since it includes environmental and landscape aspects, such as the spatial position, the physical continuity, and the presence, type and dimension of natural and anthropic structures, and functional and ecological features, such as the functional perception of species, their ecological and behavioral needs, and their specialization characteristics as well [1–3]. This is in line with Baudry and Merriam [4] who claim that flows of species across ecological networks are often correlated to the connectivity of spatial, mostly linear, elements, which can be defined as ECs.

As per the operational definition of GIs given by the European Commission, spatial connectivity concerning the provision of ESs is strictly related to the conceptual category of ecological network, since a GI can be considered as "[A] strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ESs. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings" [5] (p. 3) and, "The work done over the last 25 years to establish and consolidate the network means that the backbone of the EU's GI is already in place. It is a reservoir of biodiversity that can be drawn upon to repopulate and revitalize degraded environments and catalyze the development of GI. This will also help reduce the fragmentation of the ecosystems, improving the connectivity between sites in the Natura 2000 Network and thus achieving the objectives of Article 10 of the Habitats Directive" [5] (p. 7). This implies that GIs and ESs are strictly related to each other, and that public policies should prioritize ecological networks in terms of environmental protection and enhancement [6]. As a consequence, regional and urban planning processes should adequately manage, improve and monitor the effectiveness of GIs as an ecological network which provides ESs and the spatial connectivity of such systems.

This also entails that GIs are particularly important as in the restoration of biodiversity, the decrease of ecosystem fragmentation and the increase of their capacity of providing ESs [7]. That being so, an operational management goal concerning GIs can be identified as its role in promoting and improving ES provision and habitat restoration [6,8].

The concept of landscape connectivity was introduced by Taylor et al. [9] as a relevant measure of the landscape structure in line with the theory developed by Dunning et al. [10]. According to Taylor et al. [9], landscape connectivity is defined as the "degree to which the landscape facilitates or impedes movement among resource patches" (p. 571). According to With et al. [11], landscape connectivity concerns "the functional relationship among habitat patches, owing to the spatial contagion of habitat and the movement responses of organisms to landscape structure" (p. 151).

In particular, the second definition reflects the dual nature of connectivity, which entails a structural and a functional dimension (structural connectivity, functional connectivity). Structural connectivity is environmentally oriented, while functional connectivity is species-oriented [12]. In this study, the second dimension of connectivity is considered and used. In a nutshell, functional connectivity concerns the movement capacity of species as a function of their intrinsic mobility and of spatial patch suitability to facilitate species movement [9,13].

The concept of landscape connectivity as a means to counter landscape fragmentation has been increasingly embedded into environmental policies, e.g., through technical categories such as greenways, GIs and ECs, in order to address the problem of biodiversity loss [14,15]. The concept of EC is treated in the literature with reference to different scientific and technical profiles (among many, [16–18]). According to Hess and Fisher [18], the use of the term "corridor" is associated with two important theories of conservation biology, i.e., island biogeography [19] and metapopulations [20], which focus on functional connectivity.

Functional connectivity is often analyzed through resistance-based models, where resistance "represents the willingness of an organism to cross a particular environment, the physiological cost of moving through a particular environment, the reduction in survival for the organism moving through a particular environment, or an integration of all these factors" [21] (p. 778). Resistance-based models are widely described and discussed in the literature. The most complex models, such as the circuit theory-based [22] and the individual-based models [23], are difficult to implement due to the overwhelming quantity of input data, and the needed accuracy in data collection and computational power [24]. Building on consolidated approaches available in the current technical and scientific literature [23,25], in this study a least-cost path (LCP) model is defined and implemented in order to identify the spatial structure of ECs.

The article is structured into four sections. In the next section, the study area is described with reference to the protected areas which are assumed as the nodes of the spatial layout of the Sardinian ecological network, and the LCP-based methodology adopted to identify ECs is presented. Moreover, the methodological approach used to analyze the spatial relationship between ECs and LCFERs, identified by the RLP, is described as well.

Section 3 shows the results concerning the identification of Sardinian ECs and the assessment of the relation between ECs and the LCFERs.

Policy implications are discussed in Section 4, whereas future research directions are proposed in the concluding section, with particular reference to the positive aspects and drawbacks of the study.

2. Materials and Methods

This section is organized as follows. The first subsection describes the study area and the set of protected areas that are identified as the nodes of the Sardinian regional ecological network. This subsection was written by Lai and reproduced from a previous article by Lai et al. [26]]. The following subsection presents the LCP-based methodological approach implemented to identify the ECs, which is based on studies by Cannas published in a set of articles between 2017 and 2018 [27–30]. Finally, the third subsection discusses the regression model used to assess the relation between ECs and the LCFERs, identified by the RLP. Figure 1 reports a diagrammatic representation of the methodology implemented in this study.

2.1. Study Area

Our case study is related to the Sardinian regional context. Sardinia is the second largest Italian island, located in the Western Mediterranean, with an area of around 24,000 km^2 [31]. Sardinia is part of the European Mediterranean biogeographical region [32,33].

Two regimes of environmental protection are identified by the Italian legislation, that is, natural protected areas (NPAs) and Natura 2000 sites (N2Ss). In this study, Sardinian NPAs and N2Ss are identified as the Sardinian natural protected sites (NPSs). The set of Sardinian NPSs is shown in Figure 2.

N2Ss are managed by the national government, whereas regional governments rule over the regional NPAs.

Four regional natural parks are established under the provisions of Regional Laws nos. 1999/4, 1999/5, 2014/20 and 2014/21 respectively, that is, Porto Conte, Molentargius-Saline, Gutturu Mannu and Tepilora.

Moreover, our study includes, among the regional NPAs, public woods, permanent oases of faunal protection and Ramsar sites. Public woods, managed by the Regional Agency of Forests, are characterized by significant environmental and landscape values, whose conservation and enhancement are important in order to address and mitigate negative impacts caused by natural disasters, such as fires, floods and landslides. Regional Law no. 1998/23 identifies the permanent oases of faunal protection. Nine Sardinian sites are protected under the provisions of the Ramsar Convention, signed in 1971.

As regards the N2Ss, the Natura 2000 Network includes areas designated under the provisions of Directive no. 92/43/EEC (the Habitats Directive) and Directive no. 2009/147/EC (the Birds Directive), and encompasses more than 27,000 sites, representing the backbone of the European Union's policies on the protection of nature and biodiversity [34]. N2Ss include the following: sites of community interest (SCIs) and special areas of conservation (SACs), established under the Habitats Directive, and special protection areas (SPAs), established under the Birds Directive. SPAs are designated by the European Union member states in relation to a number of scientific criteria, in order to provide bird protection. As regards SCIs and SACs, the designation process develops from Member States' proposals addressed to the European Commission which is responsible for their establishment. SCIs can become SACs within six years of their establishment, provided that conservation measures are identified. Sardinian N2Ss are classified as follows: 31 SPAs, 87 SACs and 10 SCIs [35].

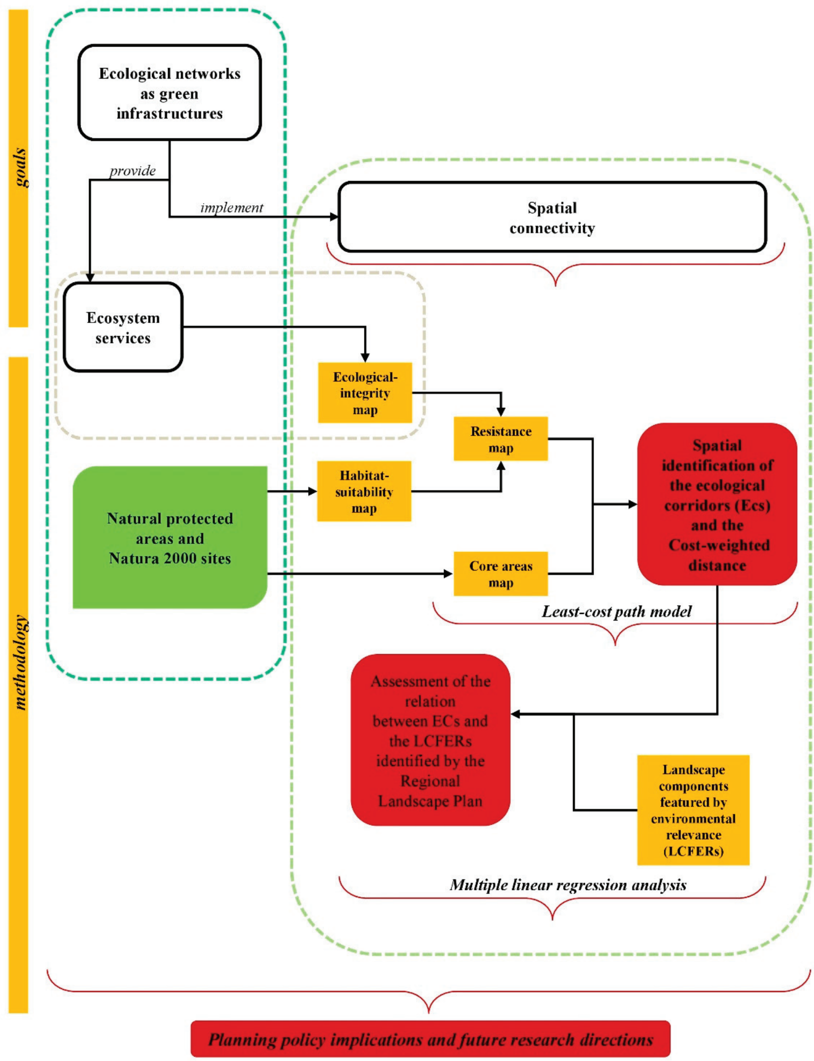

Figure 1. The methodological approach.

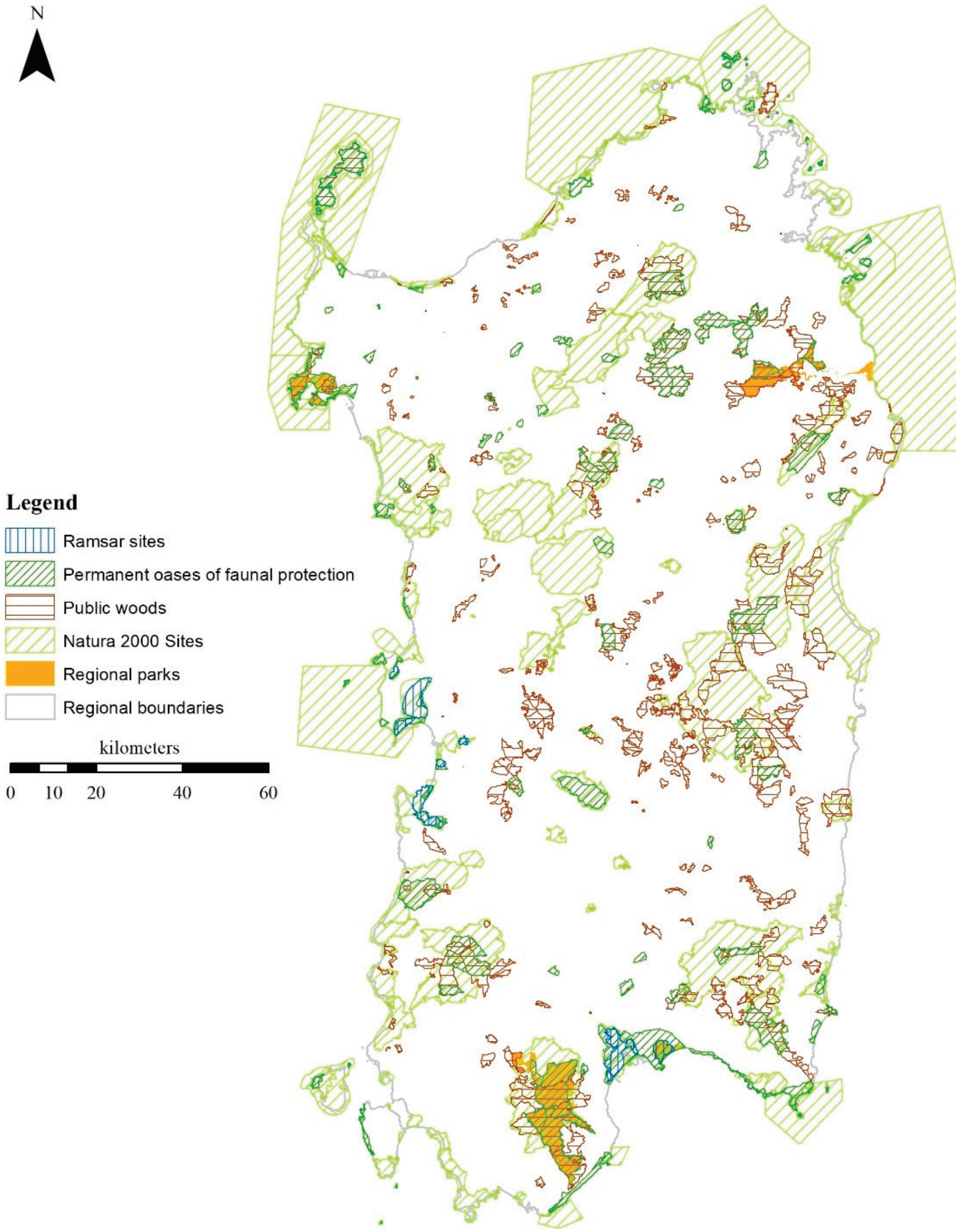

Figure 2. The system of the Sardinian protected areas.

2.2. Spatial Identification of the Ecological Corridors

LCP models detect spatially identified pathways, which connect habitat patches, characterized by the minimum resistance to species movement, or by the highest probability of movement to take place. LCP models postulate that organisms have an in-depth knowledge of the landscape that leads them to follow the optimal route [14].

According to Sawyer et al. [36], the attractiveness of this typology of models reflects three important points. First, LCP models make it possible to quantitatively compare potential movement paths within large areas. Secondly, the complex effects of habitats on species movement can be integrated into these models. Finally, LCP models go beyond the limits of analyses based exclusively on structural connectivity by incorporating the species' perception of the surrounding environment. LCP models are particularly effective regarding computational efficiency, model implementation ease, and flexibility related to the inclusion of different environmental profiles and aspects in the model structure [24,37,38]. LCP models often integrate experts' judgments into spatial datasets in order to identify resistance values of areal units [36,39–41].

Building on a methodology developed by Cannas [27–30], the spatial taxonomy of connectivity is identified on the basis of an LCP model, through four phases, as follows:

- definition of a habitat-suitability map;
- definition of an ecological-integrity map;
- definition of a resistance map;
- spatial identification of ECs.

The detail of the input data used in this study is reported in Table 1.

Table 1. Description, publication or creation year and source of input data used in this study.

Data	Description	Year	Source
Sardinian land cover map	Sardinian land cover map is a vector map produced by the Regional Administration of Sardinia, where land covers are classed in relation to four levels. The first three levels report the CLC nomenclature. Linear features include linear entities with a width of less than 25 m, related to roads, railways, and hydrography. As regards polygonal features, the minimum unit mapped is 0.5 hectares within the urban area and 0.75 hectares elsewhere	2008	https://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=14480&es=6603&na=1&n=100&esp=1&tb=14401 (accessed on 19 April 2022)
Species-specific values of habitat suitability	Habitat suitability species-specific values are defined within a study commissioned by the Regional Administration of Sardinia to AGRISTUDIO et al. [42]. The values concern species and habitats of community interest within the Sardinian N2Ss. The study provides habitat-suitability species-specific values, on an ordinal scale between 0 and 3 (0: non–suitable; 3: extremely suitable), for each CLC class of the Sardinian land cover map in relation to each Sardinian N2S. The evaluation is based on experts' judgments	2011	Unpublished work
Values of ecological integrity	Ecological integrity values are developed by Burkhard et al. [43,44] in relation to each of the 44 third-level land cover classes of the CLC taxonomy through experts' judgments. The ecological-integrity index is equal to the sum of the scores associated to seven ES-supply indicators (abiotic heterogeneity, biodiversity, biotic waterflows, metabolic efficiency, energy capture, reduction of nutrient loss and storage capacity)	2009	https://landscape-online.org/index.php/lo/article/view/LO.200915/67 (accessed on 19 April 2022)

Table 1. *Cont.*

Data	Description	Year	Source
Map of core areas	The map of core areas is a vector map, developed by the authors which combines different typologies of protected areas: national parks (NPs), regional parks (RPs), public woods (PWs), permanent oases of faunal protection (POFPs), Ramsar sites (RSs) and N2Ss	2009 as for NPs	https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:YDBMD (accessed on 19 April 2022)
		2013 as for RPs and RSs	https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:585dc615-71d2-4318-ade6-6b3341781987 (accessed on 19 April 2022)
		2009 as for PWs	https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:BLFQZ (accessed on 19 April 2022)
		2005 as for POFPs	https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:DSDPP (accessed on 19 April 2022)
		2013 as for RSs	https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:f52f111d-2a2e-4870-a623-6d6f11dc4f1d (accessed on 19 April 2022)
		2021 as for N2Ss	https://www.eea.europa.eu/data-and-maps/data/natura-13/natura-2000-spatial-data/natura-2000-shapefile-1 (accessed on 19 April 2022)
Landscape components featured by environmental relevance	The LCFER map is a vector map developed by the Regional Administration of Sardinia in relation to the RLP implementation code. As explained in Section 2.3, the LCFER map classifies the regional land into three typologies of areas: natural and subnatural, seminatural, and agricultural and forestry	2005	https://webgis2.regione.sardegna.it/geonetwork/srv/ita/catalog.search#/metadata/R_SARDEG:BYBET (accessed on 19 April 2022)

The first phase aims at defining a habitat-suitability map, where habitat suitability is defined as the probability of habitat use by species. The elaboration of this map is based on the Sardinian land cover vector map and on a study concerning species-specific values of habitat suitability. Land covers are classed according to the Sardinian land cover vector map produced by the Regional Administration of Sardinia in 2008, at the third level of the CORINE Land Cover (CLC) nomenclature. Moreover, species-specific values of habitat suitability are identified on the basis of a study by AGRISTUDIO et al. [42], commissioned by the Regional Administration of Sardinia, concerning the conservation status of species and habitats of community interest within the Sardinian N2Ss. The study provides habitat-suitability species-specific values, on an ordinal scale between 0 and 3 (0: non–suitable; 3: extremely suitable), for each CLC class of the Sardinian land cover map in relation to each Sardinian N2S. The evaluation is based on experts' judgments. A habitat-suitability map is elaborated on the basis of two assumptions. First, the habitat suitability species-specific values, associated with land cover classes located in the N2Ss by the AGRISTUDIO et al.'s [42] study, are associated with the same land cover classes of areas outside the N2Ss as well. Secondly, the total value of the species-specific habitat suitability associated with each land cover class is equal to the average value of the single species-specific values associated with the land cover class. Finally, a habitat-suitability vector map is defined, which identifies a taxonomy concerning the entire regional area.

The second phase aims at defining an ecological-integrity map, which builds on studies developed by Burkhard et al. [43,44], where an assessment of land cover classes' capacities to provide ESs is implemented through experts' judgments, on the basis of the founding concept that the higher the ecological integrity, the higher the suitability to species' transition and movement. Ecological integrity concerns supporting ESs defined as ESs which help to maintain and enhance the supply of the other types of ES, namely provisioning, regulating and cultural ES. The ecological-integrity index is equal to the sum of the scores associated with seven ES supply indicators (abiotic heterogeneity, biodiversity, biotic waterflows, metabolic efficiency, exergy capture, reduction of nutrient loss and storage capacity) that represent supporting ESs in relation to each of the 44 third-level land cover classes of the CLC taxonomy. As a result, by mapping the values of the ecological-integrity index, an ecological-integrity vector map is obtained for the entire regional area.

The third phase aims at defining the resistance map by means of the habitat-suitability and ecological-integrity maps, building on a study by LaRue and Nielsen [45]. First, the two vector maps are converted into raster maps; secondly, two maps are defined by mapping the inverse of the sum of the habitat suitability and of the ecological-integrity index; thirdly the new raster maps are scaled, on an ordinal scale between 1 and 100 (1: the lowest resistance; 100: the highest resistance), according to a study by the European Environment Agency [8]. Finally, the values of the two rescaled raster maps are summed-up and mapped on a patch-by-patch basis. The resulting spatial taxonomy is the resistance map.

The fourth phase aims at spatially identifying ECs that connect the Sardinian NPSs through the use of the Linkage Pathways Tool (LPT) of the GIS Linkage Mapper (LM) Toolbox. LPT implements the LCP approach by identifying the Cost-Weighted Distance (CWD) [46]. The LCP laying between two core areas is identified by the path which shows the minimum CWD. Input data required by the LPT are a vector map of core areas and a raster resistance map. In this study, each core area is identified either by a single NPS, in case the overlapping of multiple NPSs does not occur, or by the spatial envelope of overlapping NPSs, whereas phases 1 thru 3 identify the resistance map.

The CWD of a path between two core areas is obtained by: i. averaging the resistance values of pairs of adjacent patches; ii. multiplying such average values times the geometric distance of the patches' centers [47]; and, iii. Summing up the results of item ii. along the path.

The relevant outputs offered by LPT are the linear developments of the ECs and the raster map of the CWD values. Figure 3 shows the implementation of the LPT processing process.

LPT proceeds as follows, in order to identify the LCP between two core areas A and B.

First, the normalized distance related to each patch i connecting A and B, ND_{iAB}, is calculated, as follows:

$$ND_{iAB} = CWD_{iA} + CWD_{iB} - LCWD_{AB}, \quad (1)$$

where: ND_{iAB} is the normalized distance between A and B measured along a path which includes patch i; CWD_{iA} and CWD_{iB} are the cost-weighted distances from patch i to core areas A and B; and, $LCWD_{AB}$ is the least CWD, i.e., the CWD measured along the LCP connecting A and B [46].

Secondly, the LCP, i.e., the EC, connecting A and B, is identified by the spatial sequence of patches j's which show $ND_{iAB} = 0$.

2.3. Relation between ECs and Landscape Components

The LCFERs represent a spatial taxonomy of the regional land aimed at defining differentiated levels of protection depending on the value of nature and natural resources. This taxonomy was defined in the RLP approved by the Deliberation of the Sardinian Regional Government no. 36/7 of 5 September 2006, and implemented a protection regime which did not take account of ecological corridors, whereas their importance was recognized by art. 10 of the Habitats and Birds Directives, according to which ECs make the Natura 2000 Network internally connected from the functional and ecological points of view. As a consequence, ECs can be considered areal structures connecting habitats to enhance and support biodiversity, and, in so doing, increase the ES provision [29,30].

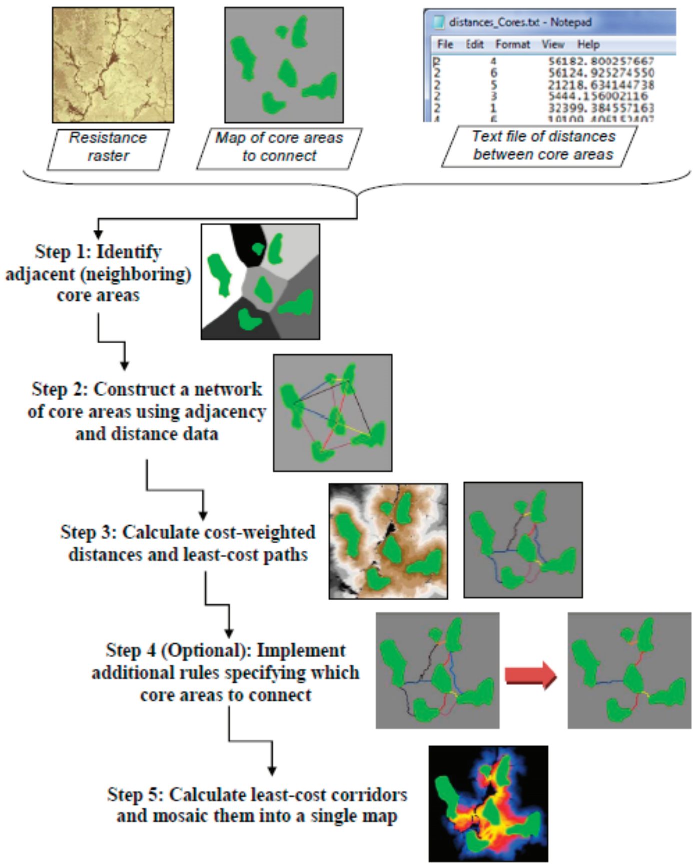

Figure 3. Processing process of LPT. Source: McRae and Kavanagh [46] (p. 11).

Thus, the implementation of EC protection into the Sardinian spatial planning framework, established under the provisions of the RLP code, has to be developed by identifying ECs as areas with the highest protection level among the LCFERs.

The spatial layout of ECs connecting core areas is defined by the raster map of CWD values clustered into ten deciles, whose second upper limit is assumed as the threshold for the inclusion of a patch in an EC [27]. The CWD of a patch j, included in an EC connecting the core areas A and B, is calculated as follows:

$$CWD_j = CWD_{jA} + CWD_{jB}, \quad (2)$$

where CWD_{jA} and CWD_{jB} are the cost-weighted distances from patch j to core areas A and B.

The assessment of the relations between ECs and LCFERs is implemented through a linear regression model which relates the eligibility of a patch to be included in an EC and the areas of the LCFERs overlaid by the corridors.

The LCFERs classed by the RLP implementation code (IC) are the following:

- natural and subnatural areas, which include: scrub vegetation in dry areas and wetlands (areas covered with sparse vegetation, between 5% and 40%; riparian areas covered with non–arboreal vegetation; Mediterranean scrub; river beds larger than

25 m; inland marshes; salt marshes; rock faces); and, woodlands (mixed coniferous and broadleaf woods; broadleaf woods);

- seminatural areas, which include: grasslands (steady meadows; natural pastures; thickets and shrublands; garrigues; natural recolonization areas); and, cork and chestnut woods;
- areas dedicated to agriculture and forestry, which include: specialized and tree crops (vineyards; orchards; temporary olive– and vineyard–related crops; temporary crops related to other permanent crops); artificial woods (coniferous woods; poplar, willow and eucalypt woods; other trees for timber; arboriculture with coniferous forest trees; artificial recolonization areas); and, specialized herbaceous crops, agricultural and forest areas, and uncultivated areas (non–irrigated arable land; artificial meadows; simple arable land and full-field horticultural crops; paddies; breeding grounds; greenhouse crops; complex parcel cropping systems; areas characterized by prevailing agricultural crops and residual important natural land; uncultivated areas).

According to the RLP IC, the protection regime concerning natural and subnatural areas forbids whichever spatial transformation, including new buildings or land use modifications, which is likely to undermine the ecosystem structure, steadiness and functionality, or the landscape enjoyment potential. As for dunal and retrodunal habitats featured by non–arboreal vegetation or Mediterranean scrub, vehicle and pedestrian access and temporary installations are not allowed if they may put at risk natural resources conservation. Moreover, the RLP IC forbids the implementation of spatial transformations which may cause water pollution or landfill as regards wetlands. Finally, afforestation is not allowed if potentially harmful to priority habitats designed by the Habitats and Birds Directives, with the exception of conservation operations.

As for seminatural areas, the RLP IC states that whichever spatial transformation, including new buildings or land use modifications, which is likely to undermine the ecosystem structure, steadiness and functionality, or the landscape enjoyment potential, is not allowed, with the exception of operations aimed at improving the ecosystems structure and functioning, the conservation status of biotic and abiotic natural resources, and at mitigating environmental hazard and degradation of natural resources. In woodlands, land-use modifications are forbidden except for land-use changes related to the development of new faunistic or floristic populations and to the enhancement of the habitats of protected wildlife. Moreover, new facilities are not permitted, whereas restoration of existing buildings is allowed provided that they will be used to improve the conditions of nature and natural resources, and that the operations do not entail an increase in building volume, floor area and covered surface.

New infrastructure, such as roads, power lines, hydraulic pipelines, etc., which may alter the forest land cover or increase fire or pollution hazards are not allowed in seminatural areas, with the exception of operations aimed at forest management and soil protection. Furthermore, the RLP IC forbids new roads, power lines and wind turbines close to wetlands and to areas characterized by the presence of species of community interest, especially with reference to birdlife, which may generate negative impacts on the landscape perception. River systems and riparian areas have to be protected from soil–sealing operations, afforestation implemented by using alien species and removal of sand and sediments from the river beds.

As for dunal systems and sandy seashores, vehicle traffic is strictly forbidden, and sand and sediment removal are not allowed as well. Finally, a general rule concerning seminatural areas concerns a ban on the use of alien species for afforestation, reforestation, and renaturation.

With reference to areas dedicated to agriculture and forestry, and uncultivated areas, the RLP IC forbids transitions from agriculture and forestry to other land uses, with the exception of changes motivated by reasons related to the implementation of relevant public utilities for which it is demonstrated that no other location is presently available. Limited land-use transitions are allowed to make more effective infrastructure, facilities and machinery exclusively devoted to agriculture or forestry. Moreover, the biodiversity improvement as regards native species of agrarian interest, the conservation of local traditional agricultural systems and the protection of typical rural scenery are indicated as important addresses, stated as planning rules as per art. 29 of the RLP IC, in particular with reference to periurban zones and historic terrace farming areas.

All in all, the RLP IC identifies rules concerning natural, subnatural and seminatural areas which are almost entirely consistent with a nature protection regime aimed at strengthening the effectiveness of ECs. The main regulatory feature of the RLP IC with respect to these areas is the general objective of protecting the structure and functionality of ecosystems, biodiversity, nature and natural resources, with particular attention to habitats and species identified by the Habitats and the Birds Directives, dunal and coastal environments, and wetlands as main sources of biodiversity, especially as regards birdlife. In woodlands, modifications of land use are not allowed, except for the improvement of wildlife habitats and an increase in faunistic and floristic populations. Rules concerning agriculture and forestry are less restrictive since land-use transitions are allowed if they aim at improving farm and forest productivity, even though protection of traditional practices, scenery and biodiversity protection with reference to rural landscapes and environments are targeted as important planning policy goals.

The relation between ECs and the LCFERs described so far is analyzed through a multiple linear regression model which assesses the correlations between CWD and the areas of the LCFERs which overlay ECs. The model takes the following form:

$$\text{ECWD} = \beta_0 + \beta_1\text{SCRB} + \beta_2\text{WOOD} + \beta_3\text{GRAS} + \beta_4\text{CCHW} + \beta_5\text{SPTC} + \beta_6\text{ARWO} + \beta_7\text{HAFU} + \beta_8\text{ALTD}, \quad (3)$$

where dependent and explanatory variables identify the areal dimensions of ECs and of the overlays of ECs and the LCFERs:

- ECWD is the CWD of a patch included in an EC;
- SCRB is for scrub vegetation in dry areas and wetlands;
- WOOD is for woodlands;
- GRAS is for grasslands;
- CCHW is for cork and chestnut woods;
- SPTC is for specialized and tree crops;
- ARWO is for artificial woods;
- HAFU is for specialized herbaceous crops, agricultural and forest areas, and uncultivated areas;
- ALTD is a control variable that represents the average altitude in an EC.

The outcomes of the regression model identify the quantitative correlations between the linear dimension of ECs, ECWD, and the presence of LCFERs.

As per many studies related to correlations between spatial variables, a regression model is used since no prior hypothesis seems to be plausible as regards the effect of covariates on the dependent variable (among many: [48–51]).

Thus, a surface, characterized by an unknown equation, representing a spatial phenomenon featured by n factors, is approximated, in an infinitesimal neighborhood of one of its points, by its tangential hyperplane. The infinitesimal area shared by the hyperplane and the surface is identified by the known equation of the tangential hyperplane, that is, by the linear relation between the covariates. Such linear relation locally approximates the unknown surface. That being so, the multiple regression model (3) estimates the trace of an eight-dimensional hyperplane on an eight-dimensional surface whose equation is unknown [52,53], which shows the linear correlations between ECWD and the eight dependent variables defined above.

The variable ALTD is utilized as a control variable to check the effect of the altitude of an EC on its areal dimension; so, if the estimate of the coefficient β_8 were significant, this would imply that the altitude is likely to cause a relevant impact on ECWD. The sign of the estimated coefficient indicates if the impact is positive or negative, i.e., if the greater the altitude, the lower ECWD, or the other way around.

Finally, a 5% *p*-value significance test is used with reference to the estimated coefficients of model (3) to see if their estimates are significantly different than zero.

3. Results

This section is organized as follows. The first subsection presents the spatial layout of the ECs identified through the implementation of the methodology described in Section 2.2. The following subsection operationalizes the regression model defined in Section 2.3.

3.1. The Spatial Layout of Ecological Corridors

The implementation of the methodological approach developed by Cannas [27–30], and described in Section 2.2, is developed through four phases, which each generates one or more outputs necessary to carry out the following phase.

The first phase provides a habitat-suitability map (see Figure 4), where habitat suitability species-specific values range from 0.1 to 1.65.

The second phase produces an ecological-integrity map (see Figure 5), where ecological integrity values range from 0.1 to 32.

The third phase delivers a resistance map (see Figure 6), where resistance values range from 2 to 200.

The last phase generates two outputs: i. the raster map of the CWD values; ii. the spatial identification of the ECs that connect the NPSs of the Sardinian protected area network. Figure 7 shows the ECs identified in the study area and Figure 8 reports the CWD values, included in a range between 0 to 225,201 km. As described in Section 2.3, the CWD values are clustered into ten deciles, whose second upper limit is assumed as the threshold for the inclusion of a patch in an EC. The CWD values included in the first two deciles range from 0 to 9741 km. In Figures 7 and 8, the ECs are shown as linear elements.

Through LPT, 240 ECs are identified, with CWD ranging between 0.07 km and 27.34 km. Moreover, two important qualitative attributes of the ECs connecting two core areas have to be emphasized: the ratio of the CWD to the Euclidean distance (CWD/ED) and the ratio of CWD to the length of the EC (CWD/LCP) [54,55]. The former measures the resistance to species movement between two core areas in relation to their proximity, i.e., the connectivity quality of the connecting EC, as long as the latter identifies the average resistance to species movement along with the EC which connects two core areas.

With reference to the CWD/ED index, ECs nos. 22, 112, and 122 show the lowest values and, as a consequence, the highest connectivity quality (see Table 2 and Figure 9), whereas ECs nos. 12, 228, and 9 show the highest values and, that being so, the lowest connectivity quality (see Table 2 and Figure 10).

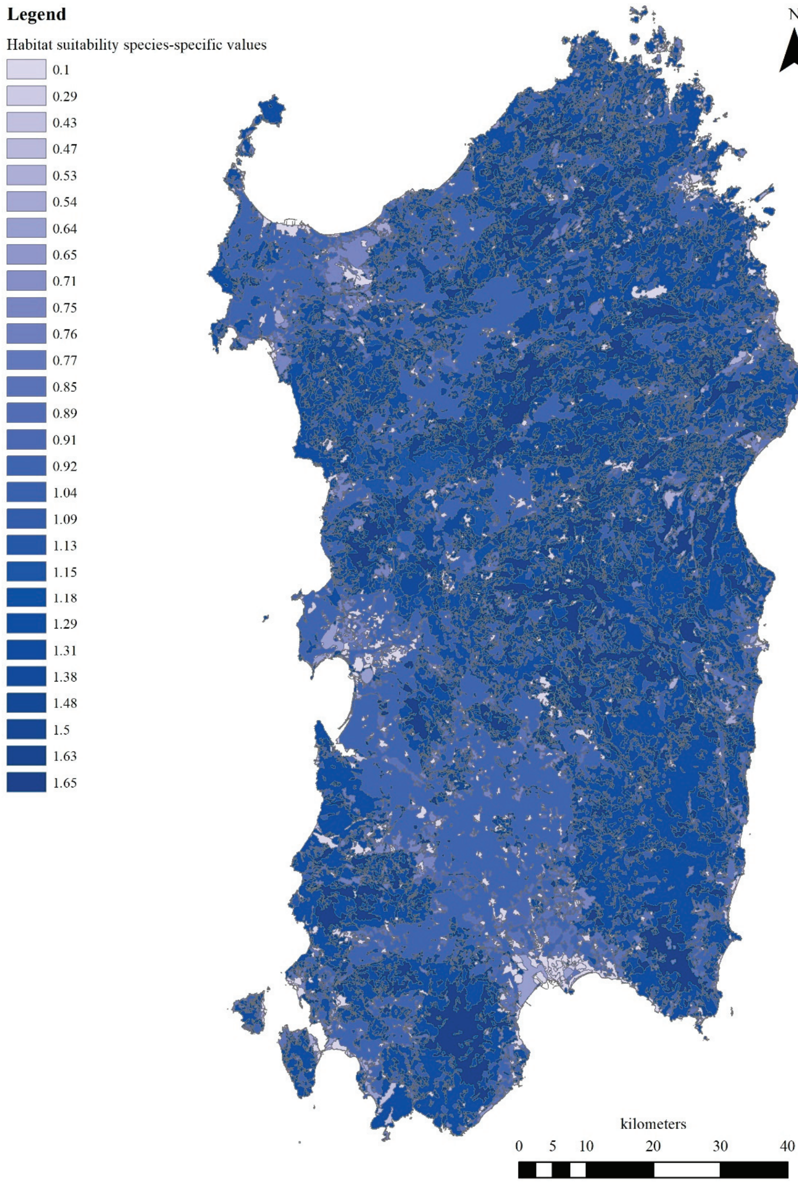

Figure 4. Habitat-suitability map.

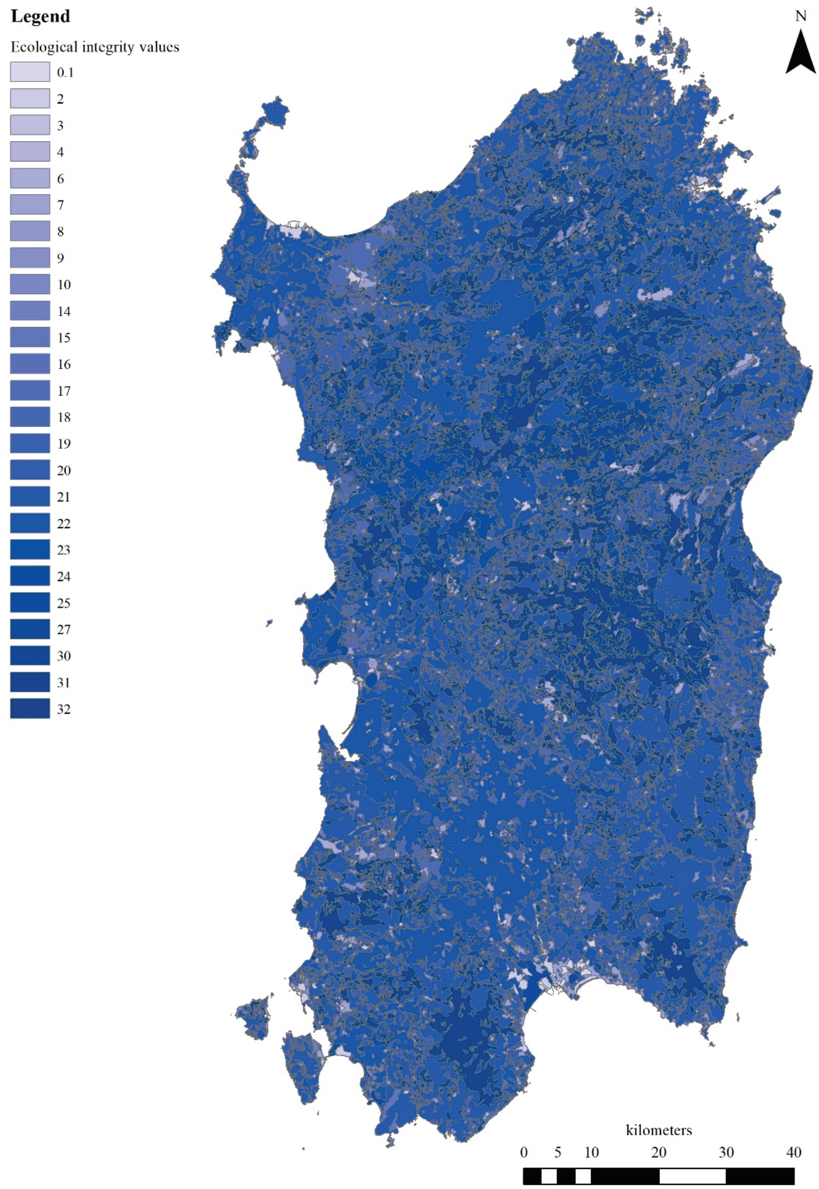

Figure 5. Ecological-integrity map.

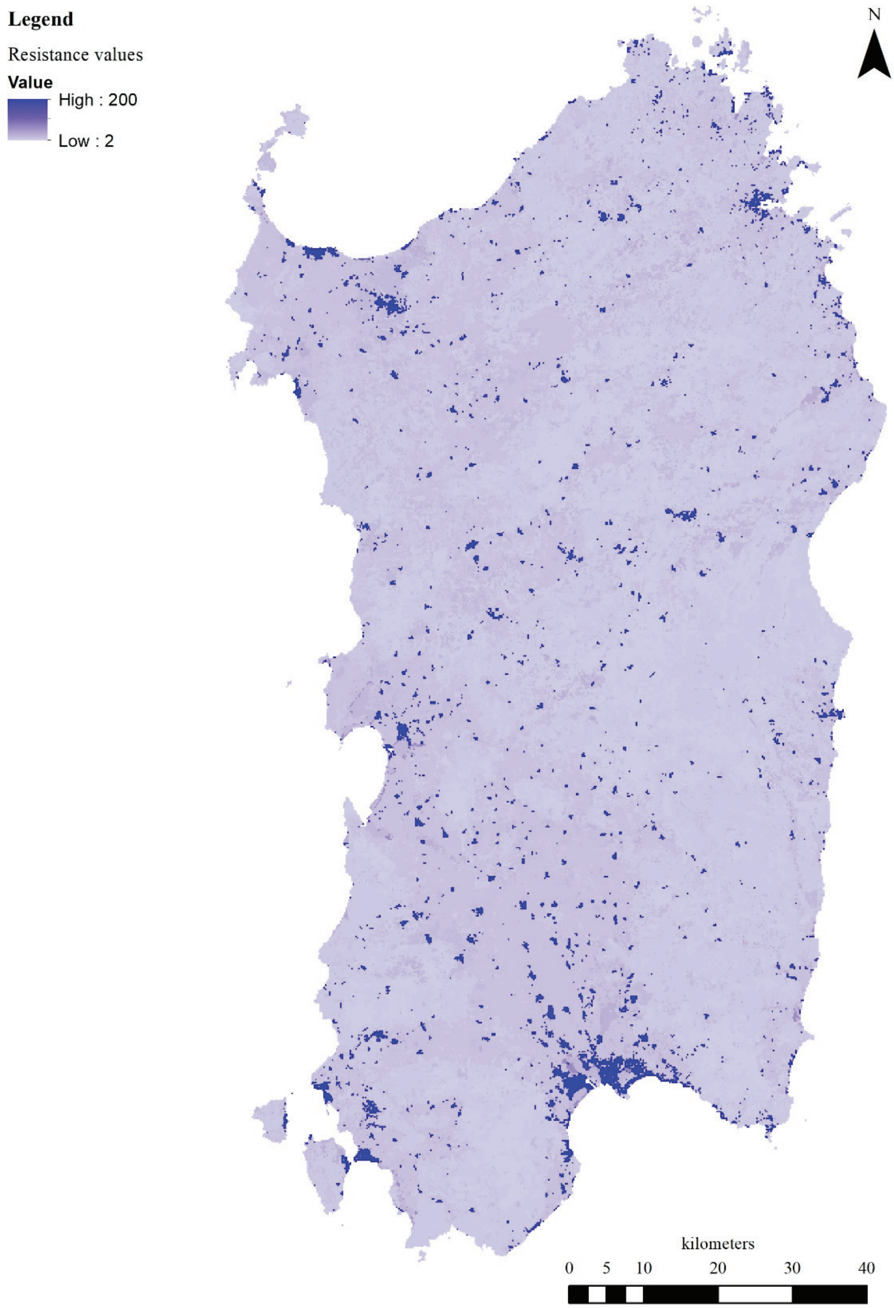

Figure 6. Resistance map.

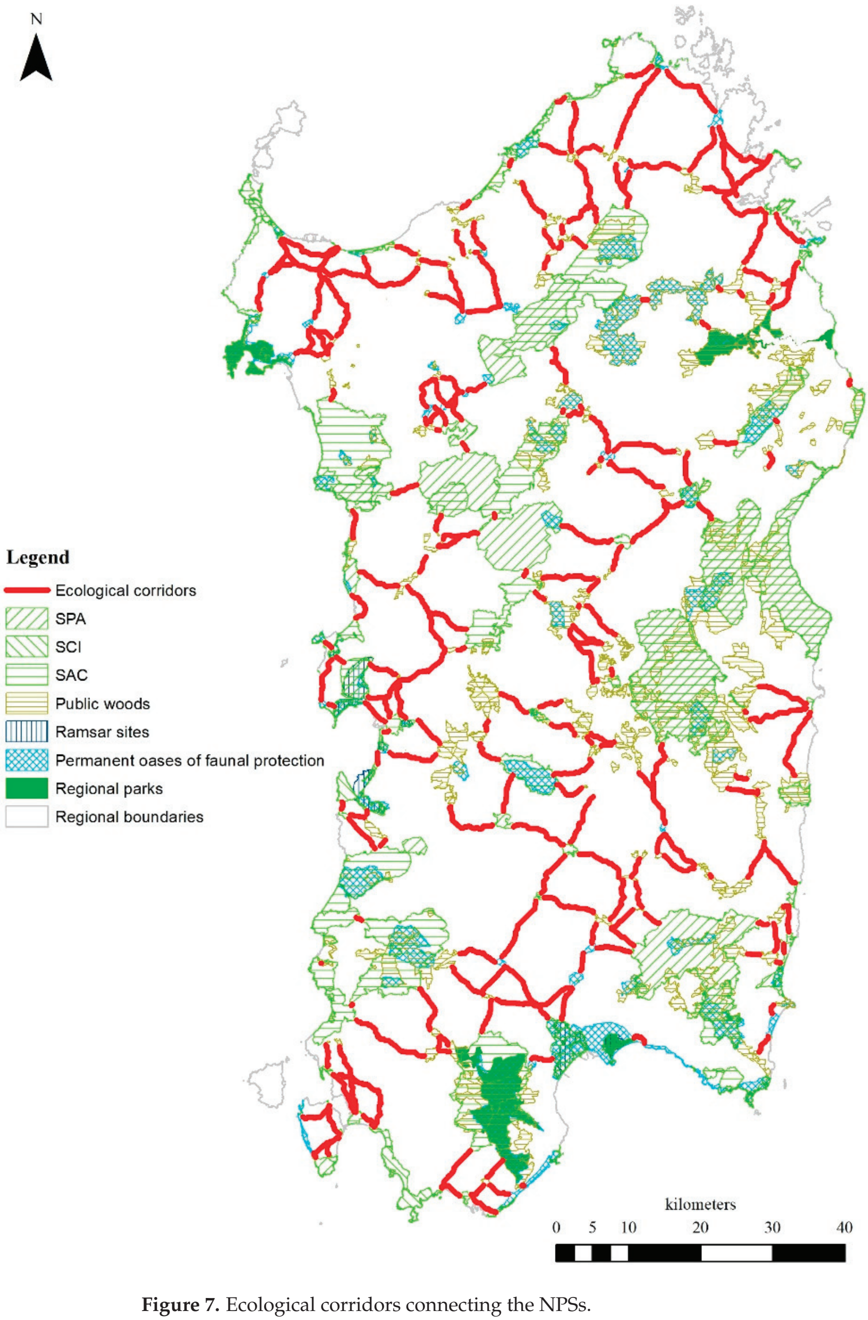

Figure 7. Ecological corridors connecting the NPSs.

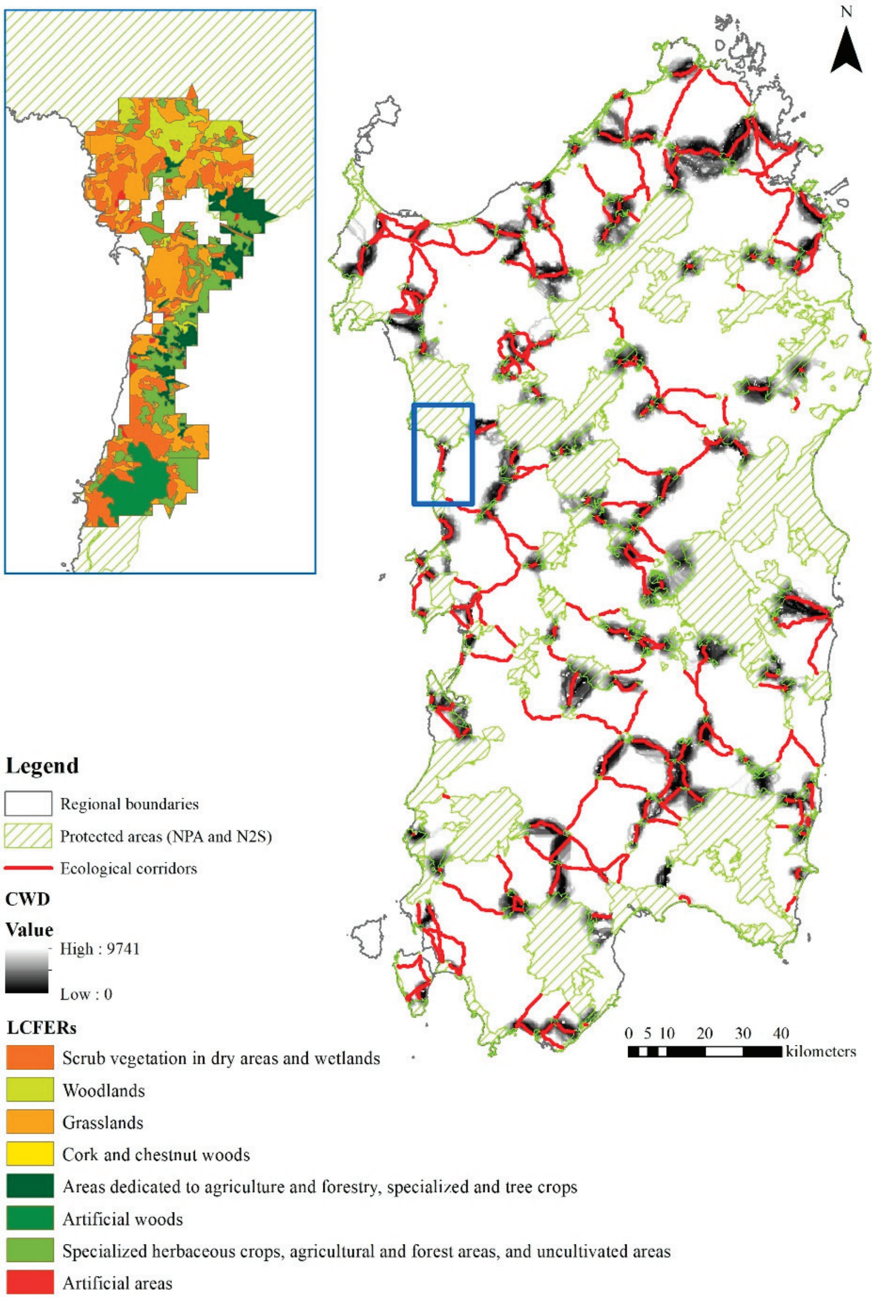

Figure 8. Identification of ecological corridors and of CWD values included in the second's upper limit decile (map on the **right**), and the overlapping map of CWD values and the LCFERs (**upper-left** map).

Table 2. Name and typology of NPSs included within core areas connected by EC which shows the highest and lowest values of CWD/ED index and CWD/LCP index.

EC Code	Core Area Code	Name of Connected NPSs	Typology of NPSs
22	7	Monte dei Sette Fratelli	SPA
		Monte dei Sette Fratelli e Sarrabus	SAC
		Monte Genis	Permanent oases of faunal protection
		Castiadas-Sette Fratelli	Permanent oases of faunal protection
		Campidano	Permanent oases of faunal protection
		Campidano	Public woods
		Campidano Santo Barzolu	Public woods
		Castiadas	Public woods
		San Vito	Public woods
		Sa Scova	Public woods
		Sette Fratelli	Public woods
		Villasalto	Public woods
	24	Baccu Arrodas—Rio Molas	Public woods
122	47	Olzai	Public woods
	148	Monte Gonare	SAC
112	49	Ussai	Permanent oases of faunal protection
		Barigadu	Public woods
	40	Foresta di Uatzo	Public woods
12	4	Parco Naturale Regionale di Molentargius saline	Natural regional park
		Monte Sant'Elia, Cala Mosca e Cala Fighera	SAC
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC
		Stagno di Molentargius e territori limitrofi	SAC
		Torre del Poetto	SAC
		Stagno di Cagliari	SPA
		Saline di Molenatrgius	SPA
		Santa Gilla	Permanent oases of faunal protection
		Stagni di Quartu Molentargius	Permanent oases of faunal protection
		Stagno di Molentargius	Ramsar Site
		Stagno di Cagliari	Ramsar Site
	10	Bruncu de Su Monte Moru—Geremean (Mari Pintau)	SAC
		Costa di Cagliari	SAC
		Capo Carbonara e stagno di Notteri—Punta Molentis	SPA
		Fascia litoranea sud orientale	Permanent oases of faunal protection

Table 2. *Cont.*

EC Code	Core Area Code	Name of Connected NPSs	Typology of NPSs
228	140	Stagno di Santa Caterina	SAC
	152	Stagno di Porto Botte	SAC
		Isola Rossa e Capo Teulada	SCI
		Promontorio, dune e zona umida di Porto Pino	SCI
9	3	Sassu-Cirras	SAC
		Stagno di S'Ena Arrubia e territori limitrofi	SAC
		Stagno di S'Ena Arrubia	SPA
		S'Ena Arrubia	Permanent oases of faunal protection
		S'Ena Arrubia	Ramsar Site
	5	Stagno di Pauli Maiori di Oristano	SAC
		Stagno di Santa Giusta	SAC
		Stagno di Pauli Maiori	SPA
		Pauli Maiori	Permanent oases of faunal protection
		Stagno di Pauli Maiori	Ramsar Site
192	80	Altopiano di Campeda	SAC
		Catena del Marghine e del Goceano	SAC
		Piana di Semestene, Bonorva, Macomer e Bortigali	SPA
		Monte Pisanu	Permanent oases of faunal protection
		Foresta Anela	Permanent oases of faunal protection
		Anela	Public woods
		Bono	Public woods
		Monte Artu	Public woods
		Monte Bassu	Public woods
		Monte Burghesu	Public woods
		Monte Pisanu	Public woods
	81	Foresta Fiorentini	Permanent oases of faunal protection
		Fiorentini	Public woods
		Monte Pirastru	Public woods
119	43	Pabarile	Public woods
	142	Riu Sos Mulinos—Sos Lavros—M. Urtigu	SAC

Table 2. *Cont.*

EC Code	Core Area Code	Name of Connected NPSs	Typology of NPSs
14	4	Parco Naturale Regionale di Molentargius saline	Natural regional park
		Monte Sant'Elia, Cala Mosca e Cala Fighera	SAC
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC
		Stagno di Molentargius e territori limitrofi	SAC
		Torre del Poetto	SAC
		Stagno di Cagliari	SPA
		Saline di Molenatrgius	SPA
		Santa Gilla	Permanent oases of faunal protection
		Stagni di Quartu Molentargius	Permanent oases of faunal protection
		Stagno di Molentargius	Ramsar Site
		Stagno di Cagliari	Ramsar Site
	15	Ovile Sardo	Permanent oases of faunal protection

As regards the CWD/LCP index, ECs nos. 192, 119, and 112 show the lowest values and, as a result (see Table 2 and Figure 11), the lowest average resistance to species movement along the path, while ECs nos. 12, 228, and 14 show the highest values and, for that reason, the highest average resistance to species movement (see Table 2 and Figure 12).

3.2. Discussion on the Overlay of Ecological Corridors and Landscape Components

The estimated coefficients of the explanatory variables of model (3) show the correlations between the ECWD of a parcel included in an EC and the covariates of the multiple linear regression, identified by the LCFERs and by the control variable ALTD.

The descriptive statistics related to dependent and explanatory variables of model (3) are shown in Table 3, whereas Table 4 reports the estimates of the multiple linear regression.

The estimated coefficient of the altitude-related variable shows significant p-values and a positive sign. This implies that a decrease in ECWD is associated with lower altitudes, everything else being equal, which is entirely consistent with expectations, since higher connectivity, or lower ECWD, is expected to take place in flat areas, generally characterized by comparative lower altitudes. Our findings entail that a decrease of 100 m in altitude will be correlated to a decrease of about 145 m in ECWD.

Since the estimate of the coefficient of the control variable is statistically significant and consistent with expectations, the estimated effects on ECWD generated by the covariates related to the LCFERs can be considered reliable as regards the implementation of model (3).

The results of the coefficient estimate of model (3), reported in Table 4, are related to the explanatory variables expressed by the percentage share of the area of a landscape component in the total area of a patch. Such estimates show the marginal effects of the explanatory variables on ECWD. The estimates exhibit p-values lower than 6.6%, with the exception of scrub vegetation in dry areas and wetlands (SCRB), which, at any rate, shows a weakly significant p-value (10.8%). The comprehensive goodness of fit is also endorsed by the value of the adjusted correlation coefficient, which exceeds 70%.

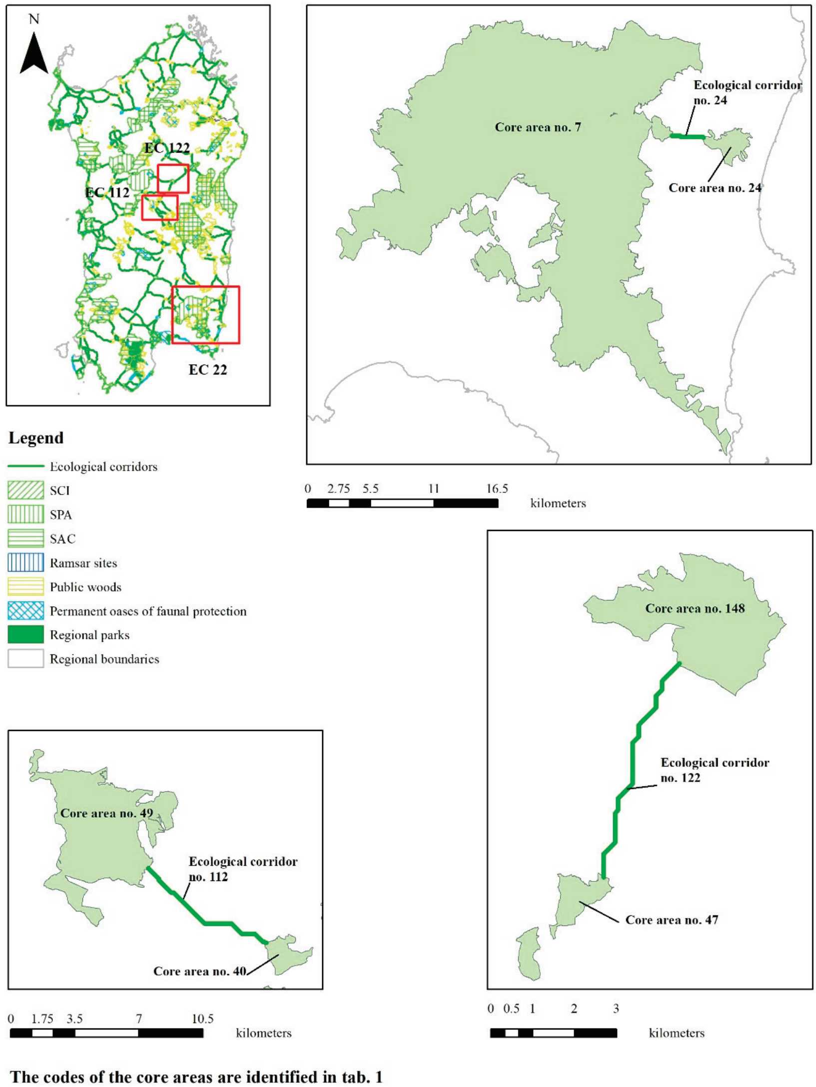

Figure 9. Spatial identification of the ECs which show the lowest values of the CWD/ED index.

Moreover, the regression results put in evidence that all the LCFERs are correlated to increases in the eligibility of a patch to be included in an EC, i.e., an increase in the percentage area of an LCFER is correlated to a decrease in ECWD everything else being equal, except for specialized and tree crops (SPTC), whose coefficient is positive and indicates that an average increase of 1% in SPTC is associated to an average increase of 7.7 m in the CWD of ECs.

As for the other LCFERs, the outcomes show that woodlands (WOOD) and cork and chestnut woods (CCHW) are the most suitable to enhance the effectiveness of ECs, since their marginal effects on ECWD imply that a 1% increase is correlated to 7.2- and 6.9-meter decrease in average CWD, respectively. Less relevant positive effects on the eligibility of a patch to be included in an EC are exhibited by grasslands (GRASS) and artificial woods (ARWO), whose marginal effects on ECWD are 5.81 and 5.33 m. The impacts of the covariates associated to scrub vegetation in dry areas and wetlands (SCRB), and specialized herbaceous crops, agricultural and forest areas and uncultivated areas (HAFU), are definitely less important since their coefficients entail that an average increase of 1% is correlated to a 2.77- and 3.16- meter decrease in ECWD, respectively.

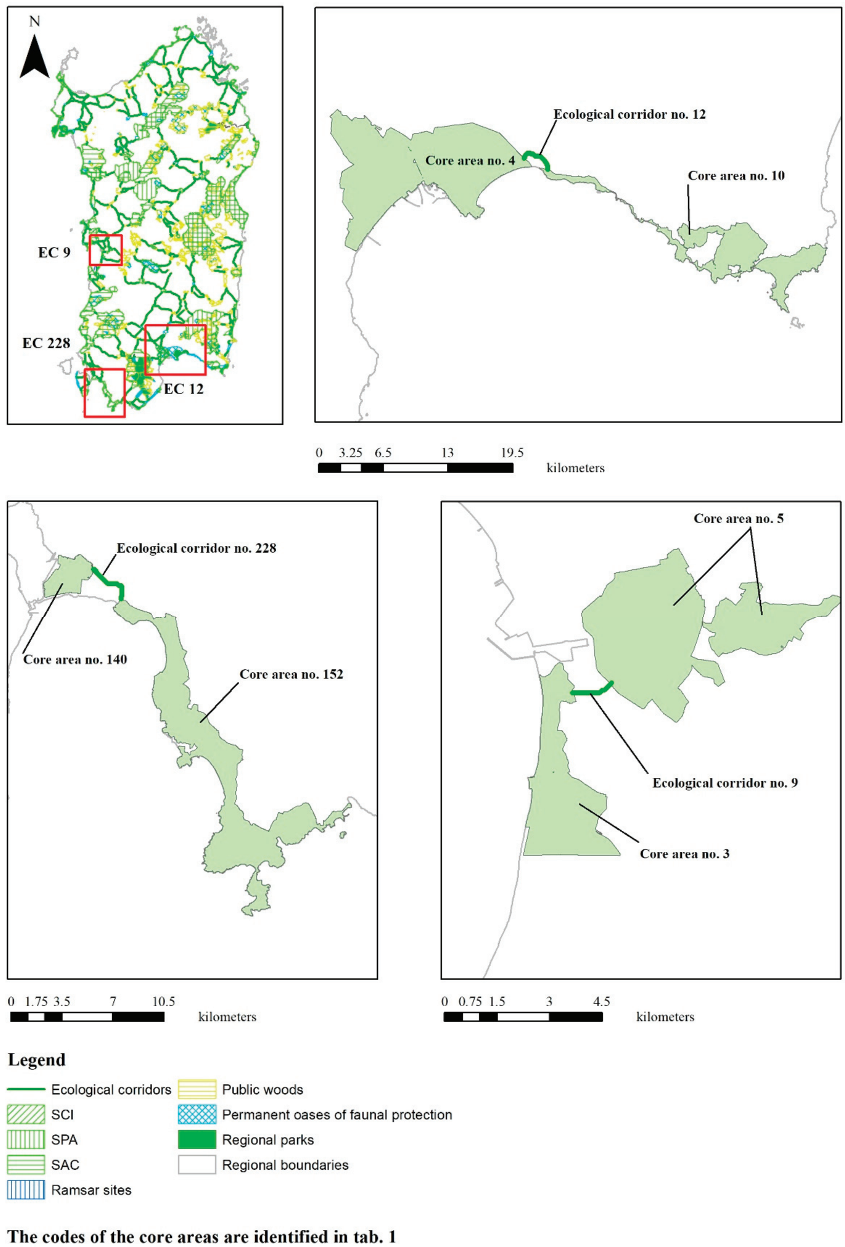

Figure 10. Spatial identification of the ECs which show the highest values of the CWD/ED index.

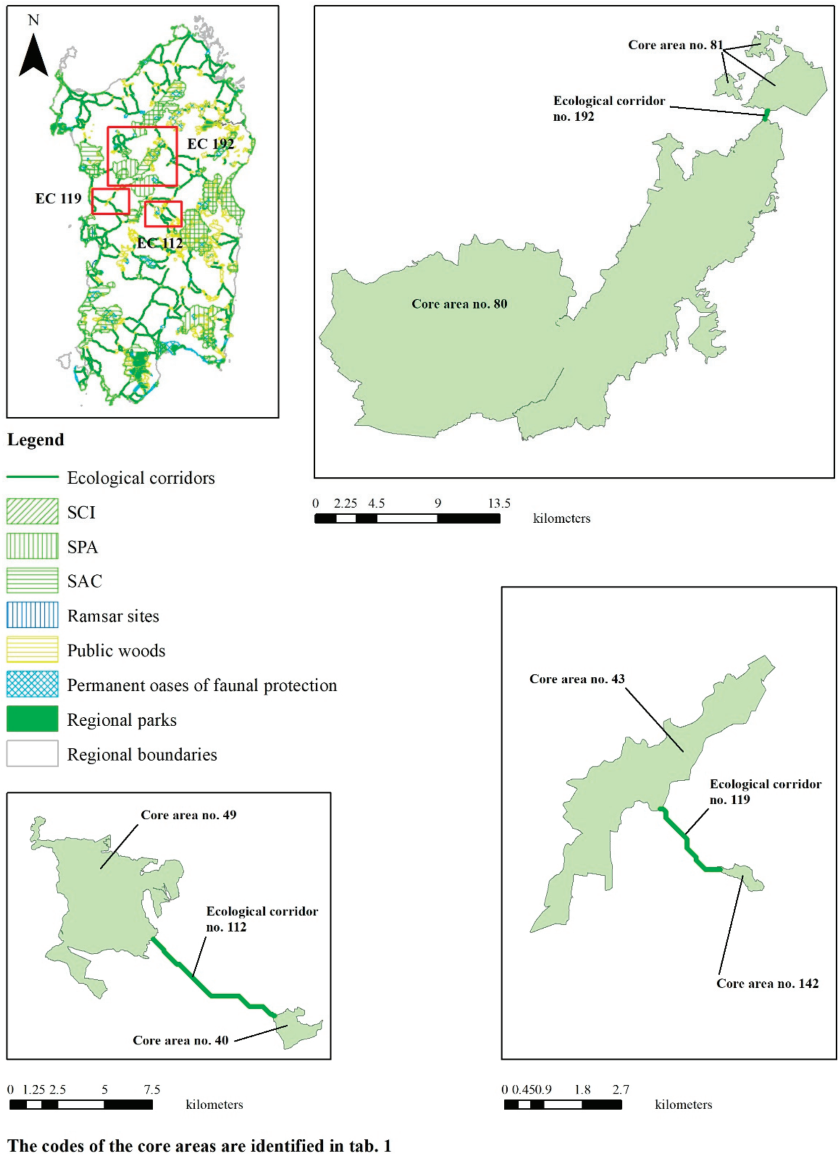

Figure 11. Spatial identification of the ECs which show the lowest values of the CWD/LCP index.

These outcomes make it easy to identify relevant planning policy implications related to the enhancement of the regional network of protected areas through the protection and the improvement of its ECs.

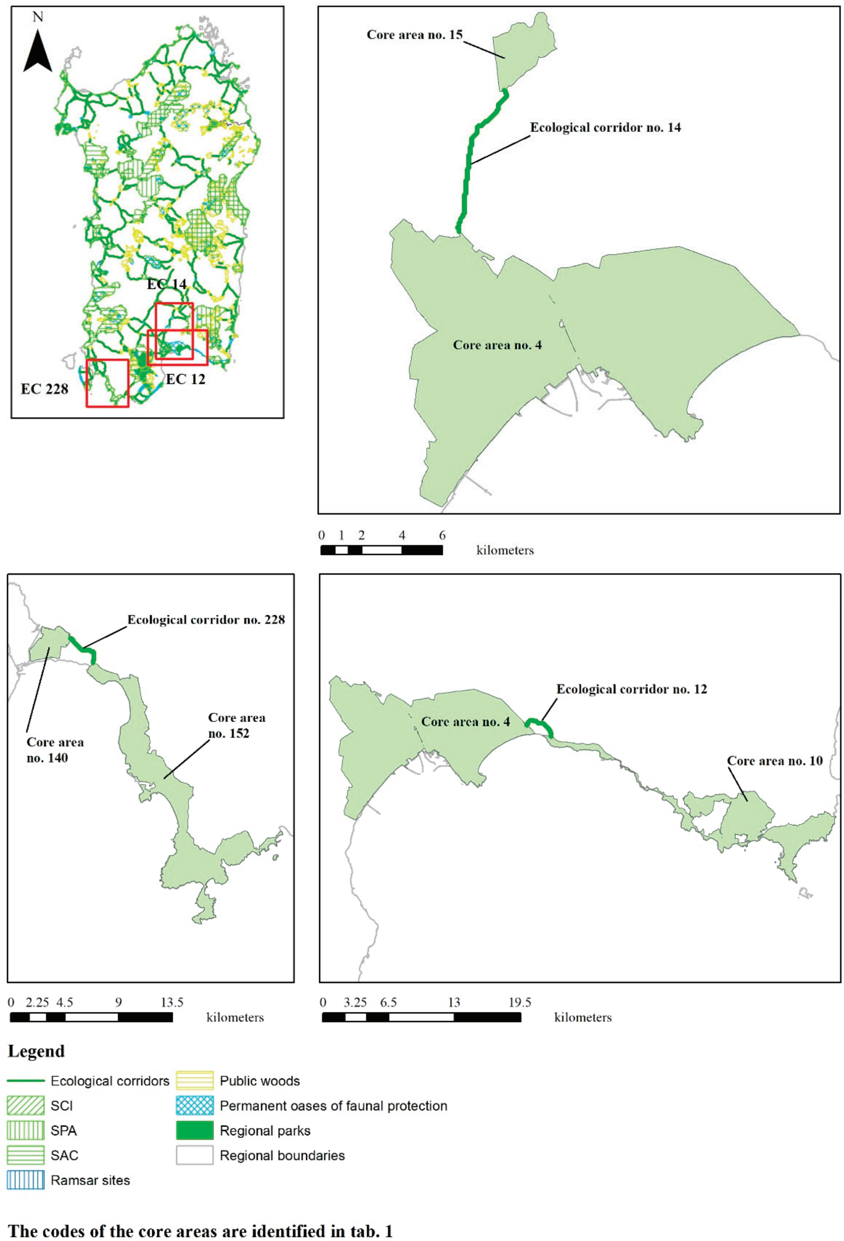

Figure 12. Spatial identification of the ECs which show the highest values of the CWD/LCP index.

Table 3. Definition of variables and descriptive statistics related to model (3).

Variable	Definition	Mean	St.dev.
ECWD	Cost–weighted distance of a patch included in an EC (km)	4947.08	2865.14
SCRB	Scrub vegetation in dry areas and wetlands in a patch included in an EC (ha)	16,962.44	26,775.40
WOOD	Woodlands in a patch included in an EC (ha)	18,038.76	29,513.47
GRAS	Grasslands in a patch included in an EC (ha)	18,879.67	27,314.39
CCHW	Cork and chestnut woods in a patch included in an EC (ha)	3190.58	12,865.24
SPTC	Specialized and tree crops in a patch included in an EC (ha)	3107.70	11,326.36
ARWO	Artificial woods in a patch included in an EC (ha)	4721.13	16,500.74
HAFU	Specialized herbaceous crops, agricultural and forest areas, and uncultivated areas, in a patch included in an EC (ha)	23,207.82	31,984.68
ALTD	Control variable which represents the average altitude in a patch included in an EC (m)	365.36	275.76

Table 4. Estimate of multiple linear regression model (3).

Variable	Coefficient	*t*-Statistic	*p*-Value
SCRB	−2.77172	−1.60534	0.108428
WOOD	−7.20867	−4.16805	0.000031
GRAS	−5.80510	−3.35834	0.000785
CCHW	−6.91227	−3.49271	0.000479
SPTC	7.70003	3.69729	0.000218
ARWO	−5.33205	−2.85482	0.004309
HAFU	−3.16692	−1.84476	0.065081
ALTD	1.45191	22.37541	0.000000
Adjusted R-squared: 0.7123			

4. Discussion

The results of model (3), shown in the third section, make it possible to assess if, and to what extent, the current zoning code of the RLP can represent a solid basis for effectively protecting ECs, and highlight important implications for spatial planning practice.

The transition from agricultural to forest land uses, which should be supported by financial grants aimed at compensating differential yields, is associated with a decrease in CWD, and, as a consequence, a strengthening in the EC's spatial structure.

Planning measures focused on agroforestry transition are more straightforward and easier to implement as regards the areas classed as HAFU (as for specialized herbaceous crops, agricultural and forest areas, and uncultivated areas), and, even more, with reference to zones classed as SPTC (as for temporary crops related to other permanent crops). On the other hand, land cover transitions from intensive agricultural production areas, characterized by high crop yields, to less profitable woodlands (WOOD) or cork and chestnut woods (CCHW), can hardly be compensated by means of public grants, due to the size of the needed financial effort [56]. As regards intensive agricultural production zones, agroforestry transition should be implemented through a cooperative and integration-oriented policy by the involved public administrations at different spatial scales, in terms of technical expertise and financial feasibility assessment [57–59]. For instance, in the case of goat and sheep farming, land cover change from grazing land to wooded areas can be effectively financed through public grants, so as to mitigate or even fully compensate for the yield decrease implied by such transition. Different is the case of cattle grazing areas, characterized by very high yields, whose transition would possibly generate relevantly, and even dramatic and destabilizing, impacts on the regional livestock economy, since wooded pasture, such as the Spanish dehesa, is not economically suitable for cattle farming.

Furthermore, afforestation intensity should be carefully assessed. As per Li et al. [60], an increasing trend in wooded areas may possibly be associated with a progressive rise in the ratio of costs to benefits of afforestation processes. Feng et al. [61] show that the unbalanced development of woodlands is likely to put at risk food safety. This implies that trade-offs between the provision of different ecosystem services and their economic and social benefits should be analyzed in detail.

A specific assessment of the question of afforestation, based on the land cover transition from farming to forestry, is proposed in a study related to social and economic factors driving from croplands to afforestation, which are particularly focused on the identification of the determinants concerning policy-making decisions [62]. From this standpoint, the perception of benefits coming from farming is an important obstacle regarding afforestation [63]. This is basically due to the farmers' strong perception of the positive effects related to the non-market value generated by flexible farming-related practices, and to their unwillingness to lose their durable expertise, which in their view is likely to be more important than the expected increase in income coming from afforestation [62]. The transition from intensive farming to forest land cover differs significantly from afforestation which originates from extensive croplands [64]. In the former case, a transition is quite unlikely, whereas it is much more probable in the latter since the expected income from forestry is likely to exceed the income coming from extensive farming, while intensive farming, which develops from permanent agriculture through high-yielding crops, is expected to have the highest rent [65]. Extensive and intensive farming should be targeted in terms of planning measures to decrease LST, based on incentive schemes. Agricultural farmers may possibly engage in afforestation, and, by doing so, disengage from low-income farming. The incentive effectiveness is likely to be identified in afforestation coming from transitions from mosaic farmlands and grazing lands, whereas it is quite unlikely that this is the case regarding intensive agriculture [56]. Moreover, the expansion of forest areas throughout rural zones featured by high-income farming should be carefully assessed by planning agencies in terms of financial feasibility as much as they should carefully consider the negative impact of afforestation on the traditional rural framework in terms of economic, social and landscape degradation [66].

All in all, planning policies and measures to strengthen the operational capacity and effectiveness of the regional network of protected areas through the protection and the improvement of the spatial framework of its ECs have to be studied, structured and implemented by focusing on the ruling concept that habitat quality, ecological integrity, and ecosystem conditions have to be enhanced and boosted-up [67].

Since the nodes of the networking spatial structure of the regional GI are identified with the system of the regional protected areas, whose protection regime implies conservation and enhancement of habitat quality, ecological integrity and ecosystem services, strengthening such spatial structure entails the establishment and implementation of planning policies aimed at extending to ECs the protection regime related to protected areas. Indeed, the locations of ECs are generally characterized by less restrictive planning rules than protected areas, in terms of conservation of nature and ecosystems. For example, as for the sites of the Natura 2000 network, which represents a relevant share of the nodes of the regional GI, conservation measures are established and implemented, under the provisions of the Habitats and Birds Directives, with reference to the nodes of the network, that is SCIs, SACs and SPAs, whereas the edges, that is ECs, are exposed to hazards coming from residential settlements and industrial activities. Urbanization and land-taking processes should be targeted by planning policies aimed at protecting ECs as fundamental elements of the regional GI. Mitigation or prevention of land uptake and soil sealing should develop from interdisciplinary scientific bases, and should provide the public administrations with analytical technical skills in order to define policy measures aimed at implementing regional and local development processes based on the improvement of habitat quality, ESs provision and ecological integrity. The extension of the protection regime of the Natura 2000 Network as a point of reference to define and implement a comprehensive planning approach based on the conservation of habitats and species can be effectively supported by the increase in the number of the established Natura 2000 sites, which can be the outcome of thorough lobbying pressures by the local municipalities on the regional, national and European public authorities, based on sound scientific motivation, analysis and assessment of the connection between land-taking and soil-sealing processes, and qualitative and quantitative decrease in ESs provision [29]. From this standpoint, afforestation and reforestation can be considered highly supportive and complimentary planning policies, as discussed above.

Planning policies aimed at strengthening the ECs spatial structure should take account of the possible trade-offs between the supply of different ESs types. As for the Millennium Ecosystem Assessment [68], habitat quality, biodiversity flows opportunities and ecological integrity are classed as supporting and regulating ESs, whose supply can very possibly compete with provisioning and recreational ESs, such as cattle and farming production, and sport and leisure infrastructure. As discussed above, the transition from agricultural to forest land uses is a typical example of how to address a trade-off issue concerning provisioning and supporting ESs by increasing the supply of supporting ESs and, by doing so, strengthening the spatial structure of ECs., Kovács et al. address this question by assessing ESs trade-offs as regards three protected areas located in Hungary [69].

5. Conclusions

Building on a methodological approach defined by Cannas [27–30], in this study the issue of the identification of ECs is discussed, and ECs are detected with reference to the regional spatial context of Sardinia. Moreover, public policy-makers are provided with sound effective support for the conservation and enhancement of regional networks of NPSs and ECs on the basis of the implications of the methodology implementation.

Such methodology, which entails the mixed use of the least-cost path and regression models, shows two innovative aspects. First, the data used in this study are open-source and easily accessible to decision-makers, planners and research scholars. Therefore, the methodological approach is cheap in terms of cost and time. Secondly, the current literature mainly focuses on how to identify ECs within either regional or national contexts, whereas the normative aspects are often understated. Indeed, assessing if, and to what extent, spatial zoning codes can be used as a basis to implement regulations aimed at protecting ECs is still an under-explored research theme.

From this standpoint, it has to be highlighted that the methodological approach defined and implemented in this study can be easily exported to the EU local, regional and national scales, since spatial databases consistent with each other are available for Sardinia and Italy as for the other regions and countries. Moreover, such methodology shows a flexible structure that makes it easy to adjust in real-time the ever-evolving process of identification, protection and enhancement of the spatial structure of ECs. This is particularly relevant as regards ESs provision and related data, expertise involvement and information retrieval.

Habitat-suitability and ecological-integrity maps are based on scientists' and practitioners' expertise. Indeed, such expertise provides the public administrations with sound and effective advice on habitat-suitability species-specific values, which works as a foundation for the elaboration of habitat-suitability maps, and on ecological integrity values, which is the basis for the definition of ecological-integrity maps. Nevertheless, the use of these maps suffers from a certain degree of subjectivity, which implies controversial results in their application, especially if scientific and technical knowledge is lacking.

This is an important issue as regards future research on the methodology defined in this study, which can be identified with reference to the ecological integrity map related to the Sardinian regional context. As was described in Section 2.2, such ecological integrity map is based on experts' judgments concerning the supply potential of CLC land cover classes with reference to seven ESs, that is, abiotic heterogeneity, biodiversity, biotic waterflows, metabolic efficiency, energy capture, reduction of nutrient loss and storage capacity, identified by Burkhard et al. [43]. At present, a systemic and detailed scientific and technical information concerning the relations between CLS classes and ESs provision is not available for Sardinia and for the other Italian regions, and, that being so, the methodological approach defined in this study, whose prototypical implementation is based on experts' judgments reported in the Burkhard et al.'s article, will be usable in the real world if, and only if, scientific and technical knowledge on the supply potential of CLC classes in terms of ESs provision will be readily and transparently available in open -data format. This implies an important further effort in theoretical and applied research on ESs and land covers and land uses, and in the implementation of these outcomes in the planning practices of the bodies at the different levels of the public administration.

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References

1. D'Ambrogi, S.; Gori, M.; Guccione, M.; Nazzini, L. Implementazione della connettività ecologica sul territorio: Il monitoraggio ISPRA 2014 [The implementation of spatial ecological connectivity: The 2014 Monitoring of ISPRA]. *Reticula* **2015**, *9*, 1–7. Available online: https://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/reticula/Reticula_n9.pdf (accessed on 19 April 2022).
2. D'Ambrogi, S.; Nazzini, L. Monitoraggio ISPRA 2012: La rete ecologica nella pianificazione territoriale [The 2012 Monitoring of ISPRA: The ecological network applied to spatial planning]. *Reticula* **2013**, *3*, 1–5. Available online: Isprambiente.gov.it/files/pubblicazioni/periodicitecnici/reticula/Reticula_n3.pdf (accessed on 19 April 2022).
3. Battisti, C. *Frammentazione Ambientale, Connettività, Reti Ecologiche. Un Contributo Teorico e Metodologico con Particolare Riferimento alla Fauna Selvatica [Environmental Fragmentation, Connectivity, Ecological Networks. A Technical and Methodological Contribution with Particolar Reference to Wildlife Species]*; Provincia di Roma, Assessorato delle Politiche Ambientali; Agricoltura e Protezione Civile [Province of Rome, Board of Envionmental Policy, Agriculture and Civil Protection]: Rome, Italy, 2004.
4. Baudry, J.; Merriam, H.G. Connectivity and connectedness: Functional versus structural patterns in landscapes. In Proceedings of the 2nd IALE Seminar "Connectivity in Landscape Ecology", Münster, Germany, 19–24 July 1987; Münsterche Geographische Arbeiten: Münster, Germany, 1988; Volume 29, pp. 23–28.
5. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Green Infrastructure—Enhancing Europe's Natural Capital. SWD (2013) 155 Final. 2013. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0249&from=EN (accessed on 19 April 2022).
6. Liquete, C.; Kleeschulte, S.; Dige, G.; Maes, J.; Grizzetti, B.; Olah, B.; Zulian, G. Mapping green infrastructure based on ecosystem services and ecological networks: A Pan–European case study. *Environ. Sci. Policy* **2015**, *54*, 268–280. [CrossRef]
7. Directorate–General Environment, European Commission. The Multifunctionality of Green Infrastructure, Science for Environment Policy, DG News Alert Service, In–depth Report. 2012. Available online: https://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf (accessed on 19 April 2022).
8. European Environment Agency. *Spatial Analysis of Green Infrastructure in Europe*; EEA Technical Report no. 2/2014; Publications Office of the European Union: Luxembourg, 2014. [CrossRef]
9. Taylor, P.D.; Fahrig, L.; Henein, K.; Merriam, G. Connectivity is a vital element of landscape structure. *Oikos* **1993**, *68*, 571–573. [CrossRef]

10. Dunning, J.B.; Danielson, J.B.; Pulliam, H.R. Ecological processes that affect populations in complex landscapes. *Oikos* **1992**, *65*, 169–175. [CrossRef]
11. With, K.A.; Gardner, R.H.; Turner, M.G. Landscape connectivity and population distributions in heterogeneous environments. *Oikos* **1997**, *78*, 151–169. [CrossRef]
12. Issii, T.M.; Lopes Pereira-Silva, E.F.; López de Pablo, C.T.; Ferreira dos Santos, R.; Hardt, E. Is there an equivalence between measures of landscape structural and functional connectivity for plants in conservation assessments of the Cerrado? *Land* **2020**, *9*, 459. [CrossRef]
13. Tischendorf, L.; Fahrig, L. On the usage and measurement of landscape connectivity. *Oikos* **2000**, *90*, 7–19. [CrossRef]
14. Balbi, M.; Petit, E.J.; Corci, S.; Nabucet, J.; Georges, R.; Madec, L.; Ernoult, A. Title: Ecological relevance of least cost path analysis: An easy implementation method for landscape urban planning. *J. Environ. Manag.* **2019**, *244*, 61–68. [CrossRef]
15. Simberloff, D.; Farr, J.A.; Mehlman, D.W. Movement corridors: Conservation bargains or poor investments? *Conserv. Biol.* **1992**, *6*, 493–504. [CrossRef]
16. Saunders, D.A.; Hobbs, R.J. The role of corridors in conservation: What do we know and where do we go? In *Nature Conservation 2: The Role of Corridors*; Saunders, D.A., Hobbs, R.J., Eds.; Surrey Beatty & Sons: Chipping Norton, NSW, Australia, 1991.
17. Rosenberg, D.K.; Noon, B.R.; Meslow, E.C. Towards a Definition of "Biological Corridor". In *Integrating People and Wildlife for a Sustainable Future, Proceedings of the International Wildlife Management Congress*; Bissonette, J.A., Krausman, P.R., Eds.; The Wildlife Society: Bethesda, MD, USA, 1995.
18. Hess, G.R.; Fischer, R.A. Communicating clearly about conservation corridors. *Landsc. Urban Plan.* **2001**, *55*, 195–208. [CrossRef]
19. MacArthur, R.H.; Wilson, E.O. *The Theory of Island Biogeography*; Princeton University Press: Princeton, NJ, USA, 1967.
20. Levins, R. Some Demographic and genetic consequences of environmental heterogeneity for biological control. *Bull. Entomol. Soc. Am.* **1969**, *15*, 237–240. [CrossRef]
21. Zeller, K.A.; McGarigal, K.; Whiteley, A.R. Estimating landscape resistance to movement: A review. *Landsc. Ecol.* **2012**, *27*, 777–797. [CrossRef]
22. McRae, B.H.; Dickson, B.G.; Keitt, T.H.; Shah, V.B. Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology* **2008**, *89*, 2712–2724. [CrossRef]
23. Palmer, S.C.F.; Coulon, A.; Travis, J.M.J. Introducing a 'stochastic movement simulator' for estimating habitat connectivity. *Methods Ecol. Evol.* **2011**, *2*, 258–268. [CrossRef]
24. Wu, J.; Delang, C.O.; Li, Y.; Ye, Q.; Zhou, J.; Liu, H.; He, H.; He, W. Application of a combined model simulation to determine ecological corridors for western black-crested gibbons in the Hengduan Mountains, China. *Ecol. Indic.* **2021**, *128*, 107826. [CrossRef]
25. Guo, X.; Zhang, X.; Du, S.; Li, C.; Siu, Y.L.; Rong, Y.; Yang, H. The impact of onshore wind power projects on ecological corridors and landscape connectivity in Shanxi, China. *J. Clean. Prod.* **2020**, *254*, 120075. [CrossRef]
26. Lai, S.; Leone, F.; Zoppi, C. Land cover changes and environmental protection: A study based on transition matrices concerning Sardinia (Italy). *Land Use Policy* **2017**, *67*, 126–150. [CrossRef]
27. Cannas, I.; Zoppi, C. Ecosystem services and the Natura 2000 Network: A study concerning a green infrastructure based on ecological corridors in the Metropolitan City of Cagliari. In *17th International Conference on Computational Science and Its Applications (IC-CSA 2017)*; Lecture Notes in Computer Sciences Series; Gervasi, O., Murgante, B., Misra, S., Borruso, G., Torre, C., Rocha, A.M.A.C., Taniar, D., Apduhan, B.O., Stankova, E., Cuzzocrea, A., Eds.; Springer: Cham, Switzerland, 2017; Volume 10409, pp. 379–400. [CrossRef]
28. Cannas, I.; Zoppi, C. Un'infrastruttura verde nell'area metropolitana di Cagliari: Corridoi ecologici come connessioni tra i Siti della Rete Natura 2000 [A Green Infrastructure in the Metropolitan Area of Cagliari: Ecological Corridors as Connections between the Sites of the Natura 2000 Network]. In *Atti Della XX Conferenza Nazionale SIU. Urbanistica E/È Azione Pubblica [Proceedings of the 20th National Conference of SIU. Spatial Planning And/Is Public Action]*; AA.VV.; Planum Publisher: Rome/Milan, Italy, 2017; pp. 1373–1386.
29. Cannas, I.; Lai, S.; Leone, F.; Zoppi, C. Green infrastructure and ecological corridors: A regional study concerning Sardinia. *Sustainability* **2018**, *10*, 1265. [CrossRef]
30. Cannas, I.; Lai, S.; Leone, F.; Zoppi, C. Integrating green infrastructure and ecological corridors: A Study concerning the Metropolitan Area of Cagliari (Italy). In *Smart Planning: Sustainability and Mobility in the Age of Change*; Papa, R., Fistola, R., Gargiulo, C., Eds.; Springer International Publishing: Basel, Switzerland, 2018; pp. 127–145. [CrossRef]
31. Subsection 2.1 Study Area builds on: Lai, S.; Leone, F.; Zoppi, C. Anthropization processes and protection of the environment: An assessment of land cover changes in Sardinia, Italy. *Sustainability* **2017**, *9*, 2174, Subsection 3.1. Study Area and Protection Levels, pp. 3–4 (written by Sabrina Lai). [CrossRef]
32. European Commission. The Natura 2000 Biogeographical Regions. 2016. Available online: http://ec.europa.eu/environment/nature/natura2000/biogeog_regions/ (accessed on 19 April 2022).
33. Council of Europe—Directorate of Culture and Cultural and Natural Heritage. Biogeographical Regions' Map. 2010. Available online: https://rm.coe.int/168074623f (accessed on 19 April 2022).
34. Directorate–General Environment, European Commission. Natura 2000 Barometer. 2016. Available online: https://ec.europa.eu/environment/nature/natura2000/barometer/index_en.htm (accessed on 19 April 2022).
35. Data Available at the Website. Available online: https://www.eea.europa.eu/data-and-maps/data/natura-13/natura-2000-spatial-data/natura-2000-shapefile-1 (accessed on 19 April 2022).

36. Sawyer, S.C.; Epps, C.W.; Brashares, J.S. Placing linkages among fragmented habitats: Do least-cost models reflect how animals use landscapes? *J. Appl. Ecol.* **2011**, *48*, 668–678. [CrossRef]
37. Adriaensen, F.; Chardon, J.P.; De Blust, G.; Swinnen, E.; Villalba, S.; Gulinck, H.; Matthysen, E. The application of "least-cost" modelling as a functional landscape model. *Landsc. Urban Plan.* **2003**, *64*, 233–247. [CrossRef]
38. Coulon, A.; Aben, J.; Palmer, S.C.F.; Stevens, V.M.; Callens, T.; Strubbe, D.; Travis, J.M.J. A stochastic movement simulator improves estimates of landscape connectivity. *Ecology* **2015**, *96*, 2203–2213. [CrossRef] [PubMed]
39. Osborn, F.V.; Parker, G.E. Linking two elephant refuges with a corridor in the communal lands of Zimbabwe. *Afr. J. Ecol.* **2003**, *41*, 68–74. [CrossRef]
40. Kong, F.; Yin, Y.; Nakagoshi, N.; Zong, Y. Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. *Landsc. Urban Plan.* **2010**, *95*, 16–27. [CrossRef]
41. Larkin, J.L.; Maehr, D.S.; Hoctor, T.S.; Orlando, M.A.; Whitney, K. Landscape linkages and conservation planning for the black bear in westcentral Florida. *Anim. Conserv.* **2004**, *7*, 23–34. [CrossRef]
42. AGRISTUDIO; CRITERIA; TEMI. Realizzazione del Sistema di Monitoraggio dello Stato di Conservazione degli Habitat e delle Specie di Interesse Comunitario della Regione Autonoma della Sardegna. Relazione Generale, Allegato 1b: Carta dell'Idoneità Faunistica [Implementation of the Monitoring System Concerning the Conservation Status of Habitats and Species of Community Interest of the Autonomous Region of Sardinia. General Report, Attachment 1b: Habitat Suitability Map]. MIMEO. Unpublished work. 2011.
43. Burkhard, B.; Kroll, F.; Müller, F.; Windhorst, W. Landscapes' capacities to provide ecosystem services—A concept for land-cover based assessments. *Landsc. Online* **2009**, *15*, 1–22. [CrossRef]
44. Burkhard, B.; Kroll, F.; Nedkov, S.; Müller, F. Mapping ecosystem service supply, demand and budgets. *Ecol. Indic.* **2012**, *2*, 7–29. [CrossRef]
45. LaRue, M.A.; Nielsen, C.K. Modelling potential dispersal corridors for cougars in Midwestern North America using least-cost path methods. *Ecol. Model.* **2008**, *212*, 372–381. [CrossRef]
46. McRae, B.H.; Kavanagh, D.M. User Guide: Linkage Pathways Tool of the Linkage Mapper Toolbox—Version 2.0—Updated October 2017. 2017. Available online: https://github.com/linkagescape/linkage-mapper/files/2204107/Linkage_Mapper_2_0_0.zip (accessed on 19 April 2022).
47. Shirabe, T. Buffered or bundled, least-cost paths are not least-cost corridors: Computational experiments on path-based and wide-path-based models to conservation corridor design and effective distance estimation. *Ecol. Inform.* **2018**, *44*, 109–116. [CrossRef]
48. Cheshire, P.; Sheppard, S. On the price of land and the value of amenities. *Econ. New Ser.* **1995**, *62*, 247–267. [CrossRef]
49. Stewart, P.A.; Libby, L.W. Determinants of Farmland Value: The case of DeKalb County, Illinois. *Rev. Agric. Econ.* **1998**, *20*, 80–95. [CrossRef]
50. Sklenicka, P.; Molnarova, K.; Pixova, K.C.; Salek, M.E. Factors affecting farmlands in the Czech Republic. *Land Use Policy* **2013**, *30*, 130–136. [CrossRef]
51. Zoppi, C.; Argiolas, M.; Lai, S. Factors influencing the value of houses: Estimates for the City of Cagliari, Italy. *Land Use Policy* **2015**, *42*, 367–380. [CrossRef]
52. Bera, A.K.; Byron, R.P. Linearised estimation of nonlinear single equation functions. *Int. Econ. Rev.* **1983**, *24*, 237–248. [CrossRef]
53. Wolman, A.L.; Couper, E. Potential consequences of linear approximation in economics. *Fed. Reserve Bank Econ. Quartely* **2003**, *11*, 51–67.
54. Feng, H.; Li, Y.; Li, Y.Y.; Li, N.; Li, Y.; Hu, Y.; Yu, J.; Luo, H. Identifying and evaluating the ecological network of Siberian roe deer (*Capreolus pygargus*) in Tieli Forestry Bureau, northeast China. *Glob. Ecol. Conserv.* **2021**, *26*, e01477. [CrossRef]
55. Dutta, T.; Sharma, S.; McRae, B.H.; Roy, P.S.; DeFries, R. Connecting the dots: Mapping habitat connectivity for tigers in central India. *Reg. Environ. Chang.* **2016**, *16*, 53–67. [CrossRef]
56. Hyytiainen, K.; Leppanen, J.; Pahkasalo, T. Economic analysis of field afforestation and forest clearance for cultivation in Finland. In Proceedings of the International Congress of European Association of Agricultural Economists, Ghent, Belgium, 26–29 August 2008. [CrossRef]
57. Sagebiel, J.; Glenk, K.; Meyerhoff, J. Spatially explicit demand for afforestation. *For. Policy Econ.* **2017**, *78*, 190–199. [CrossRef]
58. Hou, Y.; Li, B.; Müller, F.; Fu, Q.; Chen, W. A conservation decision-making framework based on ecosystem service hotspot and interaction analyses on multiple scales. *Sci. Total Environ.* **2018**, *643*, 277–291. [CrossRef]
59. Zavalloni, M.; D'Alberto, R.; Raggi, M.; Viaggi, D. Farmland abandonment, public goods and the CAP in a marginal area of Italy. *Land Use Policy* **2021**, *107*, 104365. [CrossRef]
60. Li, K.; Hou, Y.; Andersen, P.S.; Xin, R.; Rong, Y.; Skov-Petersen, H. Identifying the potential areas of afforestation projects using cost-benefit analysis based on ecosystem services and farmland suitability: A case study of the Grain for Green Project in Jinan, China. *Sci. Total Environ.* **2021**, *787*, 147542. [CrossRef]
61. Feng, Z.; Yang, Y.; Zhang, Y.; Zhang, P.; Li, Y. Grain-for-green policy and its impacts on grain supply in West China. *Land Use Policy* **2005**, *22*, 301–312. [CrossRef]
62. Ryan, M.; O'Donoghue, C. Socio-economic drivers of farm afforestation decision-making. *Ir. For. J.* **2016**, *73*, 96–121.
63. Howley, P.; Buckley, C.; O'Donoghue, C.; Ryan, M. Explaining the economic 'irrationality' of farmers' land use behaviour: The role of productivist attitudes and non-pecuniary benefits. *Ecol. Econ.* **2015**, *109*, 186–193. [CrossRef]

64. Duesberg, S.; Ní Dhubháin, A.; O'Connor, D. Assessing policy tools for encouraging farm afforestation in Ireland. *Land Use Policy* **2014**, *38*, 194–203. [CrossRef]
65. Kumm, K.-I.; Hessle, A. Economic comparison between pasture-based beef production and afforestation of abandoned land in Swedish forest districts. *Land* **2020**, *9*, 42. [CrossRef]
66. Behan, J.; McQuinn, K.; Roche, M.J. Rural land use: Traditional agriculture or forestry? *Land Econ.* **2006**, *82*, 112–123. [CrossRef]
67. Samways, M.J.; Bazelet, C.S.; Pryke, J.S. Provision of ecosystem services by large scale corridors and ecological networks. *Biodivers. Conserv.* **2010**, *19*, 2949–2962. [CrossRef]
68. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: A Framework for Assessment*; Island Press: Washington, DC, USA, 2003.
69. Kovács, E.; Kelemen, K.; Kalóczkai, A.; Margóczi, K.; Pataki, G.; Gébert, J.; Málovics, G.; Balázs, B.; Roboz, A.; Krasznai Kovács, E.; et al. Understanding the links between ecosystem service trade-offs and conflicts in protected areas. *Ecosyst. Serv.* **2015**, *12*, 117–127. [CrossRef]

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Article

A Method Proposal to Adapt Urban Open-Built and Green Spaces to Climate Change

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Abstract: To rapidly adapt cities to the growing impacts of climate change, the open space system can play important functions as climate regulators and accelerators of sustainable urban development. To this end, this paper aims to provide a methodology that classifies open spaces on the basis of their physical characteristics and their contribution to climate vulnerability and articulates them according to the costs required for adaptation and the benefits brought. The method was applied to the city of Naples, which is an interesting case study due to its heterogeneous territory in terms of geomorphological features, such as hilly conformation and coastal location, and urban assets characterised by densely built urban fabrics with different distributions and kinds of activities. The results showed that (i) the open spaces with both low thermal and hydraulic performance are predominantly located in the peripheral part of the city, and (ii) the central area is strongly characterised by this dual issue. The latter output confirms the need to update the transformation rules of high historical-architectural value areas by introducing new resilience requirements criteria that cities are asked to have.

Keywords: urban open spaces; climate vulnerability; mitigation and adaptation interventions; nature-based solutions; urban resilience; Naples (Italy)

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1. Introduction and Aim of the Work

Since the early 1990s, urban and territorial transformation policies and strategies have been oriented to guarantee the sustainable use of natural resources by balancing development needs that are intrinsic in complex and dynamic systems like urban ones [1,2]. The overall aim of "living well within the limits of our planet" [3] continues to be a foreground in national political agendas to remark the sustainable development concept and, then as now, it cannot be reached without rethinking methods and tools to govern cities and changing lifestyles. For instance, European households use, on average, nearly three times the amount of water than the minimum required for basic human needs (144 litres vs. 50 litres per person per day) [4]. The urban land take is still an ongoing process, with the total urban area expanding by approximately 7.3% between 2000 and 2020 [5]. The urgent need for collective action in response to these challenges is reflected in the 2030 Agenda and the Sustainable Development Goals (SDGs) that explicitly call for "transformative goals ... transformative vision ... [and] structural transformation". Not surprisingly, over half of the 234 indicators of the SDGs framework refer to the urban dimension so that the Recovery Plan for Europe—NextGeneration EU implementation can also be monitored [6,7].

The broad topic of how urban areas can be transformed towards the objectives of sustainable development has generated a stream of literature engaging with "urban transformation". This literature stream is oriented to study how urban areas can be rapidly and substantially transformed to become more sustainable and equitable [8,9] and, due to the urgency to face climate change impacts, to make cities inclusive, safe and climate neutral. To help frame these urban transitions, policymakers are boosting a "greening transformation" of the built environment that include interventions such as street trees, parks and green open spaces, green roofs, and facades. These urban greening solutions are recognised from the IPCC special report on global warming of 1.5 °C [10] as the most suitable options for climate change mitigation and adaptation at the local scale. Furthermore, according to World Health Organization (WHO) and numerous scientific works, an interconnected network of green spaces, both on a neighbourhood and city level, provides a wide array of benefits related to energy saving, air and noise pollution reduction, managing stormwater, the extent of possible flooding reduction, urban quality, and liveability and can drive protection and enhancement of unbuilt and abandoned natural areas into spatial planning [11,12]. Reaching these positive effects requires reorganising the urban system and optimising its physical resources use to overcome the shortage of available space for the realisation of new green areas. In densely built and stratified cities such as those in the Mediterranean, it becomes strategic to transform the open space system made of existing green areas and open built-up spaces (such as squares) in a resilient way, to strengthen their eco-system capacities and to improve their adaptive capacity to climate change. This approach is also being called by the EU, which considers built and unbuilt open spaces as elements of a single system for cooling down cities and enabling long-term adaptation thinking based on bringing nature back to cities [13,14].

The key role of open and green spaces was further emphasised during the COVID-19 lockdowns, as they were recognised as essential places in urban areas to promote human health and wellbeing (see, for example, [15–18]). This increased recognition of the numerous benefits of urban greening has accompanied the launch of ambitious tree-planting programmes in many cities. Notable examples include Beijing's 50 Million Trees Programme [19], as well as the Million Trees Projects in New York, Los Angeles [20] and Singapore [21]. Cities like Vancouver, Milan and Philadelphia have become green boosters, using pro-environmental branding strategies and practices to make them more attractive and desirable places where investing and living [22]. A green city brand can be related to a vision for increased urban environmental political oversight and/or ambition to develop urban environmental qualities to gain a competitive advantage.

The restoration, enhancement and maintenance of existing urban green elements and the development of an integrated green and open spaces network provide a valuable asset to which the definition of Nature-Based Solutions (NBS) to address the local impacts of climate change can be added. NBS refer to the "concept of nature-based solutions embodies new ways to approach socio-ecological adaptation and resilience, with equal reliance upon social, environmental and economic domains" [11] (p. 15). The implementation of NBS can be particularly effective, as they include both mitigation and adaptation actions and interventions in line with the European Climate Law (EU Regulation 2021/1119) and the Recovery Plan for Europe—Next Generation EU [6], which are the main pillars for the implementation of the ecological transition in Europe.

NBS also include further green interventions like rain gardens, bioswales, retention ponds and permeable pavements useful to restore water balance by capturing, retaining and improving the infiltration capacity to adapt urban areas to flash floods and also to alleviate water stress in cities with low rainfall and/or high population density, as rainwater/stormwater is recognised as a secondary source of water [23,24]. These solutions also contribute to evapotranspiration processes and heat island effect mitigation [25].

In general, it can be asserted that within the scientific debate, it seems that alongside the numerous studies aimed at measuring the positive benefits generated by the presence of green spaces in urban areas, a segment of studies is emerging concerning the utility of spatial optimization of NBS, to help decision makers to better meet multiple sustainability objectives when developing long term urban development strategies. These studies are mainly based on an optimisation algorithm using probability-based acceptance criteria to intelligently search iteratively for better solutions. For instance, [26] applied it in a Northeast England town to demonstrate how spatial Pareto-optimisation can be employed to derive spatial development patterns that are sensitive to climate-induced hazards, such as heatwave and flood risk. Huang et al. [27] proposed a space optimisation strategy to improve the quality and accessibility of green spaces by using this optimisation method within the urban planning process. Similarly, Zhang et al. [28] developed a multi-objective model to define the best locations and configurations for new green spaces according to their cooling effect. Multi-objective models were also used by [29,30] to improve the connectivity of green spaces and allow people to reach them by walking within a 5-min threshold. Other studies integrated fuzzy set and AHP approaches with the GIS for the assessment of land use suitability for urban green land development [31,32].

According to this scientific framework, this paper is geared toward answering the following research question: how to transform the open space system (including open-built spaces like squares and unbuilt spaces like green areas) to adapt it to climate change and increase urban resilience?

To this end, a methodology based on the following steps is provided:

- Definition of the physical characteristics of open spaces and of the urban context where they are located;
- Classification of open spaces and the neighbourhoods hosting them, according to the contribution they can provide to reduce climate vulnerability;
- Articulation of open spaces on the basis of the costs required to adapt them in terms of climate resilience and the benefits in terms of the inhabitants involved;
- Early definition of a decision support tool aimed at adapting open spaces to climate change impacts.

In other words, the main aim of the work contained in these pages is to define a methodology that reduces, on the one hand, features that may contribute to accentuating vulnerability through mitigation interventions and implements and, on the other hand, features that play in favour of resilience through adaptation interventions. The outputs of the method support local decision-makers in the definition of the most suitable adaptation interventions for open space systems, according to their physical and urban context characteristics, as well as the needed costs and the likely positive effects. The paper is structured in three parts: the first describes the methodology aimed at transforming the open space system to increase urban resilience; the second describes the results by highlighting the climate performance of open spaces; the third describes the results by highlighting the interventions to be implemented and the possible choices due to costs.

2. Methodology to Classify Open Spaces and Urban Areas Oriented to Climate Change Adaptation

The paper is oriented toward providing a methodology that classifies open spaces based on their physical characteristics and their contribution to climate vulnerability and articulates them according to the costs required for adaptation and the benefits brought. The methodology consists of five main phases (Figure 1).

The first step involves defining the set of variables useful for measuring the physical and performance characteristics of the open space system (squares, green areas...) for reducing climate vulnerability. In this first phase of work, we focused mainly on two types of extreme events: flooding and urban heat island (UHI). The most recent reports [10,32], which develop medium and long-term climate risk forecast scenarios at national and local levels, make it possible to identify them as the main impacts affecting different urban areas.

Heatwaves, heavy precipitation, flooding and droughts are identified as extreme climate events whose frequency and magnitude are expected to increase in Europe. South-European cities are required to face the highest projected increase in the frequency of heat waves combined with the lowest provision of green space and the most pronounced urban heat island (UHI) effect. On the other side, the increase of surface sealing in cities and the inadequacy of sewerage infrastructure to the heavy precipitation events make Mediterranean cities vulnerable to urban flooding.

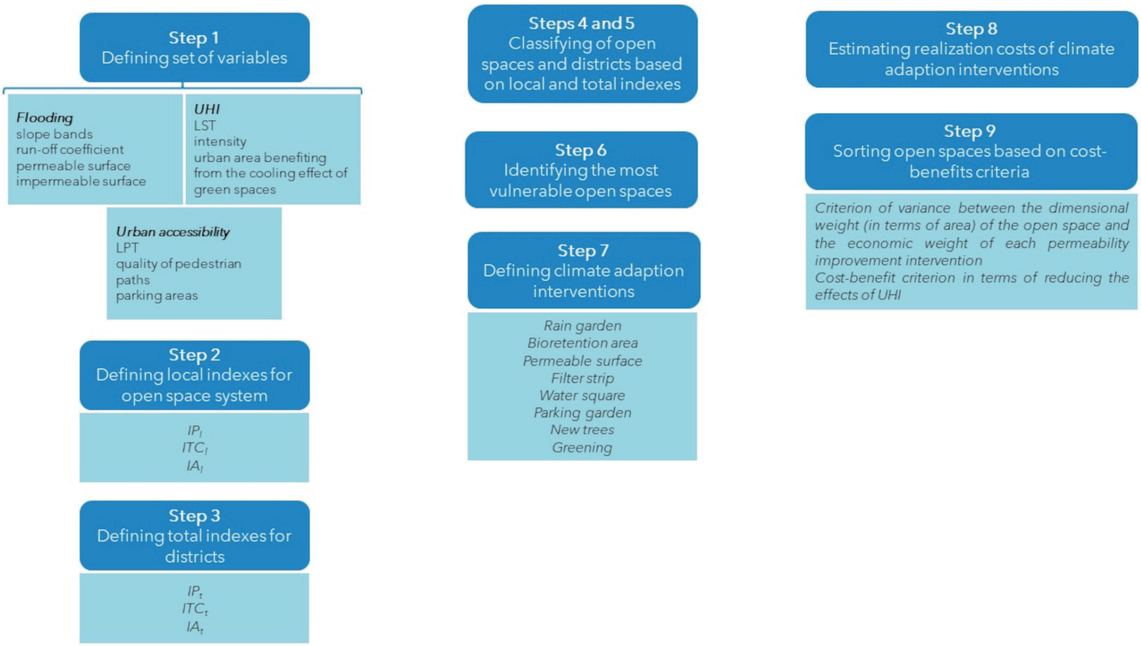


Figure 1. Flowchart of the proposed methodology.

For the first type of event, flooding, variables relating to morphology (slope bands), runoff capacity and surface drainage of the soil (runoff coefficient, permeable surface and impermeable surface) were identified.

These variables allow, in practice, the consideration of vulnerability to flooding as determined by the number of impermeable surfaces and the retention capacity of conventional drainage systems. As described by [33], runoff coefficients represent the percentage of runoff resulting from a storm event and are strongly influenced by land cover and soil permeability, but also by the slope and intensity of rainfall. The presence of an impermeable surface prevents precipitation from penetrating the soil, increasing the amount of runoff [34]. Major floods are more likely to occur in locations with steeper slopes than in areas with a lower slope [35].

For the second type of event, UHI, the variables refer to: the land surface temperature (LST), or "the radiant temperature measured at the interface between the surface of a material (tree canopy, water, soil, ice or snow) and the atmosphere" [36], also considered as the "skin temperature of the soil", influenced by solar reflectance, thermal emissivity and heat capacity [37]; the intensity of the urban heat island; the urban area benefiting from the cooling effect due to the presence of green spaces of a particular size [38–41].

Through evapotranspiration, solar radiation energy absorbed by leaves is converted into latent rather than sensible heat flux, thus lowering the temperature of the canopy and surrounding air [42,43]. Green areas, particularly those characterised by the presence of trees, can also lower air temperature by intercepting solar radiation, thus preventing the underlying surface from absorbing shortwave radiation, a process known as the shadow effect [44]. Based on these processes, the air temperature in urban green spaces can be 1–3 °C to 5–7 °C cooler than in neighbouring built-up areas, and this effect can also extend to the surroundings [45,46].

Such mitigation is particularly important in hot climates, such as the study area (Naples), where the heat island can elevate urban temperatures by up to 6 °C [47], posing a significant threat to the most vulnerable segments of the population to heat waves, including the elderly, children, as well as the poorest who often do not have the possibility of benefiting from summer air conditioning systems in their residences [48].

The size of the urban area that benefits from the cooling effect, thanks to the presence of green spaces, is the result of integrated microclimatic simulations in a GIS environment (described by the authors in previous works [38–41]). These simulations allowed defining the microclimatic behaviour of the three most widespread types of urban fabric characterised by different values of built density and different sizes of green spaces (ranging from 1000 sqm to 35,000 sqm), which are likely to be found in stratified contexts. After performing simulations using the ENVI-met software, green areas sized around 5000 sqm, which can lower the average temperature by 1 °C on the surrounding built area between 100–150 m from them, were found to be more effective and efficient [38–41]. In this study, the size range of the areas due to relative climate performance is defined.

Open spaces also promote social cohesion as places of aggregation and participation, and, in this perspective, the enjoyment of these urban endowments should be guaranteed to all segments of the population. Therefore, variables related to climate vulnerability are integrated with those of improving urban usability and accessibility to contribute to the improvement of citizens' quality of life (step two). The variables are related to open spaces accessibility, such as Local Public Transport (LPT) (no. of stops near the green area), quality of pedestrian paths (width of sidewalks, quality of pavement, etc.) and parking areas (no. of parking spaces).

After collecting the related data, the database was populated in a GIS environment using the open-source software QGIS (step three). Except for the eight variables related to the runoff coefficient, permeable and impermeable surfaces, land surface temperature, cooling distance, cost and population, the initial quantitative values of the other five variables (slope bands, heat island intensity and accessibility) were classified into three qualitative ranges (low, medium, high).

The measurement of the 13 variables for each open space is followed, in the fourth step, by the overall measurement of permeability, thermal comfort and accessibility to assess the current functioning/performance of the entire open space system about each of the objectives. For this purpose, the following three synthetic indices were defined:

$$IP_l = (\text{Runoff coefficient} + \text{Permeable surface} + \text{Impervious surface} + \text{Slope})/\text{n}, \quad (1)$$

$$ITC_l = (\text{LST} + \text{UHI} + \text{Cooling area})/\text{n}, \quad (2)$$

$$IA_l = (\text{Parking accessibility} + \text{LPT accessibility} + \text{Pedestrian accessibility})/\text{n}, \quad (3)$$

where IP_l is the Local Permeability Index, ITC_l is the Local Thermal Comfort Index, IA_l is the Local Accessibility Index, and n is the number of variables defined for each objective.

To measure these indices, it was first necessary to standardise the scale of values of some variables of the IP_l and ITC_l, due to the different "significance" that a high or low value determines for each objective and then to carry out the normalisation. For example, a high value of the permeable surface area favours the improvement of permeability, in contrast to the case of the impermeable surface area and the runoff coefficient, which contribute to the achievement of the objective when characterised by low values.

The characteristics of individual open spaces, both for improving permeability and thermal comfort, also depend on the characteristics of the urban context in which they are located. Indeed, the morphology and layout of the territory contribute to determining the "response" of the open space to an extreme climatic event, also conditioning its usability.

With this in mind, a Total Permeability Index IP_t and a Total Thermal Comfort Index ITC_t are calculated for each neighbourhood to assess the capacity of the territorial context to contribute to reducing the risk of flooding and heat island risk and to classify the neighbourhoods concerning these 2 climatic aspects (taken individually) identifying the most critical ones:

$$IP_t = (\text{Runoff coefficient} + \text{Natural surface} + \text{Impervious surface} + \text{Slope})/\text{n}, \quad (4)$$

$$ITC_t = (\text{UHI} + \text{Building density})/\text{n}, \quad (5)$$

where the values of the two variables are the average values for the neighbourhood. For the calculation of this index (step five), unlike the ITC_l of individual open spaces, the density of the built-up area was taken into account both because this variable is closely related to the phenomenon under consideration, as it contributes to the storage of heat in the urban area by capturing a large part of the incident solar radiation, and is therefore relevant in considering the context characteristics, and because the value of the area affected by the cooling effect determined by the presence of a green space already takes into account the density characteristics of the urban fabric in which the open space is inserted [38–41].

Steps four and five allow for the identification of neighbourhoods that constitute "warning areas" within the urban territory.

In step six, within the individual neighbourhoods, the open spaces characterised by the lowest and highest values of the local IP_l and ITC_l indices, respectively, are identified and thus constitute the priority ones for which appropriate adaptation solutions should be provided. The proposed intervention for each of these open spaces is to be carried out to contribute simultaneously to both the improvement of permeability and thermal comfort, thus optimising the use of the resources available to local administrators and taking into account that the reference context is the stratified historical city, typical of the European reality. The choice of intervention is such to guarantee the compatibility of the transformation with the intrinsic characteristics of the space (such as the surface, the slope and the current use) and with those of the urban context in which the space is inserted (such as the type of fabric and its historical-artistic-architectural value).

In step seven, adaptation interventions are defined with reference to the National Climate Change Adaptation Plan [49] and to the digital platforms and guidelines developed by the European Union to increase resilience through appropriate transformations (e.g., Climate-ADAPT, Blue App. Climate-ADAPT, Blue App; [50]).

The selected interventions include both mitigation interventions (such as permeable surfaces and parking gardens) to reduce the contribution of open space features to climate vulnerability and adaptation interventions (such as greening with tree species that promote microclimate regulation, filtered strips, bio-retention areas, rain gardens, water squares) aimed at strengthening features that make a positive contribution to urban resilience.

In step eight, the effectiveness of the proposed interventions is assessed by estimating their implementation costs to subsequently sort out both the open spaces and the relevant neighbourhoods where it is appropriate to intervene.

The calculation of the costs requires referring to some guide criteria for the design of the interventions [11,50,51] to have the first reliable quantification of the financial burdens that the local administration would have to bear for the implementation of the interventions (Table 1).

Table 1. Main criteria to estimate intervention costs to improve the permeability of open spaces.

Adaptation Intervention for Increasing Permeability	Slope	Surface
Rain garden	<8%	<8000 sqm
Bioretention area	<10%	<8000 and at least 200 sqm
Permeable surface	<5%	<15,000 sqm
Filter strip	<5%	-
Water square	<6%	-
Parking garden	<6%	-

The hydraulic and thermal modelling of individual interventions, which are useful for detailed design purposes, can be integrated at a later stage of the work, further verifying it with respect to the more purely engineering aspects. In fact, this paper is aimed at providing an initial cognitive and methodological result for the resilient transformation of the open space system.

The cost estimate refers to the *Prezzario delle Opere Pubbliche* (Public Works Price List), which is the reference tool for the prior quantification, design and realisation of regional public works, as required by Article 23 of Legislative Decree 50/2016 (Contracts Code). Table 2 shows the main costs of the proposed adaptation interventions.

Table 2. Main criteria to estimate costs of interventions to improve the permeability of open spaces.

Climate Adaptation Intervention	Estimated Unit Cost [€/sqm]	Climate Vulnerability	
		UHI	Flooding
Rain garden	70	x	x
Bioretention area	80		x
Permeable surface	35		x
Filter strip	150		x
Water square	250		x
Parking garden	110	x	x
New trees * (in existing green areas)	64 *	x	x
Greening	69	x	x

* Cost per single tree.

In step nine, the effectiveness of adaptation interventions is assessed for each climatic problem that may characterise an open space: low permeability, high thermal stress, and coexistence of both conditions. Effectiveness is evaluated based on two criteria:

- The criterion of variance between the dimensional weight (in terms of area) of the open space and the economic weight of each permeability improvement intervention to be carried out; the second weight refers to the economic charge of the same type of intervention on all identified attention districts;
- The cost-benefit criterion in terms of reducing the effects of UHI is based on the number of inhabitants that fall within the cooling area (determined, as we have already mentioned, by the type of urban fabric and the size of the green area itself). The number of inhabitants is related to the cost of the relevant greening intervention to obtain the cost that each inhabitant would have to bear to take advantage of the thermal improvement.

Evaluating the effectiveness of adaptation interventions based on these two criteria provides local decision-makers with a sorting of the open spaces that are in priority need of adaptation to increase the resilience of the urban system. This output represents the first tool that guides the public decision-maker in choosing the most effective intervention to be implemented.

3. Study Area: Physical Characteristics and Urban Context of the Open Space System in the City of Naples

The Municipality of Naples (Latitude 40.8517746 and Longitude 14.2681244) is the capital of the Campania Region in Southern Italy and takes a key role in the Italian urban structure as it is the centre of a very wide metropolitan system and embraces great social, economic and cultural contradictions. The city lies over an area of 118 km^2 and, with around 950,000 inhabitants and a population density of approximately 7.754 inhabitants/km^2 [52], is among the most populated Italian cities. Naples is characterised by a progressive ageing of the population, with rates above the national average [53], and it is still among the European cities where the population aged 65 and over is expected to be higher the 25% of the total number of inhabitants [54].

According to [55,56], this kind of demographic scenario represents "a risk due to a combination of exposure and increased psychosocial susceptibility or social vulnerability as older people are more susceptible to disease and the effects of stresses on the food and water supply, and reduced ability to mobilise themselves in an extreme weather event". In this perspective, the study case of Naples can provide effective insights into the development of a comprehensive set of adaptation measures, actions, and interventions that can feed into the current development of the city resilience plan. In our case, the impacts considered about the objective of reducing climate vulnerability are heat waves and flooding due to intense rainfall, which will tend to occur with greater frequency and intensity: more than 90 consecutive days of temperatures above 37 °C and intense rainfall every 4 years instead of every 10 [56].

Based on these forecasts, objectives were identified to improve urban permeability, help facilitate the drainage of rainwater, and to improve thermal comfort, to encourage a decrease in the heat island phenomenon and the consequent energy consumption related to summer air conditioning. In this regard, [57] estimated that "an additional 235 billion euros of investment and operational expenditure will be required for the generation and transmission of electricity for space cooling" in the absence of appropriate interventions and adaptation actions.

Most of the data useful for measuring the variables were retrieved through processing in a GIS environment from open databases, such as ISTAT for population, Urban Atlas for area rates and Open Street Map for the road network. In particular, the physical and geometric characteristics of the arcs of the pedestrian network within a 400 m area of each open space were identified punctually, and the stations of the rail network and stops of the road network were geolocated to measure pedestrian and LPT accessibility, respectively. For parking allocations, data retrieved from Open Street Map were integrated with those from the Sustainable Urban Mobility Plan of the city of Naples currently being drafted [58]. The definition of the three classes for the accessibility variables was done considering the willingness of the most fragile segments of the population to walk to reach open space, for which the distance of 400 m is the maximum distance to walk due to their behaviours.

Raster image processing was carried out for runoff coefficient, slope, and temperature variables. Specifically, for the slope, it was necessary to process the digital terrain elevation model (DEM) of the study area and then carry out the acclivity analysis, which allowed defining 4 bands (low, medium, high and high slope).

The measurement of temperature and related urban heat island intensity values, on the other hand, required the processing of multispectral and thermal data from Landsat 8 satellite images, which are made available from the U.S. Geological Survey website and are among the most effective for monitoring and mapping the environment at the spatial level [59,60]. Specifically, a medium-resolution (30 m/pixel) raster image was processed to analyse the spatial variation of air temperatures at the urban layer between the ground surface and 2 m, normally referred to as the canopy layer, about vegetation (Figure S6). From the temperatures of the canopy layer for the day 25 July 2022 (the date at which an image of the study area characterised by the almost complete absence of clouds was available), the urban heat island was calculated as the difference between the average temperature measured for the urbanised area and the average temperature measured in the non-urbanised (rural) area (Figure S7).

Naples case study is also interesting due to its heterogeneous territory in terms of geomorphological features, such as hilly conformation and coastal location, and urban assets characterised by densely built urban fabrics with different distributions and kinds of activities.

The city has undergone an urban transformation process over time [61,62]: starting from the 1990s, a strong planning framework was developed to recover the largely derelict industrial area of Bagnoli (the western part of the city, Figure 1); to enhance the historical central area (e.g., Montecalvario, Avvocata and San Ferdinando districts, Figure 2) by rehabilitating residential buildings, restoring and reusing other historic buildings, and transforming public spaces in pedestrian areas; to regenerate the Eastern periphery (Barra, Ponticelli, Secondigliano, Figure 2) where building public infrastructures and new collective functions.

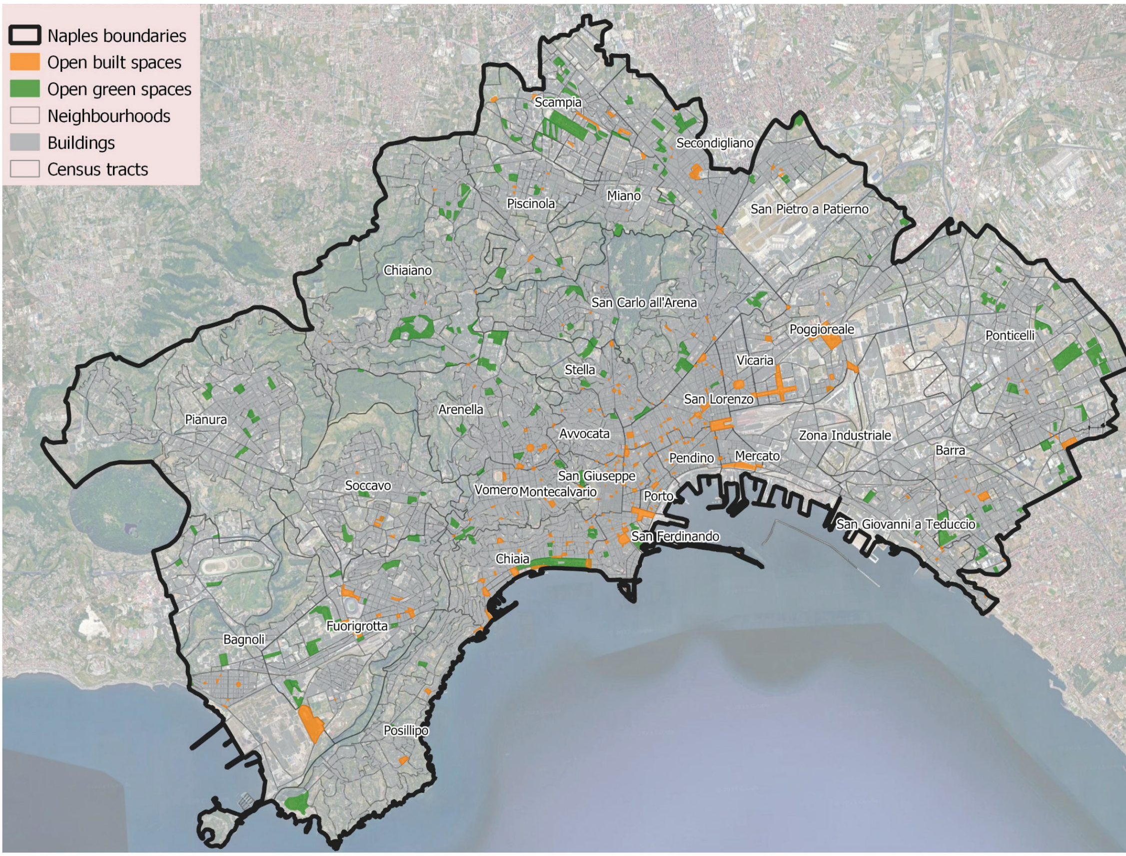


Figure 2. Localisation of open spaces (green and open built areas) in the 30 Naples districts.

Therefore, the open spaces system in a densely stratified built city like Naples represents a relevant resource to increasing urban resilience by cooling the built environment, improving stormwater management, and encouraging sustainable mobility.

Figure 2 shows the system of 179 green areas and 266 open-built spaces located in Naples. The first includes districts and green pocket spaces also equipped for play and sports, while the second refers to squares and sealed but unbuilt areas that are meeting and exchange places, shared places of urban living. Both kinds of spaces refer to the public ones with a minimal surface of 55 m^2 since, below this value, it is no longer a space but an element of street furniture (e.g., a roundabout with vegetation or a road intersection area). Zona Industriale is the only neighbourhood where there are no open spaces due to its manufacturing land use.

The distribution of the open space system is indicative of the urban planning processes, or lack of such, that have determined the urban asset of different parts of the city. In the consolidated central neighbourhoods, the result of a unified urban project, the co-presence of both types of spaces can be identified: this is the case in Vomero, Chiaia, San Ferdinando and partly Arenella. The adjacent neighbourhoods such as Avvocata, Montecalvario, San

Lorenzo, and Porto are characterised by the exclusive presence of impermeable open spaces whose dimensions and forms highlight not always controlled urban development processes.

It is worth noting that during the early 2000s, the open spaces (and main streets) of this central part of the city were interested in numerous urban redevelopment interventions aimed at favouring pedestrian usability to improve the tourist attractiveness of the relevant cultural and architectural heritage. The increase in pedestrian usability resulting from such interventions, as well as adequate accessibility through transportation offerings, significantly characterises neighbourhoods such as San Ferdinando, Chiaia, Vomero, Montecalvario, and Porto (Figures S3–S5).

The widespread presence of small-sized open spaces characterising the most stratified part of the city contrasts with those of larger dimensions located above all in the Northern suburban districts such as Scampia and Secondigliano. The lack of maintenance of these spaces located within the impressive public residential building complexes (the best-known example is Vele di Scampia) and of safety perceived by people when using them contribute to making these districts anonymous neighbourhoods with a low quality of life. The related open spaces are characterised, overall, by lower runoff coefficient values than those located in the central area of the city, due to the different urban fabric that appears to be of a unified design and recent formation.

Finally, if the limited presence of open spaces in the western districts of Barra, San Giovanni is attributable to their main productive connotation, in the eastern districts such as Pianura, Soccavo and Bagnoli, the "aggressive" building has speculated on spontaneous settlements, to the detriment of the provision of public spaces and collective services. The open space system of the eastern part of the city, as well as the western part of the city, appears to be characterised by numerous deficiencies in terms of both accessibility, especially pedestrian accessibility and adaptability to the impacts of climate change, due to the high values of UHI and runoff coefficient (Figures S1, S3 and S7).

4. Results and Discussion of the Classification of Open Spaces and Neighbourhoods According to Their Contribution to Reducing Climate Vulnerability

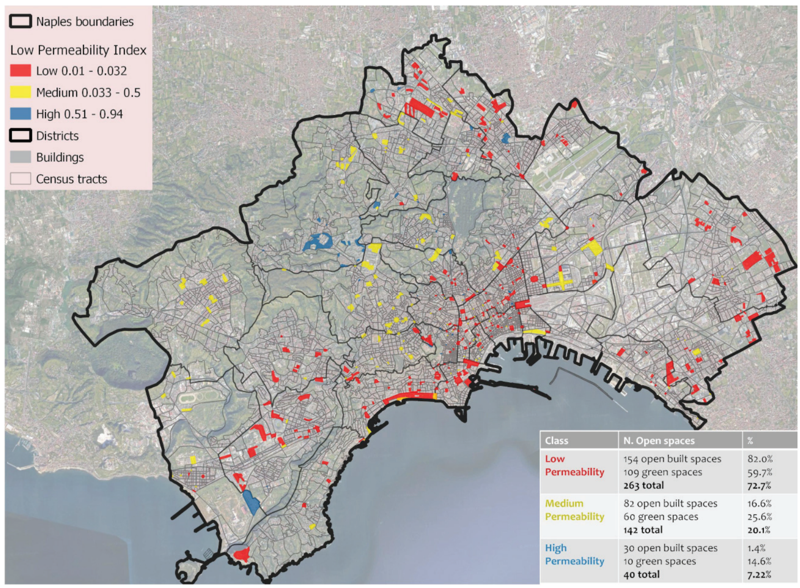
The objectives of improving permeability, thermal comfort and accessibility were measured by aggregating the respective variables into appropriate indices for each of the 445 open spaces in the study area (step 4 of the methodology, Figure 1).

Starting from Figure 3a, which shows the classification of open spaces considering local permeability index (IP_l) values, it can be seen that these are strongly characterised by a lack of drainage capacity. Almost 73% of the spaces are found to have low IP_l values, and this may be attributable to the type of soil and/or the type and maintenance of the drainage pavement present (permeability decreases in part over time due to the accumulation of dust in the joints between the slabs). This percentage of open spaces with low IPl is widespread in most of the neighbourhoods of the city of Naples, except Pianura, Bagnoli, San Carlo all'Arena, Piscinola and Chiaiano, which are instead predominantly characterised by spaces with medium and high permeability; in particular, the last two neighbourhoods just mentioned include almost the few spaces (40) with the best water drainage performance.

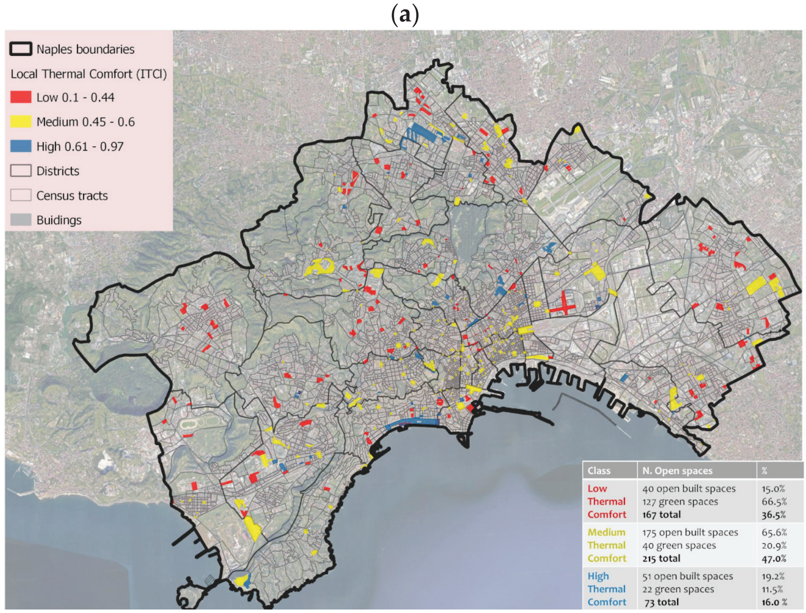
The open space system of the city of Naples is characterised by an average ITC_l of 47%, distributed mainly in the districts of Fuorigrotta, Scampia, Porto, Vomero, and Poggioreale. This result can be attributed, on the one hand, to the cooling effect due to the contiguity between open spaces, causing an amplification of the cooling effect (Figure S2) and, on the other hand, to the circumstance that in these neighbourhoods, the LST values do not exceed 31 °C on average (Figure S6).

It is interesting to note that open spaces with a low ITC_l value characterise almost 36% of the 455 spaces, which fall almost entirely in the districts of Pianura, Arenella, Piscinola, Ponticelli and Barra, confirming the relevance and urgency of defining effective adaptation solutions in the face of both heat waves and flooding, in the light of what has been described for IP_l. Scampia, San Carlo all'Arena, Stella, Chiaia and Vomero are, finally, the neighbourhoods in which most of the 73 spaces with low ITC_l are located (Figure 3b) thanks to the consistent presence of green spaces (Figure S2).

As far as IA_l is concerned, open spaces turn out to have, on the whole, medium-high accessibility (about 73% of the total, Figure 3c) due to the adequate supply of both the LPT and pedestrian network (Figures S3 and S4). These are, for example, the open spaces located in the neighbourhoods of Arenella, Vomero and San Ferdinando, neighbourhoods characterised by significant tourist attractiveness, and those found in Fuorigrotta, Scampia and Vicaria, neighbourhoods with an adequate pedestrian network.

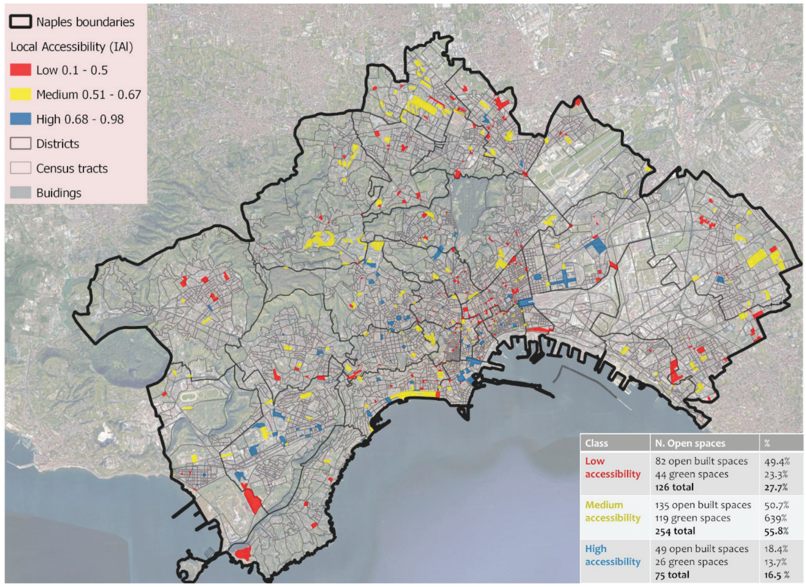


(**a**)



(**b**)

Figure 3. *Cont.*



(**c**)

Figure 3. Classification of open spaces system according to the Index of Local Permeability (**a**), Index of Local Thermal Comfort (**b**) and Index of Local Accessibility (**c**).

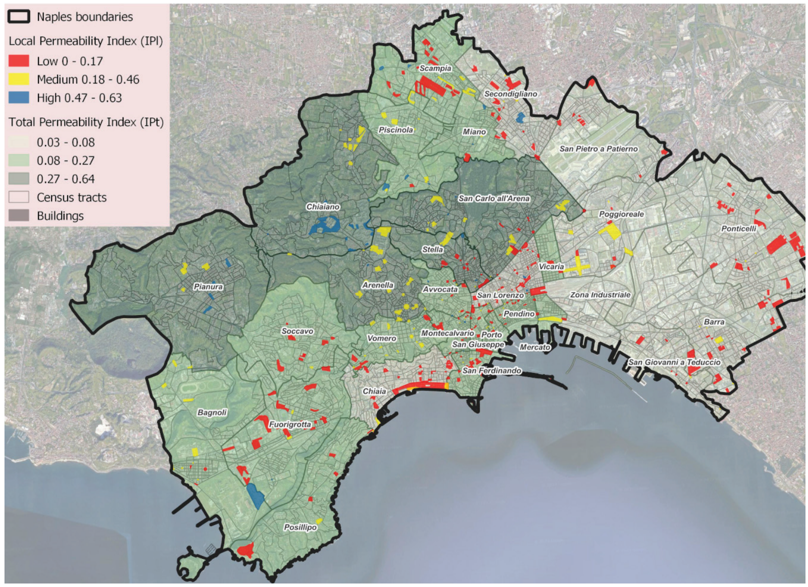
The measurement of the permeability and thermal comfort indices of the open space system was followed by that of the neighbourhoods to identify the "warning areas" regarding these two aspects (step five of the methodology, Figure 1). In general, it is possible to note that neighbourhoods such as Pianura, Chiaiano, Bagnoli and San Carlo all'Arena are characterised by a significant presence of natural surface (between 2 and 5 sq km), as shown in Figure S8; furthermore, the same figure shows the IP_t values (which are high) for the calculation of which the rate of unbuilt territory was considered. Within these neighbourhoods, open spaces reach medium-high IP_l values, which seems to demonstrate the key influence of context factors such as permeability.

In the rest of the city, there are neighbourhoods, mainly located in the central and eastern area, with low IP_t values (Figure 4a) and high permeability of individual open spaces, and neighbourhoods, mainly located in the western area, with medium *IP* values and low permeability of individual open spaces, which can be attributed to the intense degree of sealing.

As far as the thermal comfort index on a neighbourhood scale is concerned, the urban area of Naples is characterised by medium-high values of ICT_t (Figure 4b) due to the high values of both LST, which strongly characterise the municipal territory, and building density, which contributes to exacerbating the UHI phenomenon (Figures S6, S7 and S9).

This is the case of Arenella, Avvocata, San Lorenzo and Barra, with high values even of ITC_l relative to open spaces (Figure 3b). In neighbourhoods such as Posillipo, Pianura, Soccavo and San Carlo all'Arena, the key role of vegetation in terms of regulating the urban microclimate is evident, which contributes to determining, on the whole, an average ICT_t, with the same values of built density (Figure S9).

Chiaiano, Bagnoli and San Giovanni a Teduccio are, finally, the neighbourhoods characterised by low ICT_t (Figure 4b) values due to the medium-low values of both UHI and building density, but where the open spaces present a lack of thermal comfort attributable to the presence of sealed surfaces and high emissivity materials, which contribute to storing solar radiation (Figure S7).



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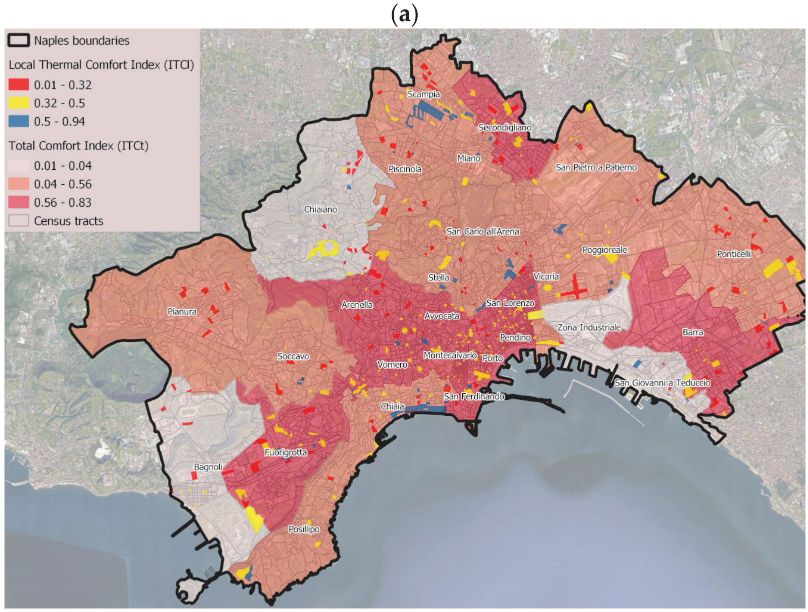


(**b**)

Figure 4. Classification of neighbourhoods and open space systems according to the total and local Permeability Index (**a**) and to the total and local Thermal Comfort Index (**b**).

The "warning areas" are the neighbourhoods that have IP_t and ICT_t values, respectively lower and higher than the average ones (Figures 5 and S10). The coexistence of these conditions results in a high climatic vulnerability for 11 neighbourhoods located mainly in the central and eastern areas of the city of Naples: Avvocata, Barra, Fuorigrotta, Montecalvario, Pendino, Poggioreale, Ponticelli, San Ferdinando, San Lorenzo, Secondigliano and Vomero.

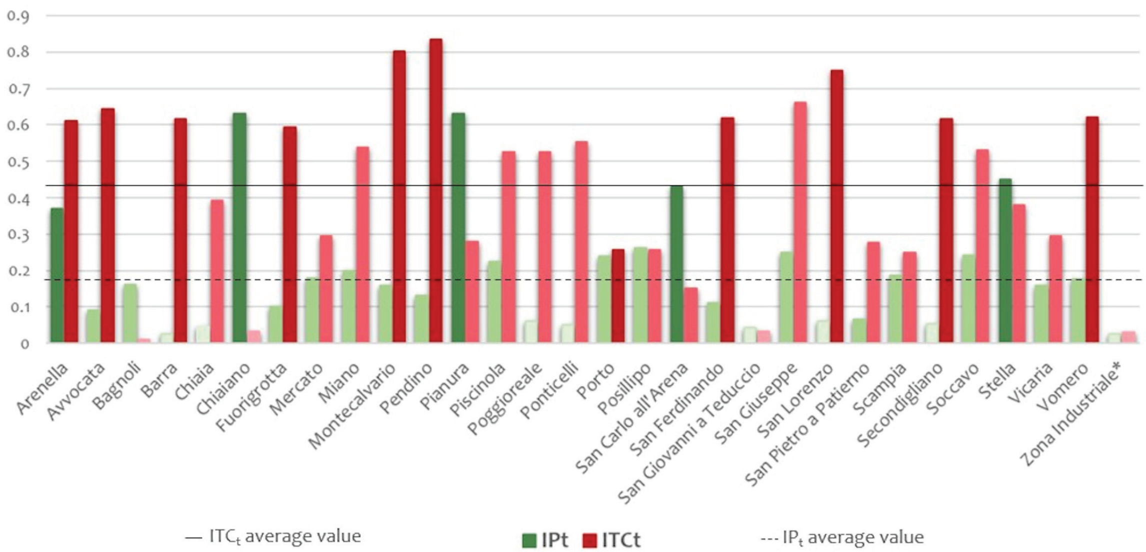


Figure 5. Total permeability and thermal comfort indexes of Naples neighbourhoods and related average values. * Zona Industriale has not open spaces.

5. Results and Discussion of the Classification of Open Spaces Based on the Costs and Benefits and Definition of the Decision Support Tool

In these warning neighbourhoods, the open spaces characterised by the worst climatic performance were taken into consideration, i.e.,: those with a low IP_l value, those with a high ICT_l value and those with the "critical" values of both indices at the same time. The occurrence of one of these conditions would require the implementation of an adaptation intervention, which was proposed with an estimate of the main implementation costs. Each solution was suggested by considering the main climate vulnerability, the physical characteristics of the open space and the neighbouring urban context. These three elements are oriented to guarantee that the interventions are consistent with the existing land use and urban asset to reach transformation compatibility.

First, the results of step 6 of the methodology (Figure 1) related to the different climate adaptation interventions that were proposed for the open spaces located in the "warning districts" are presented and discussed (Sections 5.1–5.3). Next, the results of steps 8 and 9 of the methodology (Figure 1) related to the sorting of the proposed interventions, according to their effectiveness assessed in terms of costs and potential benefits, are presented and discussed (Section 5.4).

5.1. Open Spaces with Low IP_l Value

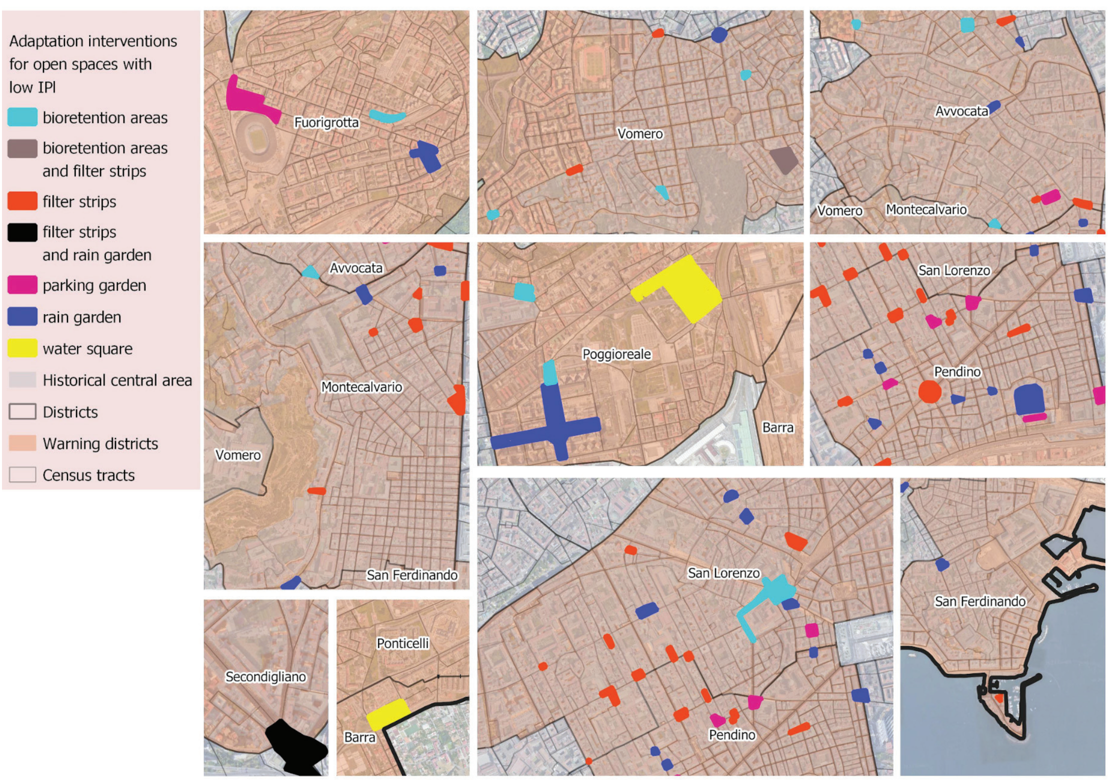
Starting with the 77 open spaces characterised by permeability problems (Figure 6a,b), these are mainly located in the historic and consolidated neighbourhoods in the central area of Naples, such as Avvocata, Pendino and San Lorenzo. While in the Avvocata neighbourhood, the open spaces are almost empty spaces enclosed in the dense built-up fabric, which extends to the slopes of the Arenella hill area, in the adjacent neighbourhoods of San Lorenzo and Pendino, the system of open spaces consists of numerous squares, some of which are the result of the redefinition of the street grid and urban fabric that took place at the end of the 19th century, such as Piazza Nicola Amore and Piazza Calenda.

This urban layout has made it possible to propose "small-scale" interventions (rain gardens, filtered strips, bioretention areas) to improve the permeability of the system of open spaces located in these neighbourhoods of a historical layout, as well as those in the Vomero district. For the open spaces where there are areas for parking, the proposed intervention is the parking garden to ensure functional compatibility with a view to greater sustainability, especially in the central area (Pendino, San Lorenzo), where finding new spaces for parking would not be an easily achievable objective.

It is worth noting that for two open spaces located in the neighbourhoods of Secondigliano and Vomero, integrated interventions have been proposed (filter strips and rain garden in the first case, bioretention and filter strip in the second case) to improve the permeability of the unbuilt surface area and facilitate drainage also by improving the channelling of rainwater, due to the limited surface area available.

The greater extension of open spaces in the Poggioreale, Secondigliano and Ponticelli neighbourhoods also is appropriate for interventions such as water squares. The latter allows to satisfy both the needs for temporary water storage during heavy rainfall as well as those for the redevelopment of public spaces, key places for aggregation and participation in neighbourhoods characterised by phenomena of social distress such as those of the north-eastern suburbs of the city of Naples.

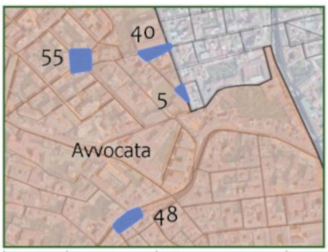
Figure S11 shows that interventions aimed at improving permeability alone amount to approximately 26 million euros, with larger investments in the Vomero, Fuorigrotta and Poggioreale neighbourhoods due to the larger and more numerous areas in which to intervene. Almost all of the open spaces also fall within the historic centre, which is also recognised as a UNESCO heritage site, which implies the presence of urban planning rules and regulations oriented towards protecting the heritage of historical, architectural and cultural interest to the detriment of possible transformations that climate change has now made unavoidable.



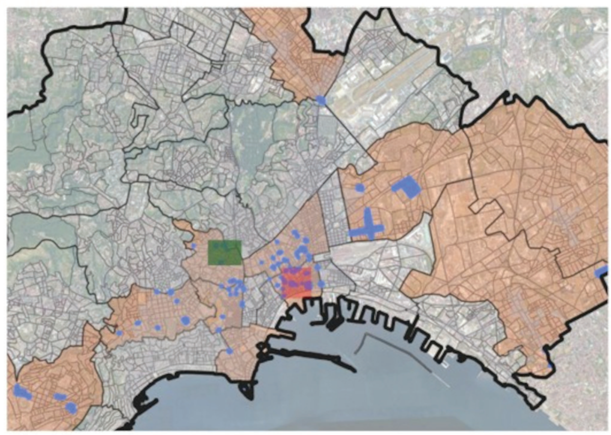
(**a**)

Figure 6. *Cont.*

ID	Surface [sqm]	Intervention	Estimated Cost [€]	Context area
71	7,744.56	rain garden	216,847.57	Historical ring
37	885.77		24,801.62	
14	453.73		12,704.47	
6	303.21		8,489.91	
23	615.56		17,235.79	
37	885.77		24,801.62	
20	558.67		15,642.73	
21	565.29	filter strips	50,876.37	
45	1,155.04		103,953.69	
25	638.52		57,466.98	
35	823.89		74,150.19	
27	657.87	parking garden	27,630.37	



ID	Surface [sqm]	Intervention	Estimated Cost [€]	Context area
55	1,775.09	bioretention areas	56,802.91	Historical ring
40	906.62	filter strips	81,595.62	
5	302.75	rain garden	8,477.08	
48	1,273.84		35,667.60	



(**b**)

Figure 6. Classification of open spaces with local Low Permeability Index in warning districts (**a**) and some examples of interventions and related costs of open spaces with a Low Permeability Index (**b**).

5.2. Open Spaces with Low ITC_l Value

The 31 open spaces found to be deficient in terms of thermal comfort are mainly located in the central-western part of the city (Figure 7a,b). Here, the neighbourhoods of Fuorigrotta and Vomero are mostly green areas where, presumably, the evapotranspiration process is affected by the UHI phenomenon and the intense presence of built-up areas, especially those located in the latter neighbourhood (Figures S7 and S9). In the Secondigliano neighbourhood, on the other hand, the open spaces are areas intended for parking, except a larger area characterised by the presence of an extensive green area. In the latter case, the proposed intervention is aimed at increasing the number of trees to help improve the cooling effect; this solution also concerns the other green spaces located in Fuorigrotta and Vomero.

For the remaining open spaces not currently characterised by the presence of vegetation and distributed both in the districts just mentioned and in the remaining ones in Montecalvario, San Ferdinando, San Lorenzo and Barra, the suggested interventions are those of greening to mitigate the effects of the UHI and contribute to the reduction of energy consumption.

The costs to be borne for the implementation of these types of interventions amount to just under 5 million euros, with the highest rate due to the ex novo planting of tree species which also concerns areas located within the historical centre of the city of Naples (Figure S12).

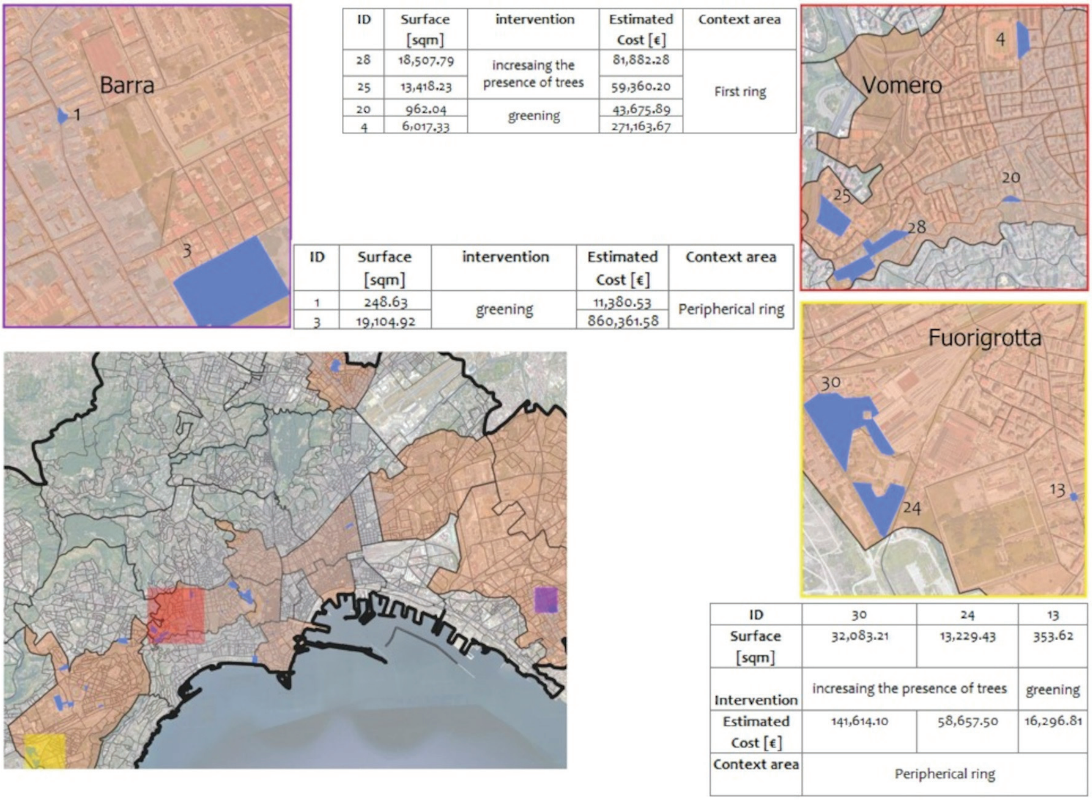
5.3. Open Spaces with Low IP_l and ITC_l Values

Turning finally to the 58 open spaces characterised by both thermal comfort and permeability problems, these are distributed in almost all the neighbourhoods that constitute the city warning areas identified above, with the exception of Pendino and Poggioreale (Figure 8a,b). It is worth noting that the neighbourhoods of Fuorigrotta, Secondigliano, Barra and Ponticelli are almost exclusively green areas subject to significant thermal and stormwater runoff loads caused by the highly impermeable context in which they are located. This state of affairs may be ascribable to a process of both expansions that have not always been planned and orderly and redevelopment that does not yet seem to have fully valorised and renewed urban places, also because of the current climatic-energetic scenarios. The only exception in this respect is an open space intended for parking located near the Maradona stadium in the Fuorigrotta district.

Moving to the central area of the city, numerous open spaces are located in the San Ferdinando district and play an important role in the usability and attractiveness of this area, given their proximity to buildings and places of cultural and architectural interest, as well as their intrinsic historical value. This is the case of piazza Municipio, the Molosiglio area, and piazza Santa Maria degli Angeli, to name but a few. To these can be added piazza Montecalvario, located in the district of the same name, which constitutes one of the few voids within the stratified building fabric, and piazza Giannone and piazza Carlo III in the San Lorenzo district which, although close to each other, differ in size (the former has a limited surface area compared to the latter, which is among the city's largest squares) and in current use (the former is entirely intended for parking).

(**a**)

Figure 7. *Cont.*



ID	Surface [sqm]	intervention	Estimated Cost [€]	Context area
28	18,507.79	increasing the presence of trees	81,882.28	First ring
25	13,418.23		59,360.20	
20	962.04	greening	43,675.89	
4	6,017.33		271,163.67	

ID	Surface [sqm]	intervention	Estimated Cost [€]	Context area
1	248.63	greening	11,380.53	Peripherical ring
3	19,104.92		860,361.58	

ID	30	24	13
Surface [sqm]	32,083.21	13,229.43	353.62
Intervention	increasing the presence of trees		greening
Estimated Cost [€]	141,614.10	58,657.50	16,296.81
Context area	Peripherical ring		

(**b**)

Figure 7. Classification of open spaces with local High Thermal Comfort Index in warning districts (**a**) and some examples of interventions and related costs of open spaces with a Low Permeability Index (**b**).

The proposed interventions require a total cost of just under 8 million euros and relate to both an increase in vegetation, to be implemented above all in the open spaces of Secondigliano, Barra and Ponticelli, and integrated solutions such as the creation of permeable surfaces and bioretention areas to support the existing drainage network by reducing runoff volumes and increasing the presence of vegetation above all in the open spaces of the peripheral districts such as Barra and Fuorigrotta (Figure S13).

In the open spaces located in the central urban area, the prevalent interventions are to increase vegetation and rain gardens, thanks to both the high ITC_l values and the physical characteristics that guided the choice of interventions to be proposed. In particular, in the case of Piazza Municipio, it was decided to create a rain garden to further enhance the redevelopment of the open space now being completed and to act on improving permeability, given the presence of vegetation, albeit limited.

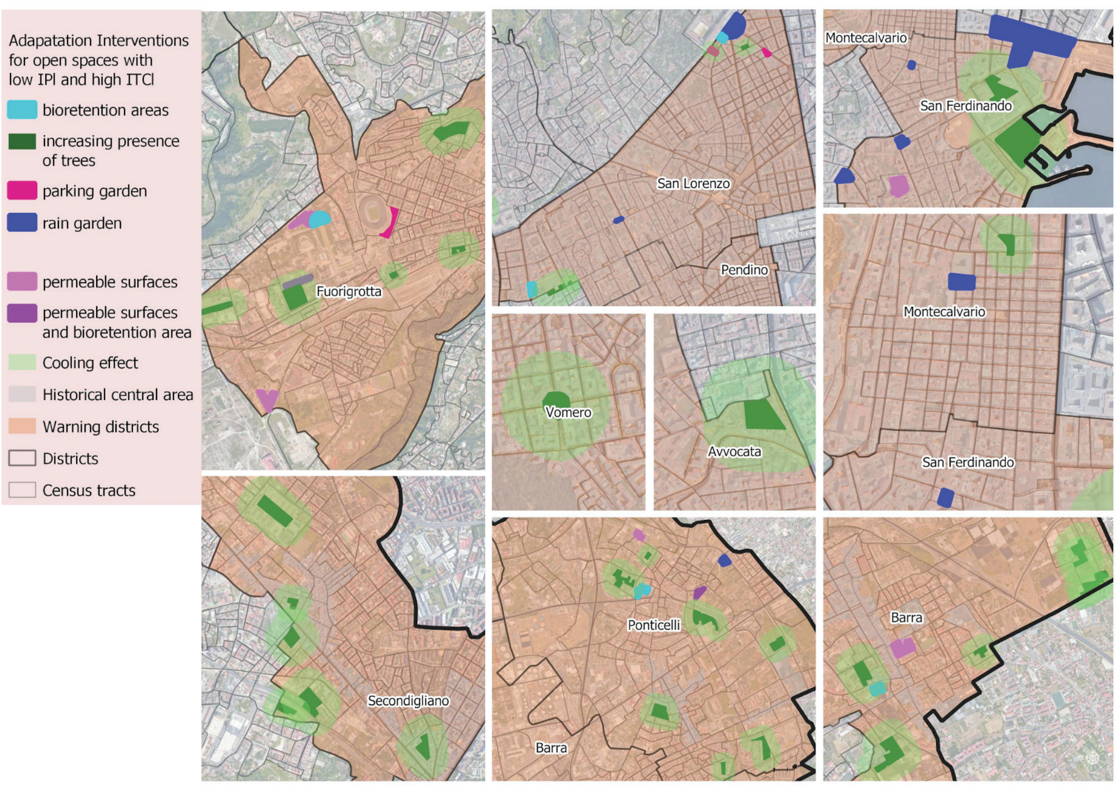
Remaining within the San Ferdinando district, it is worth noting that for the Molosiglio area, the work to strengthen the presence of trees fits in well with the redevelopment project for this green space located in the section of the promenade between the maritime station and the seafront, to contribute to increasing its attractiveness and usability, also by tourists, especially during the summer period of greatest thermal stress.

The cost estimate for adapting the open space system of the city of Naples to climate change seems to be higher for permeability improvement interventions due to the problem of the widespread vulnerability in different parts of the municipal territory and to the consistency of the interventions requiring a greater degree of transformation of the space, compared to greening solutions which seem to be the least costly from an economic point of view.

5.4. Sorting Open Spaces According to Costs and Potential Benefits

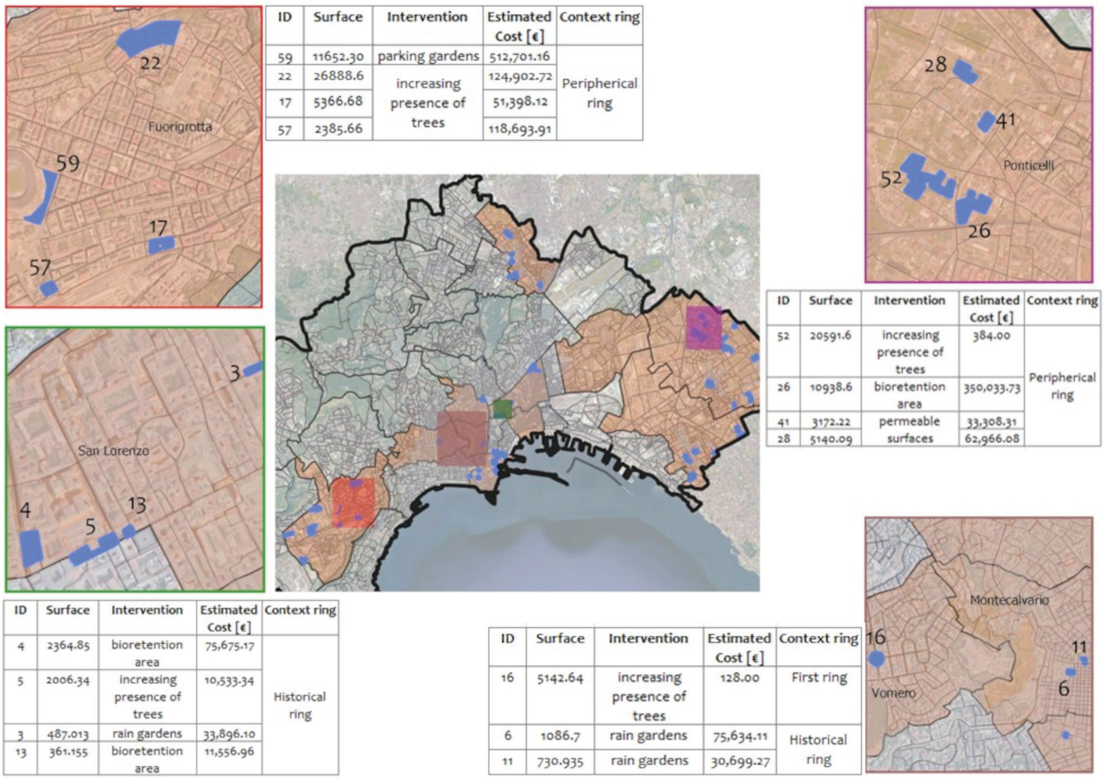
Finally, the proposed adaptation measures were evaluated based on their effectiveness in carrying out a sorting useful to public decision-makers for the choice of open spaces to be transformed with priority. The sorting was carried out for each of the three climate vulnerability conditions considered (low IP_l value, high ICT_l value and co-presence of both "critical" values of both indices) and because of the two criteria underlying the study defined earlier (deviation criterion and cost-benefit criterion).

The orders were also defined by applying the Jenks algorithm that sets the limits between the various classes in correspondence with discontinuities or "jumps" in the distribution of values. In particular, this algorithm was applied as far as permeability is concerned, considering the size of the areas, and as far as thermal comfort is concerned, bearing in mind the cost per inhabitant. It was, thus, possible to define a first cluster of open spaces based on their size (defined by the largest jump in size in the Jenks sorting) and based on cost per inhabitant (defined by the significant jumps in the Jenks sorting), and a second cluster including all the other spaces (defined by the lack of significant jumps in the two sortings).



(**a**)

Figure 8. *Cont.*



(**b**)

Figure 8. Classification of open spaces with local Low Permeability Index and local High Thermal Comfort Index in warning districts (**a**) and some examples of interventions and related costs of open spaces with a Low Permeability Index (**b**).

In detail, as far as permeability is concerned, the first cluster is composed of 11 open spaces located mainly in the peripheral area (Table 3), having both positive signs (identifying a low possibility of the economic burden of adaptation) and negative signs (identifying a high possibility of the economic burden of adaptation). Among the negative ones, two have a high delta signifying a significant economic burden related to the intervention of water squares. It is emphasised that all values with a positive sign refer to adaptation measures such as rain and parking gardens and bioretention areas to be realised in all areas of the city.

Table 3. Sorting and clusters of open spaces with low permeability, according to Δ values.

ID	Surface [sqm]	District	Climate Adaption Intervention	Estimated Cost [€]	Context Area	Dimensional Weight of Open Space %	Economic Weight of Open Space %	Δ
77	85,951.13	Poggioreale	water square	12,892,669.80	Peripherical ring	29.82%	49.50%	−19.68%
76	35,467.85	Poggioreale	rain garden	993,099.74	Peripherical ring	12.31%	3.81%	8.49%
75	26,638.03	Barra	water square	3,995,704.50	Peripherical ring	9.24%	15.34%	−6.10%
74	24,565.03	Fuorigrotta	parking garden	1,621,292.18	Peripherical ring	8.52%	6.22%	2.30%
73	8395.37	Secondigliano	filter strips and rain garden	990,653.42	Peripherical ring	2.91%	3.80%	−0.89%
72	8070.28	San Lorenzo	bioretention areas	258,249.02	Historical ring	2.80%	0.99%	1.81%
71	7744.56	Pendino	rain garden	216,847.57	Historical ring	2.69%	0.83%	1.85%

Table 3. *Cont.*

ID	Surface [sqm]	District	Climate Adaption Intervention	Estimated Cost [€]	Context Area	Dimensional Weight of Open Space %	Economic Weight of Open Space %	Δ
70	7394.53	Vomero	bioretention areas and filter strips	902,132.78	First ring	2.57%	3.46%	−0.90%
69	6321.09	Poggioreale	bioretention areas	202,274.88	Peripherical ring	2.19%	0.78%	1.42%
68	4945.77	Fuorigrotta	rain garden	138,481.42	Peripherical ring	1.72%	0.53%	1.18%
67	3770.04	Poggioreale	bioretention areas	120,641.34	Peripherical ring	1.31%	0.46%	0.84%
66	3726.93	Pendino	filter strips	335,423.97	Historical ring	1.29%	1.29%	0.01%
65	3463.71	San Ferdinando	rain garden	96,983.82	Historical ring	1.20%	0.37%	0.83%
64	3228.01	Fuorigrotta	rain garden	90,384.22	Peripherical ring	1.12%	0.35%	0.77%
63	2713.25	Pendino	parking garden	65,117.95	Historical ring	0.94%	0.25%	0.69%
62	2179.46	Avvocata	parking garden	52,307.06	Historical ring	0.76%	0.20%	0.56%
61	2069.04	San Lorenzo	filter strips	186,213.33	Historical ring	0.72%	0.71%	0.00%
60	1944.51	Fuorigrotta	bioretention areas	62,224.22	Peripherical ring	0.67%	0.24%	0.44%
59	1926.56	Barra	rain garden	53,943.74	Peripherical ring	0.67%	0.21%	0.46%
58	1864.44	Montecalvario	filter strips	167,799.60	Historical ring	0.65%	0.64%	0.00%
57	1839.17	San Ferdinando	rain garden	51,496.82	Historical ring	0.64%	0.20%	0.44%
56	1837.22	San Lorenzo	rain garden	51,442.19	Historical ring	0.64%	0.20%	0.44%
55	1775.09	Avvocata	bioretention areas	56,802.91	Historical ring	0.62%	0.22%	0.40%
54	1707.33	San Lorenzo	filter strips	153,659.70	Historical ring	0.59%	0.59%	0.00%
53	1643.94	Avvocata	filter strips	147,954.33	Historical ring	0.57%	0.57%	0.00%
52	1639.47	Pendino	rain garden	45,905.08	Historical ring	0.57%	0.18%	0.39%
51	1401.48	Avvocata	filter strips	126,133.02	Historical ring	0.49%	0.48%	0.00%
50	1350.54	Montecalvario	filter strips	121,548.51	Historical ring	0.47%	0.47%	0.00%
49	1304.90	Pendino	parking garden	54,805.93	Historical ring	0.45%	0.21%	0.24%
48	1273.84	Avvocata	rain garden	35,667.60	Historical ring	0.44%	0.14%	0.31%
47	1213.14	San Lorenzo	rain garden	33,967.78	Historical ring	0.42%	0.13%	0.29%
46	1173.49	San Lorenzo	parking garden	49,286.50	Historical ring	0.41%	0.19%	0.22%
45	1155.04	Pendino	filter strips	103,953.69	Historical ring	0.40%	0.40%	0.00%
44	1100.03	San Lorenzo	rain garden	30,800.73	Historical ring	0.38%	0.12%	0.26%
43	1099.31	Vomero	filter strips	98,937.81	First ring	0.38%	0.38%	0.00%
42	1012.56	Montecalvario	rain garden	28,351.62	Historical ring	0.35%	0.11%	0.24%
41	924.17	San Lorenzo	filter strips	83,175.57	Historical ring	0.32%	0.32%	0.00%
40	906.62	Avvocata	filter strips	81,595.62	Historical ring	0.31%	0.31%	0.00%
39	891.25	San Lorenzo	rain garden	24,955.00	Historical ring	0.31%	0.10%	0.21%
38	887.06	San Lorenzo	filter strips	79,835.58	Historical ring	0.31%	0.31%	0.00%
37	885.77	Pendino	rain garden	24,801.62	Historical ring	0.31%	0.10%	0.21%
36	874.73	Vomero	bioretention areas	41,987.14	First ring	0.30%	0.16%	0.14%
35	823.89	Pendino	filter strips	74,150.19	Historical ring	0.29%	0.28%	0.00%
34	799.41	Montecalvario	rain garden	22,383.59	Historical ring	0.28%	0.09%	0.19%
33	780.34	San Lorenzo	filter strips	70,230.96	Historical ring	0.27%	0.27%	0.00%
32	770.35	Montecalvario	rain garden	21,569.86	Historical ring	0.27%	0.08%	0.18%
31	768.70	Vomero	bioretention areas	36,897.50	First ring	0.27%	0.14%	0.13%
30	732.06	Pendino	filter strips	65,885.49	Historical ring	0.25%	0.25%	0.00%
29	726.68	Vomero	rain garden	20,347.04	First ring	0.25%	0.08%	0.17%
28	662.57	Pendino	filter strips	59,631.03	Historical ring	0.23%	0.23%	0.00%
27	657.87	Pendino	parking garden	27,630.37	Historical ring	0.23%	0.11%	0.12%

Table 3. *Cont.*

ID	Surface [sqm]	District	Climate Adaption Intervention	Estimated Cost [€]	Context Area	Dimensional Weight of Open Space %	Economic Weight of Open Space %	Δ
26	646.03	Barra	rain garden	18,088.92	Peripherical ring	0.22%	0.07%	0.15%
25	638.52	San Lorenzo	filter strips	57,466.98	Historical ring	0.22%	0.22%	0.00%
24	638.44	Pendino	filter strips	57,459.78	Historical ring	0.22%	0.22%	0.00%
23	615.56	Pendino	rain garden	17,235.79	Historical ring	0.21%	0.07%	0.15%
22	577.55	Avvocata	bioretention areas	27,722.35	Historical ring	0.20%	0.11%	0.09%
21	565.29	Pendino	filter strips	50,876.37	Historical ring	0.20%	0.20%	0.00%
20	558.67	Pendino	rain garden	15,642.73	Historical ring	0.19%	0.06%	0.13%
19	494.87	San Ferdinando	filter strips	44,537.94	Historical ring	0.17%	0.17%	0.00%
18	474.03	San Lorenzo	filter strips	42,662.52	Historical ring	0.16%	0.16%	0.00%
17	468.77	Pendino	filter strips	42,189.39	Historical ring	0.16%	0.16%	0.00%
16	468.55	San Lorenzo	filter strips	42,169.14	Historical ring	0.16%	0.16%	0.00%
15	465.30	Pendino	rain garden	13,028.40	Historical ring	0.16%	0.05%	0.11%
14	453.73	Pendino	rain garden	12,704.47	Historical ring	0.16%	0.05%	0.11%
13	445.28	Avvocata	bioretention areas	21,373.44	Historical ring	0.15%	0.08%	0.07%
12	404.69	San Lorenzo	parking garden	16,997.15	Historical ring	0.14%	0.07%	0.08%
11	396.45	Pendino	rain garden	11,100.66	Historical ring	0.14%	0.04%	0.09%
10	392.90	Montecalvario	rain garden	11,001.28	Historical ring	0.14%	0.04%	0.09%
9	386.61	Montecalvario	filter strips	34,794.99	Historical ring	0.13%	0.13%	0.00%
8	366.33	Vomero	bioretention areas	17,583.89	First ring	0.13%	0.07%	0.06%
7	329.61	Avvocata	filter strips	29,664.90	Historical ring	0.11%	0.11%	0.00%
6	303.21	Pendino	rain garden	8489.91	Historical ring	0.11%	0.03%	0.07%
5	302.75	Avvocata	rain garden	8477.08	Historical ring	0.11%	0.03%	0.07%
4	284.39	San Lorenzo	filter strips	25,594.83	Historical ring	0.10%	0.10%	0.00%
3	263.79	Montecalvario	filter strips	23,741.37	Historical ring	0.09%	0.09%	0.00%
2	188.73	Montecalvario	filter strips	16,985.25	Historical ring	0.07%	0.07%	0.00%
1	109.65	San Lorenzo	filter strips	9868.41	Historical ring	0.04%	0.04%	0.00%

The second cluster consists of open spaces located mainly in the central districts of Avvocata, San Lorenzo and Pendino, characterised by more limited burdens (Table 3).

Within this cluster, it is possible to define groups of open spaces classified according to the type of intervention and the urban sector (peripheral crown, first crown, central crown) in which it falls to provide the local decision maker with further useful elements for choosing how and where to intervene (Figures S14 and S15). For example, rain gardens and filter strips are the most widespread interventions to improve permeability, which especially lack in the peripheral area (Figures S14 and S15).

As far as thermal comfort is concerned, the effectiveness was evaluated concerning the cost per inhabitant of the greening intervention to be carried out due to the results of the previous work developed by the authors. Again, two clusters were identified. The first is made up of four open spaces (characterised by a higher economic burden to bear) located in the peripheral districts of Fuorigrotta, Secondigliano and Barra (Table 4). The second cluster consists of 27 open spaces located in more densely populated areas, which entail a lower unit cost of just over 150 euros.

Depending on the type of intervention and the urban sector (peripheral crown, first crown, central crown) in which each open space falls, greening interventions are needed in the most stratified areas, while in the peripheral areas, interventions aimed at improving thermal comfort are needed (Figures S16 and S17).

Table 4. Sorting and clusters of open spaces with high thermal comfort, according to cost per inhabitant values.

ID	Surface [sqm]	District	Climate Adaption Intervention	Estimated Cost [€]	Context Area	Cost Per Inhab.	Inhab.
19	31,273.59	Secondigliano	greening	1408.271.42	Peripherical ring	1635.62	861
7	8962.93	Fuorigrotta	greening	403,907.63	Peripherical ring	585.37	690
31	39,463.07	Fuorigrotta	increasing the presence of trees	174,085.51	Peripherical ring	391.20	445
3	19,104.92	Barra	greening	860,361.58	Peripherical ring	375.38	2292
6	13,416.13	San Ferdinando	greening	603,981.85	Historical ring	150.88	4003
29	30,742.18	Vomero	increasing the presence of trees	135,713.57	First ring	110.61	1227
4	6017.33	Vomero	greening	271,163.67	First ring	82.05	3305
28	18,507.79	Vomero	increasing the presence of trees	81,882.28	First ring	56.78	1442
8	2534.14	Vomero	greening	114,420.35	First ring	53.59	2135
30	32,083.21	Fuorigrotta	increasing the presence of trees	141,614.10	Peripherical ring	45.22	3132
20	962.04	Vomero	greening	43,675.89	First ring	36.52	1196
9	1932.27	Fuorigrotta	greening	87,335.93	Peripherical ring	27.21	3210
26	13,442.93	Vomero	increasing the presence of trees	59,596.89	First ring	26.87	2218
5	653.90	Vomero	greening	29,809.59	First ring	26.08	1143
27	17,594.65	Fuorigrotta	increasing the presence of trees	77,864.46	Peripherical ring	24.79	3141
17	1733.07	Secondigliano	greening	78,372.33	Peripherical ring	23.81	3292
23	10,771.52	Fuorigrotta	increasing the presence of trees	47,842.70	Peripherical ring	22.36	2140
18	1.606,77	Secondigliano	greening	72,688.52	Peripherical ring	21.70	3350
25	13,418.23	Vomero	increasing the presence of trees	59,360.20	First ring	18.84	3150
16	1150.11	Secondigliano	greening	52,139.13	Peripherical ring	15.90	3280
24	13,229.43	Fuorigrotta	increasing the presence of trees	58,657.50	Peripherical ring	14.62	4011
15	339.53	San Ferdinando	greening	15,342.90	Historical ring	7.15	2145
13	353.62	Fuorigrotta	greening	16,296.81	Peripherical ring	6.67	2442
21	2841.12	Fuorigrotta	increasing the presence of trees	12,820.92	Peripherical ring	5.78	2220
22	3779.97	San Lorenzo	increasing the presence of trees	16,951.86	Historical ring	5.17	3281
2	289.28	Vomero	greening	13,209.78	First ring	4.14	3188
12	78.02	San Ferdinando	greening	3894.81	Historical ring	3.55	1098
1	248.63	Barra	greening	11,380.53	Peripherical ring	3.20	3555
11	59.11	Montecalvario	greening	3043.73	Historical ring	1.40	2172
14	94.05	Montecalvario	greening	4296.25	Historical ring	1.38	3122
10	52.53	Montecalvario	greening	2428.03	Historical ring	0.77	3155

A third result of the work is the identification of spaces that need contextual adaptation to the two types of vulnerability (Table 5).

Table 5. Sorting and clusters of open spaces with low permeability and high thermal comfort, according to Δ values and cost per inhabitant values.

ID	Surface [sqm]	District	Climate Adaption Intervention	Estimated Cost [€]	Context Ring	Dimensional Weight of Open Space %	Economic Weight of Open Space %	Δ	Cost Per Inhab.	Inhab.
1	45,010.06	San Ferdinando	rain gardens	1,890,422.52	Historical ring	13.3%	43.0%	−29.7%		
29	14,983.65	San Ferdinando	permeable surfaces	183,549.71	Historical ring	4.4%	4.2%	0.3%		
21	13,299.43	Fuorigrotta	permeable surfaces	162,918.03	Peripherical ring	3.9%	3.7%	0.2%		
20	13,229.43	Fuorigrotta	bioretention area	423,341.79	Peripherical ring	3.9%	9.6%	−5.7%		
30	12,329.24	Fuorigrotta	bioretention area	394,535.74	Peripherical ring	3.7%	9.0%	−5.3%		
59	11,652.30	Fuorigrotta	parking gardens	512,701.16	Peripherical ring	3.5%	11.7%	−8.2%		
27	11,538.52	Fuorigrotta	permeable surfaces	141,346.92	Peripherical ring	3.4%	3.2%	0.2%		
47	11,518.50	Barra	permeable surfaces	120,944.22	Peripherical ring	3.4%	2.8%	0.7%		
26	10,938.55	Ponticelli	bioretention area	350,033.73	Peripherical ring	3.2%	8.0%	−4.7%		
46	9831.81	San Ferdinando	increasing presence of trees	51,065.39	Historical ring				1021.31	50
35	25,801.66	Ponticelli	increasing presence of trees	48,513.64	Peripherical ring				312.99	155
39	13,526.49	Fuorigrotta	increasing presence of trees	43,643.95	Peripherical ring				256.73	170
19	8822.32	Fuorigrotta	permeable surfaces and bioretention area	727,841.32	Peripherical ring	2.6%	16.6%	−13.9%		
45	7289.34	Ponticelli	rain gardens	306,152.36	Peripherical ring	2.2%	7.0%	−4.8%		
36	5753.30	Ponticelli	permeable surfaces and bioretention area	312,116.47	Peripherical ring	1.7%	7.1%	−5.4%		
28	5140.09	Ponticelli	permeable surfaces	62,966.08	Peripherical ring	1.5%	1.4%	0.1%		
43	4840.49	Barra	permeable surfaces and bioretention area	166,996.94	Peripherical ring	1.4%	3.8%	−2.4%		
41	3172.22	Barra	permeable surfaces	33,308.31	Peripherical ring	0.9%	0.8%	0.2%		
4	2364.85	San Lorenzo	bioretention area	75,675.17	Historical ring	0.7%	1.7%	−1.0%		
9	2021.07	San Ferdinando	rain gardens	140,666.33	Historical ring	0.6%	3.2%	−2.6%		
7	1182.67	San Lorenzo	bioretention area	37,845.47	Historical ring	0.4%	0.9%	−0.5%		
6	1086.70	Montecalvario	rain gardens	75,634.11	Historical ring	0.3%	1.7%	−1.4%		
15	844.99	San Lorenzo	bioretention area	27,039.74	Historical ring	0.3%	0.6%	−0.4%		
11	730.94	Montecalvario	rain gardens	30,699.27	Historical ring	0.2%	0.7%	−0.5%		
10	545.40	San Ferdinando	rain gardens	37,960.05	Historical ring	0.2%	0.9%	−0.7%		
2	537.95	San Lorenzo	parking gardens	23,669.76	Historical ring	0.2%	0.5%	−0.4%		
3	487.01	San Lorenzo	rain gardens	33,896.10	Historical ring	0.1%	0.8%	−0.6%		
13	361.16	San Lorenzo	bioretention area	11,556.96	Historical ring	0.1%	0.3%	−0.2%		
44	28,357.89	San Ferdinando	v presence of trees	837.46	Historical ring				20.94	40
37	28,089.60	Fuorigrotta	increasing presence of trees	837.46	Peripherical ring				111.46	814
22	26,888.62	Fuorigrotta	increasing presence of trees	124,902.72	Peripherical ring				105.40	1185
40	23,053.21	Ponticelli	increasing presence of trees	118,693.91	Peripherical ring				73.03	195
55	21,023.59	Barra	increasing presence of trees	113,911.31	Peripherical ring				61.45	1118
52	20,591.57	Ponticelli	increasing presence of trees	101,818.10	Peripherical ring				60.31	1968
50	16,777.54	Ponticelli	increasing presence of trees	92,887.80	Peripherical ring				57.56	1979
24	15,527.81	Ponticelli	increasing presence of trees	90,730.89	Peripherical ring				41.45	2241
33	13,466.58	Secondigliano	increasing presence of trees	68,706.36	Peripherical ring				41.12	954
34	13,466.58	Secondigliano	increase presence of trees	59,900.54	Peripherical ring				39.56	2574
48	11,518.53	Barra	increasing presence of trees	59,636.94	Peripherical ring				37.89	1574
8	10,536.70	San Lorenzo	increasing presence of trees	59,380.94	Historical ring				35.16	385
18	8827.36	Barra	increasing presence of trees	46,489.49	Peripherical ring				22.75	1009
38	7640.75	Secondigliano	increasing presence of trees	15,473.50	Peripherical ring				21.16	986
44	28,357.89	San Ferdinando	increase presence of trees	837.46	Historical ring				20.94	40
31	7058.82	Avvocata	increasing presence of trees	39,224.38	Historical ring				20.52	968
51	6792.21	Secondigliano	increase presence of trees	34,003.29	Peripherical ring				19.85	3017
49	5766.92	Barra	increase presence of trees	31,442.79	Peripherical ring				19.53	3041

Table 5. *Cont.*

ID	Surface [sqm]	District	Climate Adaption Intervention	Estimated Cost [€]	Context Ring	Dimensional Weight of Open Space %	Economic Weight of Open Space %	Δ	Cost Per Inhab.	Inhab.
17	5366.68	Fuorigrotta	increasing presence of trees	30,013.74	Peripherical ring				18.30	1245
16	5142.64	Vomero	increasing presence of trees	25,502.45	First ring				17.03	1846
53	5129.80	Ponticelli	increase presence of trees	23,997.37	Peripherical ring				15.00	3100
54	5129.80	Ponticelli	increasing presence of trees	23,011.59	Peripherical ring				13.78	2178
23	4683.99	Secondigliano	increase presence of trees	22,955.12	Peripherical ring				11.33	3001
32	4427.60	Barra	increasing presence of trees	22,782.72	Peripherical ring				11.29	1270
25	3755.27	Barra	increase presence of trees	20,865.56	Peripherical ring				9.96	2310
42	3172.22	Ponticelli	increasing presence of trees	19,865.42	Peripherical ring				8.95	2682
14	3149.29	San Ferdinando	increasing presence of trees	16,651.19	Historical ring				7.72	2005
58	3047.32	Secondigliano	increasing presence of trees	14,341.77	Peripherical ring				6.37	4001
57	2385.66	Fuorigrotta	increasing presence of trees	14,240.88	Peripherical ring				5.08	165
5	2006.34	San Lorenzo	increasing presence of trees	13,536.22	Historical ring				4.53	3677
12	1395.41	San Lorenzo	increasing presence of trees	10,624.90	Historical ring				3.67	2898

Therefore, two clusters were identified based on both the delta between dimensional weight and economic weight (for permeability) and the cost per inhabitant (for thermal comfort). The first cluster is represented by open spaces with a negative delta, i.e., with the highest economic burden to be borne, relative to rain garden interventions (in the San Ferdinando district) and parking garden and bioretention area interventions (in the Fuorigrotta district); by open spaces with numerically lower positive deltas (e.g., Barra neighbourhood, Table 5); by open spaces with the highest cost per inhabitant relative to increases in trees (in the San Ferdinando neighbourhood) and very large open spaces (14,000 sqm) in a non-densely inhabited area (in the Ponticelli and Fuorigrotta neighbourhoods).

Interventions to increase vegetation are the most numerous for the reduction of the dual climatic vulnerability that characterises the open spaces under consideration (Figure S18). The peripheral part of the city is the one where the open spaces with low thermal and hydraulic performance are mainly located (Figure S19); however, it is worth noting that the central crown is also strongly characterised by this dual problem, confirming the need to update the transformation rules of areas of high historical-architectural value with the criteria that take into account the resilience essentials cities require.

6. Conclusions

Climate change is a long-term challenge, but the pace and intensity of its effects that affect cities all over the planet require urgent and innovative strategies not only in the "mitigation" of the phenomena but, above all, in the "adaptation" of cities to the growing impacts of these new climatic events. This is even more true for the urban systems of the countries bordering the Mediterranean, which are threatened by the effects of global warming. In this geographic area, a large part of the population lives in coastal areas, which are more exposed and vulnerable to the natural phenomena associated with climate change [63,64].

To rapidly adapt cities to new climatic conditions, reducing their vulnerability to likely negative impacts, the open space system can play a relevant role in cooling the built environment, improving stormwater drainage and promoting sustainable mobility. These spaces can be assigned important climate-regulating functions as drivers and accelerators of sustainable urban development, urban regeneration and resilient systems [65–67].

From this perspective, this contribution represents the first result of a work aimed at developing a decision-support tool to sustainably transform the open space system (built and unbuilt spaces) by reducing its vulnerability and increasing its attractiveness and urban quality.

The application of the proposed method to the urban scale allows for (i) obtaining an initial cognitive result of the system of open spaces in terms of their characteristics (physical, climatic and usability) and the external agents by which they may be affected (such as heat waves and extreme rainfall events) and (ii) outlining some possible adaptation strategies in the different parts of the city that also take into account the resources required for their implementation. The estimated costs, the type of intervention proposed and the urban reference context represent three possible elements for local decision-makers to validate/choose the climate change adaptation interventions to be implemented. The results can represent useful inputs to support the development of climate adaptation strategy and plan at the urban scale that is strongly needed in populous and built densely cities like Naples, where chronic social and economic issues can be exacerbated by the increase of frequency and intensity of extreme precipitation events and heat waves, representing a signal of the ongoing climate change [10].

The low performance of the open spaces to extreme climatic events, like flooding and UHI, is mostly due to the high imperviousness and building density levels of the city. Two hundred and seventy-nine open spaces out of a total of four hundred and forty-five require adaptation interventions with a higher financial burden for permeability improvement, which underlines the relevance of the issue of land use in relation to sustainability and urban resilience. The context of the densely built and stratified city, where the need to adapt the physical, functional and architectural heritage is bound to clash, inevitably, with the immobility of transformations determined by urban planning and building rules and regulations, makes the results significant for the Italian panorama.

The proposed work, in the next step of the research, will allow defining intervention practices that, according to the preservation of a city's historical heritage, will stimulate the sensitivity of local administrators in innovating the urban planning tools in force in the light of current climatic-energy requirements.

To the best of our knowledge, the present study is the first to provide climate adaptation interventions based on NBSs and relative estimated costs for the Naples case study and, representing an initial result, in a subsequent phase of work, it will be necessary to measure the weight of the relationships between context characteristics and open spaces and to define the "connection network" between open spaces and the set of adaptation interventions for each space. Further applications will rely on flood and microclimate simulations to assess the hydrological and thermal suitability effects of the proposed interventions. Different scenarios can be simulated to measure and compare consequent benefits in terms of reduction of temperature and runoff coefficient and level of pluvial floods. Through these future developments, the following current limits of the work can be overcome: (i) the lack of data on the flooded surfaces, as they require hydrologic models and sewer system information; (ii) the statistical significance of the variables to assess the influence of the territorial context on permeability and thermal comfort properties of the open spaces; (iii) the data related to microclimate changes consequent to the realisation of the proposed NBSs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15108111/s1, The supplementary materials contains additional maps and tables related to the classification of open spaces and neighbourhoods based on (i) physical characteristics that are relevant to climate vulnerability and (ii) estimated costs and benefits determined by proposed climate adaptation interventions. Figure S1. Classification of open spaces based on Runoff coefficients. Figure S2. Classification of open spaces based on cooling effect, according to green areas dimensions and urban fabrics building density. Figure S3. Classification of open spaces based on Pedestrian accessibility. Figure S4. Classification of open spaces based on LPT accessibility. Figure S5. Classification of open spaces based on Parking supply accessibility. Figure S6. Land Surface Temperature (30 × 30 m grid). Figure S7. Classification of districts based on UHI levels. Figure S8. Amount of natural surfaces within districts and their classification based on IP_t. Figure S9. Classification of districts based on Building density. Figure S10. Naples neighbourhoods representing "warning areas" due to their permeability and thermal comfort values indexes.

Figure S11. Proposed adaptation interventions for increasing permeability and related estimated costs. Figure S12. Proposed adaptation interventions for improving thermal comfort and related estimated costs. Figure S13. Proposed adaptation interventions for improving permeability and thermal comfort and related estimated costs. Figure S14. Classification of open spaces, according to adaptation interventions for improving permeability. Figure S15. Classification of open spaces for improving permeability, according to their district localisation. Figure S16. Classification of open spaces, according to adaptation interventions for improving thermal comfort. Figure S17. Classification of open spaces for improving thermal comfort, according to their district localisation. Figure S18. Classification of open spaces according to adaptation interventions for improving permeability and thermal comfort. Figure S19. Classification of open spaces for improving permeability and thermal comfort, according to their district localisation.

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References

1. Burch, S.; Hughes, S.; Romero-Lankao, P.; Schroeder, H.; Elmqvist, T.; Bai, X.; Frantzeskaki, N.; Griffith, C.; Maddox, D.; McPhearson, T. Governing urban sustainability transformations. In *The Urban Planet: Knowledge towards Sustainable Cities*; Elmqvist, T., Bai, X., Frantzeskaki, N., Griffith, C., Maddox, D., McPhearson, T., Eds.; Cambridge University Press: Cambridge, UK, 2018; pp. 303–326. [CrossRef]
2. Iwaniec, D.M.; Cook, E.M.; Barbosa, O.; Grimm, N.B. The framing of urban sustainability transformations. *Sustainability* **2019**, *11*, 573. [CrossRef]
3. European Commission. Living Well, within the Limits of Our Planet. Available online: https://op.europa.eu/s/p3AJ (accessed on 1 May 2023).
4. European Environmental Agency. Close Up—Water in the City. Available online: https://www.eea.europa.eu/signals/ (accessed on 2 January 2023).
5. European Environmental Agency. *Land Take and Land Degradation in Functional Urban Areas*; Publications Office of the European Union: Luxembourg, 2021. [CrossRef]
6. European Committee of the Regions. *Regional and Local Authorities and the National Recovery and Resilience Plans*; Publications Office of the European Union: Luxembourg, 2021; Available online: https://data.europa.eu/doi/10.2863/978895 (accessed on 10 January 2023).
7. Koundouri, P.; Devves, S.; Plataniotis, A. Alignment of the European green deal, the sustainable development goals and the European semester process: Method and application. *TEL* **2021**, *11*, 743–770. [CrossRef]
8. Hölscher, K.; Frantzeskaki, N. Perspectives on urban transformation research: Transformations in, of, and by cities. *Urban Transform.* **2021**, *3*, 2. [CrossRef]
9. Wolfram, M.; Frantzeskaki, N.; Maschmeyer, S. Cities, systems and sustainability: Status and perspectives of research on urban transformations. *COSUST* **2016**, *22*, 18–25. [CrossRef]
10. IPCC. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2022.
11. European Commission. Evaluating the Impact of Nature-Based Solutions: A Handbook for Practitioners. Available online: https://op.europa.eu/en/publication-detail/ (accessed on 10 January 2023).
12. Hiemstra, J.A.; Saaroni, H.; Amorim, J.H. The urban heat Island: Thermal comfort and the role of urban greening. In *The Urban Forest: Cultivating Green Infrastructure for People and the Environment*; Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Ostoić, S.K., Sanesi, G., del Amo, R.A., Eds.; Springer: Cambridge, UK, 2017; pp. 7–19. [CrossRef]
13. Ataíde Lampe, F. Climate Adaptation: The Race to Cool Down Europe's Cities. Available online: https://www.epc.eu/content/PDF/2023/Climate_Adaptation (accessed on 1 May 2023).
14. European Environmental Agency. *Urban Sustainability in Europe: Avenues for Change*; Publications Office of the European Union: Luxembourg, 2021. [CrossRef]
15. Ugolini, F.; Massetti, L.; Calaza-Martínez, P.; Cariñanos, P.; Dobbs, C.; Ostoić, S.K.; Marin, A.M.; Pearlmutter, D.; Saaroni, H.; Šaulienė, I.; et al. Understanding the benefits of public urban green space: How do perceptions vary between professionals and users? *Landsc. Urban Plan* **2022**, *228*, 104575. [CrossRef]

16. Carpentieri, G.; Guida, C.; Fevola, O.; Sgambati, S. The COVID-19 pandemic from the elderly perspective in urban areas: An evaluation of urban green areas in 10 European capitals. *TeMA-J.* **2020**, *13*, 389–408. [CrossRef]
17. De Luca, C.; Libetta, A.; Conticelli, E.; Tondelli, S. Accessibility to and availability of urban green spaces (Ugs) to support health and wellbeing during the COVID-19 pandemic—The case of Bologna. *Sustainability* **2021**, *13*, 11054. [CrossRef]
18. Marconi, P.L.; Perelman, P.E.; Salgado, V.G. Green in times of COVID-19: Urban green space relevance during the COVID-19 pandemic in Buenos Aires City. *Urban Ecosyst.* **2022**, *25*, 941–953. [CrossRef]
19. Yao, N.; van den Bosch, C.C.K.; Yang, J.; Devisscher, T.; Wirtz, Z.; Jia, L.; Duan, J.; Ma, L. Beijing's 50 million new urban trees: Strategic governance for large-scale urban afforestation. *Urban For. Urban Green* **2019**, *44*, 126392. [CrossRef]
20. McNamara, K.A.; Kostelny, M.; Kim, G.; Keating, D.M.; Estiandan, J.; Armbruster, J. A novel resident outreach program improves street tree planting outcomes in Los Angeles. *Environ. Chall.* **2022**, *9*, 100596. [CrossRef]
21. Friess, D.A.; Gatt, Y.M.; Fung, T.K.; Alemu, J.B.; Bhatia, N.; Case, R.; Chua, S.C.; Huang, D.; Kwan, V.; Lim, K.E.; et al. Blue carbon science, management and policy across a tropical urban landscape. *Landsc. Urban Plan* **2023**, *230*, 104610. [CrossRef]
22. McCann, S. Nature-Based Solutions, Sowing the Seeds for Sustainable Cities? 2021. Available online: https://theses.ubn.ru.nl/ (accessed on 20 February 2023).
23. Biswal, B.K.; Bolan, N.; Zhu, Y.G.; Balasubramanian, R. Nature-based Systems (NbS) for mitigation of stormwater and air pollution in urban areas: A review. *Resour. Conserv. Recycl.* **2022**, *186*, 106578. [CrossRef]
24. Wendling, L.A.; Holt, E.E. Integrating Engineered and Nature-Based Solutions for Urban Stormwater Management. In *Women in Water Quality*; Women in Engineering and Science; O'Bannon, D., Ed.; Springer International Publishing: Cham, Switzerland, 2020. [CrossRef]
25. Majidi, A.N.; Vojinovic, Z.; Alves, A.; Weesakul, S.; Sanchez, A.; Boogaard, F.; Kluck, J. Planning nature-based solutions for urban flood reduction and thermal comfort enhancement. *Sustainability* **2019**, *11*, 6361. [CrossRef]
26. Caparros-Midwood, D.; Barr, S.; Dawson, R. Optimised spatial planning to meet long term urban sustainability objectives. *Comput. Environ. Urban Syst.* **2015**, *54*, 154–164. [CrossRef]
27. Huang, H.; Yang, H.; Chen, Y.; Chen, T.; Bai, L.; Peng, Z.R. Urban green space optimization based on a climate health risk appraisal—A case study of Beijing city, China. *Urban For. Urban Green* **2021**, *62*, 127154. [CrossRef]
28. Zhang, Y.; Murray, A.T.; Turner Ii, B.L. Optimizing green space locations to reduce daytime and night-time urban heat island effects in Phoenix, Arizona. *Landsc. Urban Plan* **2017**, *165*, 162–171. [CrossRef]
29. Unal, M.; Uslu, C. Evaluating and optimizing urban green spaces for compact urban areas: Cukurova District in Adana, Turkey. *ISPRS Int. J. Geoinf.* **2018**, *7*, 70. [CrossRef]
30. Yoon, E.J.; Kim, B.; Lee, D.K. Multi-objective planning model for urban greening based on optimization algorithms. *Urban For. Urban Green* **2019**, *40*, 183–194. [CrossRef]
31. Nesticò, A.; Passaro, R.; Maselli, G.; Somma, P. Multi-criteria methods for the optimal localization of urban green areas. *J. Clean. Prod.* **2022**, *374*, 133690. [CrossRef]
32. CMCC. Annual Report. 2021. Available online: https://files.cmcc.it/Annual_Report/AR_2021_cmcc_final.pdf (accessed on 18 January 2023).
33. Sriwongsitanon, N.; Taesombat, W. Effects of land cover on runoff coefficient. *J. Hydrol.* **2011**, *410*, 226–238. [CrossRef]
34. Li, X.; Willems, P. A hybrid model for fast and probabilistic urban pluvial flood prediction. *Water Resour. Res.* **2020**, *56*, e2019WR025128. [CrossRef]
35. Pacetti, T.; Cioli, S.; Castelli, G.; Bresci, E.; Pampaloni, M.; Pileggi, T.; Caporali, E. Planning Nature Based Solutions against urban pluvial flooding in heritage cities: A spatial multi criteria approach for the city of Florence (Italy). *J. Hydrol. Reg. Stud.* **2022**, *41*, 101081. [CrossRef]
36. Brivio, P.A.; Colombo, R.; Meroni, M. The use of remotely sensed data for the estimation of energy balance components in a mountainous catchment. In *Remote Sensing and Climate Modelling: Synergies and Limitations*; Beniston, M., Verstraete, M., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2001; pp. 307–327.
37. Hofierka, J.; Gallay, M.; Onačillová, K.; Hofierka, J., Jr. Physically-based land surface temperature modelling in urban areas using a 3-D city model and multispectral satellite data. *Urban Clim.* **2020**, *31*, 100566. [CrossRef]
38. Gargiulo, C.; Tulisi, A.; Zucaro, F. Climate change—Oriented urban green network design: A decision support tool. In *Network Design and Optimization for Smart Cities*; Gakis, K., Pardalos, P., Eds.; World Scientific Press: New York, NY, USA, 2017; ISBN 978-981-3200-00-5.
39. Gargiulo, C.; Ayad, A.; Tulisi, A.; Zucaro, F. Effect of Urban Greenspaces on Residential Buildings' Energy Consumption: Case Study in a Mediterranean Climate. In *Smart Planning: Sustainability and Mobility in the Age of Change*; Papa, R., Fistola, R., Gargiulo, C., Eds.; Springer: Cham, Switzerland, 2018. [CrossRef]
40. Gargiulo, C.; Zucaro, F. Greening networks for smart and resilient cities: From methodology to application in densely built urban Contexts. *ASUR* **2020**, *127*, 127–148. [CrossRef]
41. Papa, R.; Gargiulo, C.; Zucaro, F. Towards the Definition of the Urban Saving Energy Model (UrbanSEM). In *Smart Energy in the Smart City: Urban Planning for a Sustainable Future*; Papa, R., Fistola, R., Eds.; Springer: Cham, Switzerland, 2016; pp. 151–175. [CrossRef]

42. Naeem, S.; Cao, C.; Qazi, W.A.; Zamani, M.; Wei, C.; Acharya, B.K.; Rehman, A.U. Studying the association between green space characteristics and land surface temperature for sustainable urban environments: An analysis of Beijing and Islamabad. *ISPRS Int. J. Geo-Inf.* **2018**, *7*, 38. [CrossRef]
43. Rahman, M.A.; Moser, A.; Rötzer, T.; Pauleit, S. Within canopy temperature differences and cooling ability of *Tilia cordata* trees grown in urban conditions. *Build Environ.* **2017**, *114*, 118–128. [CrossRef]
44. Bowler, D.E.; Buyung-Ali, L.; Knight, T.M.; Pullin, A.S. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landsc. Urban Plan* **2010**, *97*, 147–155. [CrossRef]
45. Aram, F.; García, E.H.; Solgi, E.; Mansournia, S. Urban green space cooling effect in cities. *Heliyon* **2019**, *5*, e01339. [CrossRef]
46. Yang, G.; Yu, Z.; Jørgensen, G.; Vejre, H. How can urban blue-green space be planned for climate adaption in high-latitude cities? A seasonal perspective. *SCS* **2020**, *53*, 101932. [CrossRef]
47. Oliveira, A.; Lopes, A.; Niza, S.; Soares, A. An urban energy balance-guided machine learning approach for synthetic nocturnal surface Urban Heat Island prediction: A heatwave event in Naples. *Sci. Total Environ.* **2022**, *805*, 150130. [CrossRef]
48. Harlan, S.L.; Brazel, A.J.; Prashad, L.; Stefanov, W.L.; Larsen, L. Neighborhood microclimates and vulnerability to heat stress. *Soc. Sci. Med.* **2006**, *63*, 2847–2863. [CrossRef]
49. Ministero dell'Ambiente e Della Sicurezza Energetica. Piano Nazionale di Adattamento ai Cambiamenti Climatici. 2019. Available online: https://www.mase.gov.it/sites/ (accessed on 12 January 2023).
50. Vojinovic, Z. *Nature-Based Solutions for Flood Mitigation and Coastal Resilience: Analysis of EU-Funded Projects*; Publications Office of the European Union: Luxembourg, 2020. [CrossRef]
51. Città Metropolitana di Genova e Università degli Studi di Genova. *Infrastrutture Verdi per L'adattamento ai Cambiamenti Climatici. Strategie e Indicazioni Progettuali per la Gestione Sostenibile Delle Acque Meteoriche Urbane Nell'area Mediterranea Nord-Occidentale*; ModusOperandi Editore: Genova, Italy, 2020; ISBN 9788898102075.
52. ISTAT. Il Censimento Permanente Della Popolazione in Campania. Available online: https://www.istat.it/it/files/2021/ (accessed on 10 January 2023).
53. European Union. *The Ageing Revolution: Towards a European Silver Deal? Demographic Transformations for Age-Friendly Territories*; Publications Office of the European Union: Luxembourg, 2021; Available online: https://www.espon.eu/sites/ (accessed on 20 January 2023).
54. Schwela, D. Climate Change, Vulnerability, and Older People. In *Encyclopedia of Gerontology and Population Aging*; Gu, D., Dupre, M.E., Eds.; Springer International Publishing: Cham, Switzerland, 2022. [CrossRef]
55. World Health Organization. UN Decade of Healthy Ageing 2021–2030. Available online: https://cdn.who.int/media/docs/ (accessed on 10 January 2023).
56. Spano, D.; Mereu, V.; Bacciu, V.; Barbato, G.; Buonocore, M.; Casartelli, V.; Ellena, M.; Lamesso, E.; Ledda, A.; Marras, S.; et al. *Analisi del rischio: I Cambiamenti Climatici in Sei Città Italiane*; CMCC: Roma, Italy, 2021. [CrossRef]
57. Colelli, F.P.; Emmerling, J.; Marangoni, G.; Mistry, M.N.; De Cian, E. Increased energy use for adaptation significantly impacts mitigation pathways. *Nat. Commun.* **2022**, *13*, 4964. [CrossRef]
58. Comune di Napoli. Piano Urbano della Mobilità Sostenibile. 2017. Available online: https://www.comune.napoli.it (accessed on 10 February 2023).
59. Feizizadeh, B.; Blaschke, T.; Nazmfar, H.; Akbari, E.; Kohbanani, H.R. Monitoring land surface temperature relationship to land use/land cover from satellite imagery in Maraqeh County, Iran. *J. Environ. Plan Manag.* **2013**, *56*, 1290–1315. [CrossRef]
60. Liu, L.; Zhang, Y. Urban heat island analysis using the Landsat TM data and ASTER Data: A case study in Hong Kong. *Remote Sens.* **2011**, *3*, 1535–1552. [CrossRef]
61. Mazzeo, G. Naples. *Cities* **2006**, *26*, 363–376. [CrossRef]
62. Papa, R.; Battarra, R. Tra strumenti di pianificazione e programmi di intervento. In *L'Italia si Trasforma: Città in Competizione*; Monti, C., Ronzoni, M.R., Eds.; BE-MA Editrice: Milano, Italy, 2006; pp. 109–118.
63. Karani, P.; Failler, P. Comparative coastal and marine tourism, climate change, and the blue economy in African Large Marine Ecosystems. *Environ. Dev.* **2020**, *36*, 100572. [CrossRef]
64. Guida, C.; Gargiulo, C.; Papa, R.; Carpentieri, G. Vulnerability and Exposure of Mediterranean Coastal Cities to Climate Change-Related Phenomena. *Environ. Sci. Proc.* **2022**, *21*, 79. [CrossRef]
65. Mazzeo, G.; Zucaro, F.; Morosini, R. Green is the colour. Standards, equipment and public spaces as paradigm for the Italian sustainable city. *TeMA-J.* **2019**, *12*, 31–52. [CrossRef]
66. Lai, S.; Isola, F.; Leone, F.; Zoppi, C. Assessing the potential of green infrastructure to mitigate hydro-geological hazard. *TeMA-J.* **2021**, *30*, 109–133. [CrossRef]
67. Pilogallo, A.; Saganeiti, L.; Scorza, F.; Murgante, B. Ecosystem Services' Based Impact Assessment for Low Carbon Transition Processes. *TeMA-J.* **2019**, *12*, 127–138. [CrossRef]

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High-Resolution Greening Scenarios for Urban Climate Regulation Based on Physical and Socio-Economical Factors

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Abstract: Urban ecosystems represent the main providers of ecosystem services in cities and play a relevant role, among the many services, in the regulation of the urban microclimate and mitigation of the urban heat island effect. The amount, localization, and spatial configuration of vegetation (i.e., urban trees) are key elements for planners and designers aiming at maximizing the climate regulation potential and therefore extending the related benefits to a higher number of residents and city users. Different factors and constraints related to urban morphology and socio-economical characteristics of the urban environment influence the localization of new greening scenarios, therefore impacting the potential benefits that can be obtained by residents. This paper investigates these factors by identifying high-resolution greening scenarios that are able to maximize the cooling benefits for people and local residents. For the case study of metropolitan areas of Catania (Italy) with a hot Mediterranean climate, scenarios are derived by modelling physical and socio-economic factors as spatial constraints with the UMEP model and GIS spatial analysis. Results show that new greenery should be mostly located in public areas that are mostly used by residents. Built on the results obtained in the case study analyzed, the paper also proposes some general planning criteria for the localization of new urban greenery, which should be extended to other geographical urban contexts.

Keywords: climate simulations; climate regulation; urban planning; UMEP

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1. Introduction

Urban systems are complex thermodynamic systems that are far from thermodynamic equilibrium and import energy, matter, and information from outer sources and dissipate heat as the result of different activities that make use of energy [1]. Urban environments are increasingly characterized by different issues related to climate change with global and local patterns, such increasing temperatures and pollution degrees and an increased quantity of water run-off and decreased quality of stormwater [2,3]. Such issues pose dramatic environmental and public health issues, impacting cities with increased frequency in the last decades [4,5], especially for highly vulnerable social subjects [6].

The positive role of urban vegetation in addressing the abovementioned urban issues is well known, as demonstrated by the rich and still-growing body of research, but also implemented urban projects and policies [7,8]. When strategically planned and designed in an integrated green infrastructure, urban vegetation and related ecosystems have the capacity to deliver a full array of ecosystem services, with direct and measurable benefits to urban communities and their well-being [9–11]. In the last years, the awareness of residents and city users of the importance of the services provided by urban vegetation has sharply increased so that requests for projects and tangible actions toward greener cities and more ecological neighbors are intensifying [12].

Among the many ecosystem services, climate regulation is of utmost importance in cities and represents the high concern of residents, who are increasingly asking for public policy and actions to improve the local climate conditions of urban environments [13]. In Mediterranean geographical context, the rate of mortality due to heat waves has shown an increasing trend in the last 10 years. For example, data for 2021 in regions of south Italy revealed an increase of 15% in mortality [14].

Climate regulation of urban ecosystems is achieved by three main functions: physical shading of elements of the built environment; the modification of the flow of air; and the decrease in outdoor air temperature by evapotranspiration processes [15]. These functions generate relevant positive impacts on the energy consumptions of buildings that are directly shaded by trees and cool the air around buildings, with the effect of reducing the need of energy for cooling inside the buildings [16,17].

The positive effects of urban vegetation can be even more significant for elements of the urban environment that are directly and daily used by people. These include, streets, sidewalks, parking areas, and all different types of open spaces. Correct planning and design strategies of new greening can therefore reduce pedestrians' and other city dwellers' heat exposure thanks to the shading, transpiration, and wind-breaking functions [18,19] while also contributing to keeping impervious surfaces cooler, so they can emit less longwave radiation [20].

For these reasons, planting of urban trees is becoming a crucial planning and design strategy to reduce the excess heat in contemporary cities [21], and choosing the most effective spatial configurations of street trees may help optimize reductions of excessive heat, for example, by focusing on the street locations most in need of tree shade [22].

Climate simulations are modelling tools to the evaluate environmental behavior of specific environments (buildings and urban environments) and therefore inform planning choices on policy for urban greening and the localization of new vegetation, for example, by identifying portions of cities most in need of tree shade. Many researchers have explored the optimization of the location of trees shapes to reduce urban heat and mean radiant temperature according to specific urban geometries [23,24], and very recently, studies have specifically targeted the positive effects of new trees on pedestrians [20,25]. Furthermore, most of the research focuses on the spatial optimization of urban greenery, mainly at a very local scale (i.e., single building) [20] or at a wider regional scale [26].

However, limited efforts have been made to integrate results from these advanced pieces of research with more practical indication for urban planning [27] while taking into account the real opportunities offered by urban environments and morphologies [28]. More specifically, the integration of physical and socio-economic factors acting as important constraints in the planning and design of new urban vegetation remains unexplored. Such factors include land tenure, actual conditions of land use and land cover, and the possibility of generating benefits for a large number of residents. This paper thus proposes a spatially explicit method to identify high-resolution scenarios that are able to maximize the cooling benefits of urban vegetation for people and local residents by modelling physical and socio-economic factors as spatial constraints for the localization of new vegetation. At the same time, this research proposes planning criteria for the localization of new urban greenery that are built on the results obtained in the case study analyzed.

Section 2 presents the case study and data/material used. Section 3 introduces the methodology used, based on climate simulation and socio-environmental spatial analysis on the characteristics of the urban environment. Section 4 presents the results obtained with related maps, while Section 5 discusses them in the light of other relevant literature and recent research. Finally, the objectives of the research, main findings, and possible future work are summarized in Section 6.

2. Case Study and Material

The method was applied in three peri-urban areas located in the metropolitan area of Catania, Sicily, Italy (Figure 1). The metropolitan areas is the largest conurbation in the region, accounting for more than 700,000 residents in 27 municipalities. More than 60% of the total residents live in the municipalities surrounding the main city of Catania, which has seen a progressive move of the population from the main city to smaller municipalities of the metropolitan area.

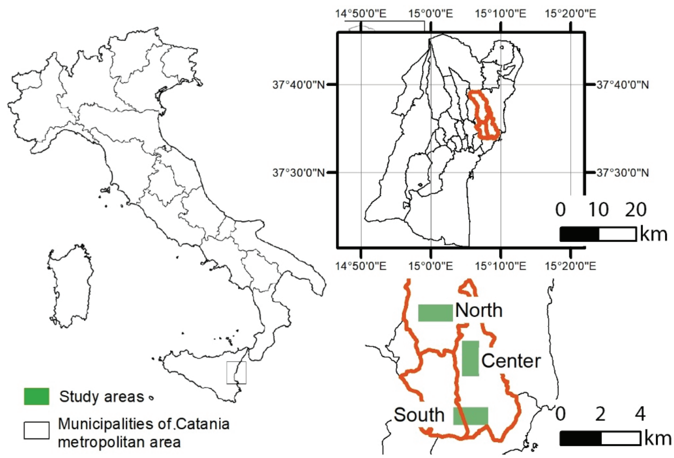

Figure 1. Location of the three case studies (north, center, and south) in the metropolitan area of Catania in Sicily (Italy).

These areas were chosen as they include different types of land use and land covers (Figure 2) with differentiated residential complexes, ranging from isolated villas to semi-detached houses and multi-story apartment complexes, which are typical features of European metropolitan areas [29]. Such variety of land use and land cover is functional in the evaluation of the impact of planned greening scenarios on different types of urban environments and is also useful for identifying different design options.

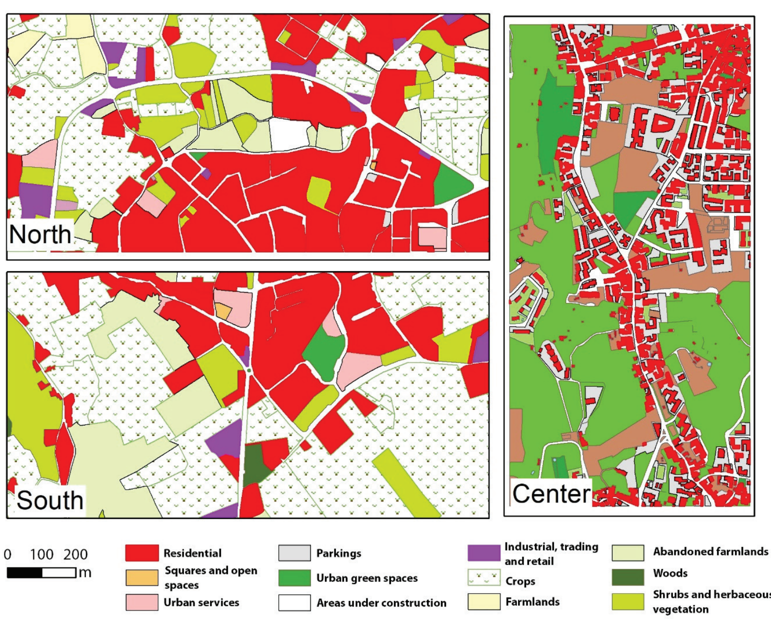

Figure 2. Land use of the three case studies.

From a climatic point of view, the Catania metropolitan area has a hot-mild Mediterranean climate (37.62° N, 15.17° E, 50 m a.s.l., annual average temperature of 17 °C) with hot summer temperatures very often above 30 °C, combined with a strong solar radiation of about 800 W/m^2 [16]. The close presence of the Mediterranean sea tends to ease natural ventilation, produces local cooling effects. In such climate conditions, the shadow effect of vegetation is a crucial factor that should be increased as much as possible by appropriate greening interventions in the built environment [16].

3. Method—Planning Criteria for Greening Scenarios

The methodology for the identification of greening scenarios is based on three main criteria that interact in the overall choice for the location of new greenery, with the aims of generating higher benefits for residents and, at the same time, ensuring a physical and socio-economic viability. The criteria are as follows: identification of areas with high outdoor thermal stress, physical/social feasibility of greening scenarios, and the maximization of the number of potential beneficiaries. The integration of these criteria identifies suitable areas for the planning of new greening scenarios. The criteria are illustrated in the next sub-sections.

3.1. High-Resolution Climate Simulations

The first step of the method identifies the areas with the most unfavorable conditions in terms of outdoor thermal comfort. They were selected by the evaluation of outdoor comfort in a reference condition of an hot summer day by the use of the Urban Multi-scale Environmental Predictor (UMEP) model.

UMEP is an integrated, open-access set of tools and models for urban climatology and climate-sensitive planning application, whose applications are mainly related to outdoor thermal comfort, consumption of urban energy, and climate change mitigation [30]. The most important feature of the model is its complete integration in the Geographical Information System (specifically QGIS open-access software). This allows users to use in a spatially explicit way all parameters of the model and, more importantly, to edit and map inputs and results directly in the GIS.

Among the different tools and models of UMEP, SOLWEIG (Solar and Long Wave Environmental Irradiance Geometry) is a model that simulates spatial variations of 3D radiation fluxes and Mean Radiant Temperature (Tmrt) in urban contexts [31]. Tmrt is one of the key meteorological variables accounting for energy balance and the thermal comfort of human beings, integrating shortwave and longwave radiation fluxes (both direct and reflected) to which the human body is exposed in outdoor and indoor environments [32]. In urban environments, Tmrt depends on building 3D geometries, street network, the albedo of building's facades, and land cover, and for this close relationship with urban morphology, it was chosen as a proxy of thermal comfort in this work. In SOLWEIG, Tmrt is derived by modelling shortwave and longwave fluxes in six directions (upward, downward, and from the four cardinal points) and angular factors.

To successfully perform a simulation, a set of information is requested by the model: meteorological data (global shortwave radiation, air temperature, and relative humidity), a digital surface model of buildings (including their height from ground) and vegetation, land cover above and below the canopy and maps of sky view factors. Vegetation and land cover (below-canopy land cover) maps are used to model the relationship between the built environment and vegetation so as to increase the accuracy of the results obtained. The reference day used for the meteorological data is the 9 July 1985, which was characterized by a maximum air temperature of 38°, humidity of 35%, and solar irradiance of 900 W m^2. The final outputs of SOLWEIG are raster maps of values of Tmrt for the reference day considered. The raster data necessary for the model are shown in Figure 3.

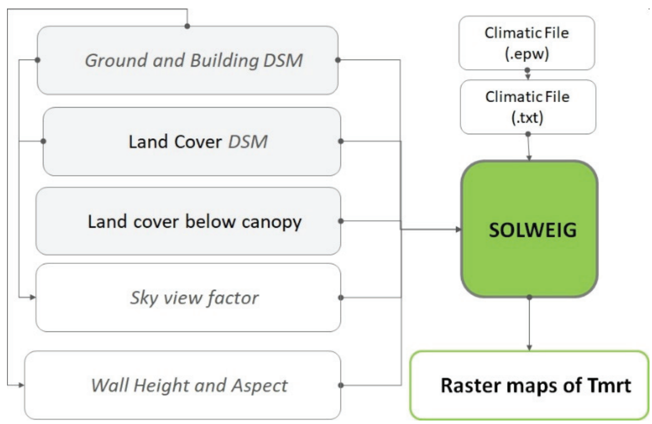

Figure 3. Input and output spatial layers in the SOLWEIG module of the UMEP model.

The above- and below-canopy land-cover values were analyzed by visual interpretation of high-resolution orthophotos (25 cm) available from regional cartography and further validated by comparison with photos from Google™ Street View. The following land-cover categories were identified: deciduous trees, evergreen trees, grass, paved areas, building, bare soil, and water. These categories are the land-cover types that are used as input layer in the SOLWEIG and, at the same time, represent typical land-cover classes that can be found in many urban and peri-urban contexts.

3.2. Physical/Social Feasibility of Greening Scenarios

The areas selected in the previous step were further evaluated in terms of social and physical constraints related to their potential transformation into green areas. The considered factors are the current land cover and land tenure. The first represents a constraint because greening scenarios can be developed on specific land-cover categories such as grass or bare soil, while other categories are unsuitable for the presence of buildings or trees (evergreen and deciduous trees) or less suitable due to their higher costs related to the planting of trees in paved and impervious areas.

Land tenure represents a socio-economical constraint because greening retrofitting in privately owned areas is more difficult to plan by public administrations and is often dependent on the willingness of single owners, although they can be subject to specific financial mechanisms to promote private greening interventions [33].

The categories of below-canopy land cover were further reclassified according to their suitability of being used as new areas to plant new trees in the greening scenarios. Suitable land-cover types included bare soil and grass but also paved areas belonging to roads' sideways or public squares. Despite the higher costs of implementation, some paved areas can be considered suitable for planting new trees because they are likely to generate benefits in terms of shading to higher number of people (see Section 3.3) [16].

Land tenure was derived by reclassification of available land-use maps in two main categories, namely private (mainly for residential/commercial and agricultural land-use categories) and public (for roads, public areas, parks, and public facilities). The land-use layer was derived from the urban atlas [34] of the metropolitan area of Catania, which was validated by visual interpretation of the available aerial photos.

The two vector layers derived by the re-classifications of land cover and land use are intersected in the next step of the method (Section 3.4) with the raster maps obtained in the climate simulations described in Section 3.2 to identify the proposed greening scenarios.

3.3. Maximization of the Number of Beneficiaries from Greening Scenarios

The third criterion considered was the potential usability of the built environment by pedestrians moving in the city, as they are the social subjects that can directly benefit from the presence of trees, especially when they make use of important urban elements such as sideways or other public spaces [35]. We analyzed the most highly used public areas so as to identify the areas where new greening scenarios could maximize their cooling effects on a higher number of beneficiaries. Such areas include highly used roads (including space for sideways, where pedestrian movement can occur), public spaces, and parking lots.

The most-used roads are considered to be those with the highest level of traffic, as traffic conditions are often related to the central localization of roads and high density of urban uses [36,37]. The roads with the highest level of traffic were selected by using traffic data extracted by the World Traffic Service of Arcgis™ Online Resources on a typical working day (13 October 2022). This service includes different types of traffic data, such as historical, live, and predictive traffic [38].

Other public spaces with a high level of usability (squares, green spaces and other public open spaces, and parking areas) were selected from the available land-use and land-cover vector layers.

3.4. Identification of the New Greening Scenarios

Greening scenarios are intended as spatial configurations of new trees to be planted in the three sub-areas and were obtained by the spatial integration of the three planning criteria introduced in the previous sections. Two scenarios were designed.

The first greening scenario involves public areas only. From the climate simulation performed with the SOLWEIG module of UMEP model, the areas with Tmrt values above 70° were selected, as these values represent a typical threshold value for outdoor thermal discomfort, and therefore, these areas represent prior targets for greening actions. From the criterion of physical/social feasibility of greening scenarios, pervious land (belonging to land-cover categories of bare soil and grass) and public areas were selected. From the criterion of the maximization of the number of beneficiaries, streets with a high level of traffic and all public areas were selected.

The second scenario was designed by adding private areas with pervious land covers to the areas already selected in the first scenario.

The vector layers expressing the above conditions for the three criteria were spatially overlaid, and the result was further refined by visual analysis and deleting or adjusting specific unsuitable situations (i.e., street with no space for sidewalks or areas with no physical accessibility by pedestrians). Table 1 summarizes the specific conditions of the three planning criteria that were used for the design of the greening scenarios.

Table 1. Criteria for the identification of the greening scenarios.

Criterion	Scenario 1 (Public Areas)	Scenario 2 (Public + Private Areas)
Identification of areas with high outdoor thermal stress	Areas with median radiant temperature > 70°	Areas with median radiant temperature > 70°
Physical/social feasibility of greening scenarios	Land-cover categories - Bare soil - Grass Land tenure: - Public	Land-cover categories - Bare soil - Grass Land tenure: - Public - Private
Maximization of the number of beneficiaries of the greening scenario	Highly used street Public areas: - Squares - Open spaces - Parking areas	Highly used street Public areas: - Squares - Open spaces - Parking areas

Finally, new simulations on the two newly designed greening scenarios were performed with SOLWEIG module of the UMEP model to quantitively evaluate the resulting changes in Tmrt. Specifically, new evergreen trees with an average height of 9 m and canopy volume equal to 25% of the total volume of each tree (default option) were simulated in SOLWEIG. These trees are located in the areas identified in the two scenarios.

4. Results

4.1. Areas with High Outdoor Thermal Stress

Figure 4 maps the above-canopy land cover of the three areas. As already discussed, land-cover information is one of the input layers of the SOLWEIG module of the UMEP model.

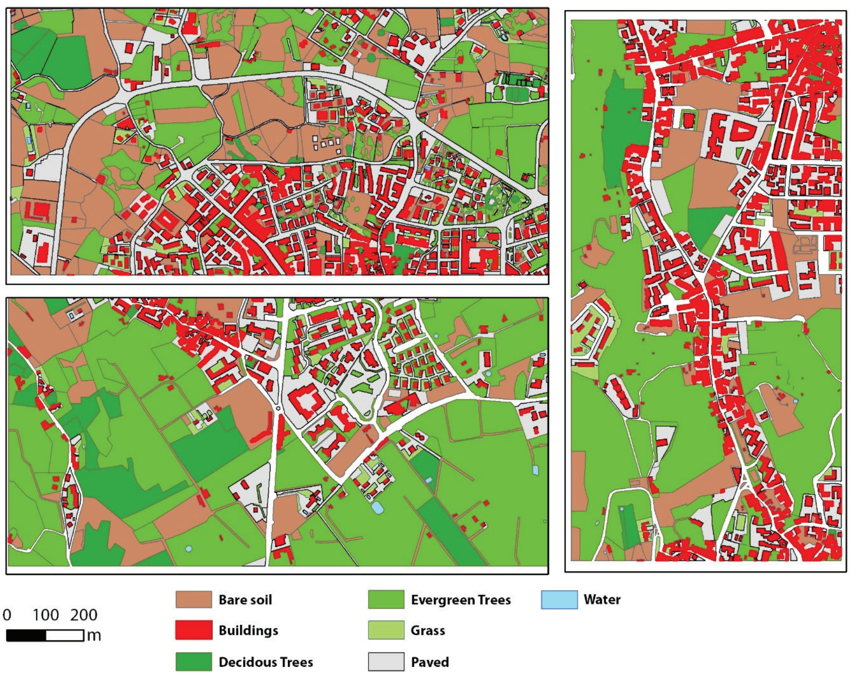

Figure 4. Maps of land cover for the three study areas.

Results from the simulation of the current situation are shown in Figure 5. Because of the considered very hot day on a summer afternoon, many pixels with very high values of Tmrt (above 80°) can be found, with similar values in the three areas. The share of values of Tmrt (classified by equal interval) is reported in Table 2 and Figure 6.

Table 2. Share of TMR values in the three areas.

Area 1 (South)		Area 2 (Central)		Area 3 (North)	
Min: 40; Max: 85 Mean: 55 Std. Dev: 14		Min: 39; Max: 87 Mean: 63 Std. Dev: 14		Min: 38; Max: 86 Mean: 63 Std. Dev: 13	
40–50	52%	39–50	35%	38–50	27%
50–60	3%	50–60	11%	50–60	6%
60–70	10%	60–70	1%	60–70	16%
70–85	33%	70–87	53%	70–86	51%

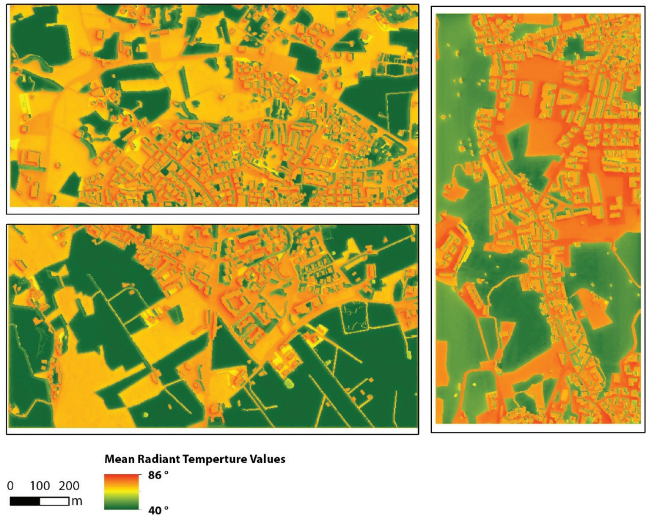

Figure 5. Results from the climate simulation for the current scenario.

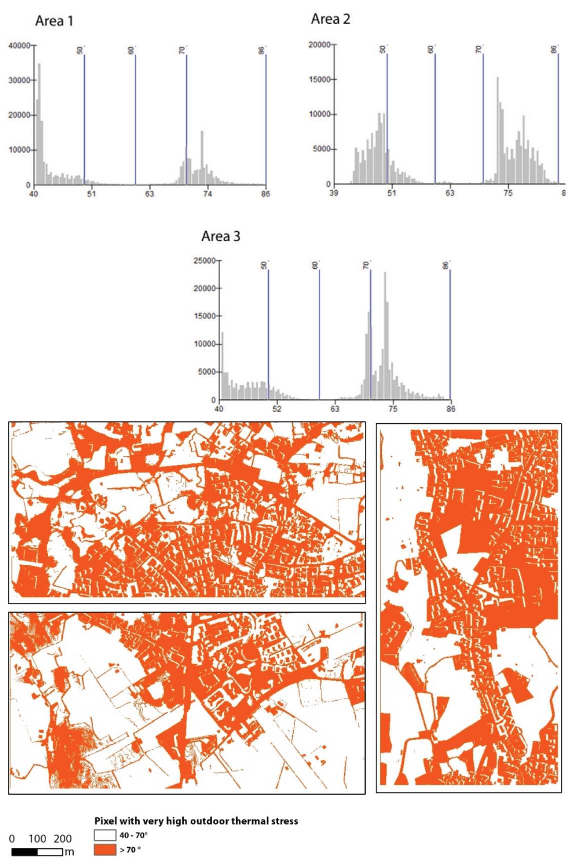

Figure 6. Distribution of Tmrt for the three areas in the current scenario. Pixels with Tmrt higher than 70°.

Pixels with Tmrt higher than 70° are present in relevant portions of the areas and are mapped in Figure 6. They represent 33% for area 1, 53% for area 2, and 51% for area 3, with an average of 45%.

All the three areas show similar distribution of values and are concentrated on lower values (around 40–45°) characterizing rural context and extreme values (around 70–75°) for buildings, streets, and paved areas but also bare soil. Being the most rural, area 1 has average and maximum values of TMR lower than the other two areas.

4.2. Physical/Social Feasibility of Greening Scenarios

Figure 7 maps the physical constraints related to the suitability of land-cover categories that can be used as new areas to plant new trees in the greening scenarios. Suitable land-cover categories sum up to 61% of area 1, 55% of area 2, and 54% of area 3. Figure 8 maps the land tenure for the three areas, with public areas accounting for 15% in area 1, 23% in area 2, and 11% for area 3.

Figure 7. Physical constraints for greening scenarios: suitable land-cover categories.

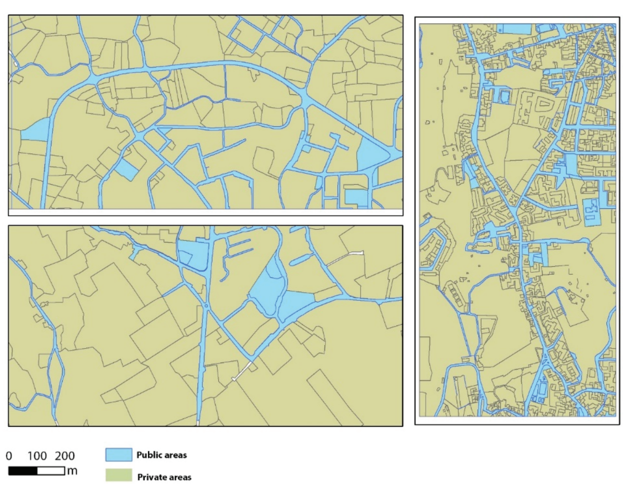

Figure 8. Social constraints for greening scenarios: land tenure.

4.3. Areas That Maximize the Number of Beneficiaries

Figure 9 maps the most-used spaces of the three areas (highly used streets with space for sideways and other public areas) where the new greenery can generate potential benefits to a high number of pedestrians and users of the urban environment.

Figure 9. Highly used streets, squares, green spaces, and other public areas.

4.4. Greening Scenarios and New Simulations

The planning criteria reported in Table 1 were applied to the geographical layers presented in the previous Section 4.1, Section 4.2, and Section 4.3, following GIS geo-processing and further local refinement of the results obtained by visual validation using Google Street View.

Figures 10 and 11 map the two scenarios obtained after Table 1, where the areas highlighted in cyan are the portion of the urban environment where new trees can be located. Scenario 1 includes public areas only, while scenario 2 includes both public and private areas. The extent of new greenery in the three areas is reported in Table 3. Area 1 is the one where the higher amount of new greening can be planned for the two scenarios. This is mainly due to the presence of an urban park, which is central to the area, that can be retrofitted with a good amount of new trees. Areas 2 and 3 show similar results, and new greening is mainly located along the sideways of the most-used streets and, to a more limited extent, in other public or private areas (squares, small urban parks, and private courtyards).

Table 3. Amount of new greenery in the 3 areas.

	Area 1 (South)		**Area 2 (Central)**		**Area 3 (North)**	
	Extent of New Greening (m^2)	*% Total Area*	*Extent of New Greening (m^2)*	*% Total Area*	*Extent of New Greening (m^2)*	*% Total Area*
Scenario 1 (Public areas)	22,646	9, 2	6992	2, 9	5534	2, 3
Scenario 2 (Private + Public areas)	39,627	16, 2	9906	4	13,109	5, 4

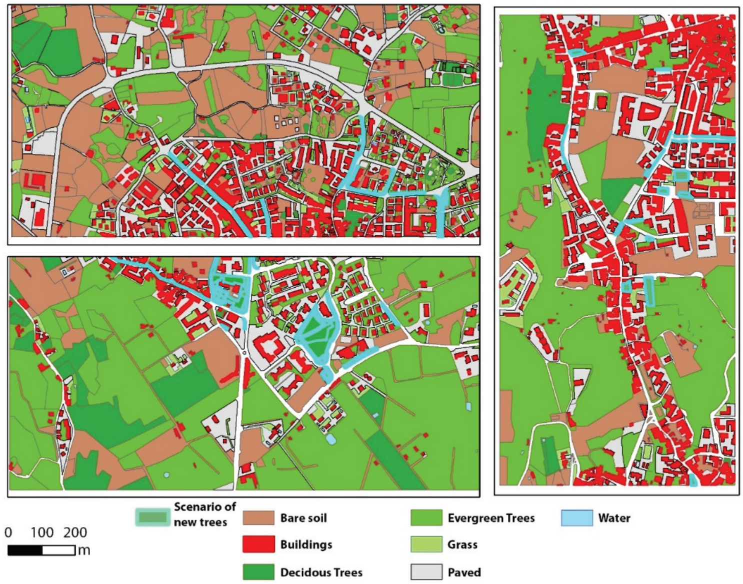

Figure 10. New greening scenarios in public areas (scenario 1).

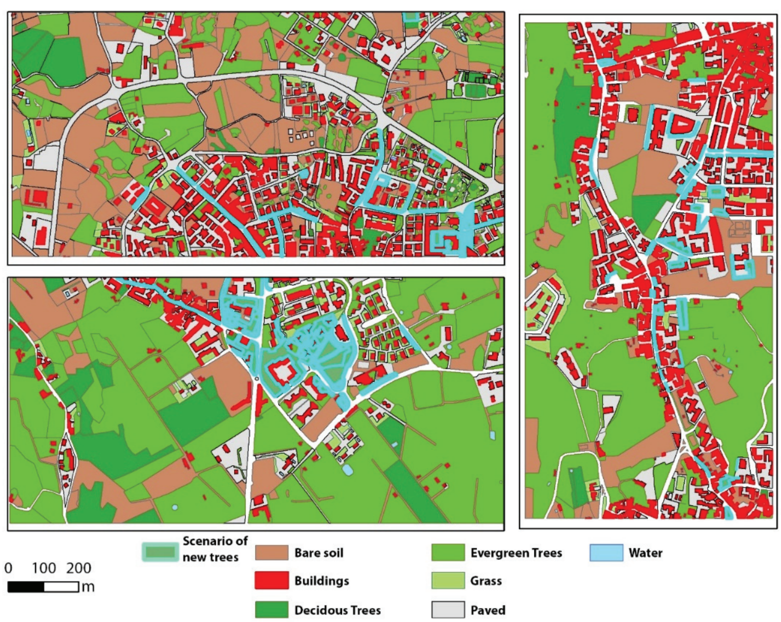

Figure 11. New greening scenarios in private and public areas (scenario 2).

The maps of Tmrt simulated from the two greening scenarios are shown in Figures 12 and 13 for scenarios 1 and 2, respectively.

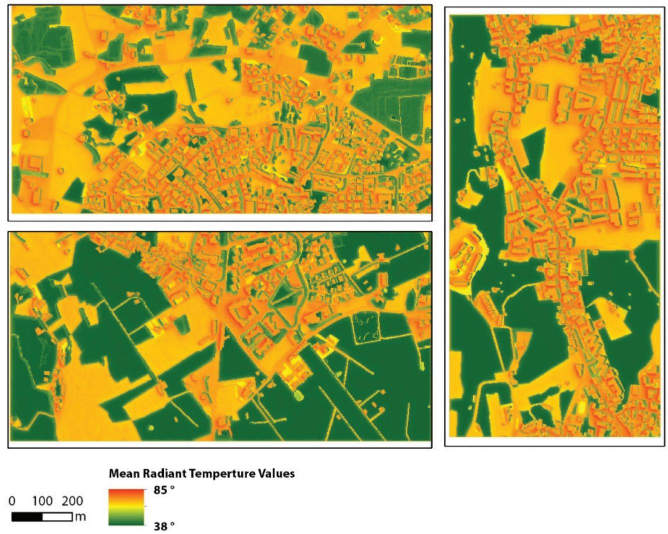

Figure 12. Results from the climate simulation for the scenario 1—public areas.

Figure 13. Results from the climate simulation for the scenario 2—public and private areas.

Changes in values of Tmrt with respect to the current situation are almost entirely localized in the space occupied by the new trees or in the areas that benefit from the direct shade of the trees. A very limited effect of the mass canopy can be seen from the resulting reduction of Tmrt. Table 4 reports the share of areas belonging to four classes of Tmrt values. The positive contribution of the new greening scenarios is visible yet limited: the comparison with the current scenario (Table 2) highlights that the amount of area with critically high Tmrt (>70) slightly decreases, and the area belonging to classes with the lowest Tmrt (40–50 and 50–60) increases by 2–3%.

Table 4. Tmrt values in the three areas for the two scenarios simulated.

Area 1 (South)			**Area 2 (Central)**			**Area 3 (North)**		
Min: 40; Max: 84			Min: 39; Max: 87			Min: 38; Max: 86		
Mean: 55			Mean: 63			Mean: 63		
Std. Dev: 14			Std. Dev: 14			Std. Dev: 13		
Tmrt Values	*Scenario 1*	*Scenario 2*	*Tmrt Values*	*Scenario 1*	*Scenario 2*	*Tmrt Values*	*Scenario 1*	*Scenario 2*
40–50	54%	55%	39–50	36%	39%	38–50	28%	29%
50–60	4%	3%	50–60	6%	6%	50–60	8%	6%
60–70	10%	11%	60–70	12%	10%	60–70	17%	20%
70–85	32%	30%	70–87	45%	45%	70–86	47%	45%

To highlight the spatial differences of Tmrt values between the current and the greening scenarios, Figure 14 shows a smaller portions of area 1 (south) where the new greening is concentrated. An example of a possible design for area 3 (north) related to scenario 2 is shown in Figure 15.

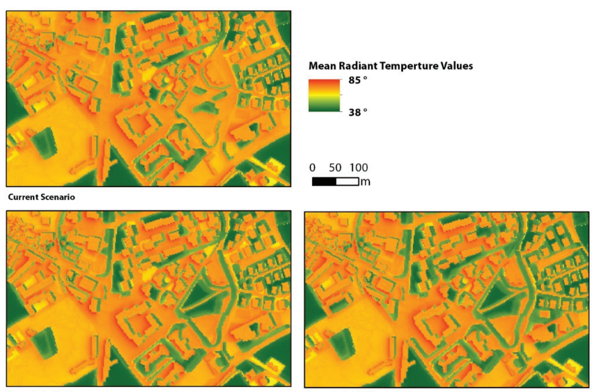

Figure 14. Excerpt from the simulations of Tmrt values for the greening scenarios in area 1 (south).

Figure 15. Design of greening scenario 2 (public + private areas) for area 2 (north).

5. Discussion

5.1. Evaluating the Effectiveness of Greening Scenarios in Decreasing the MRT

The main reason for the limited reduction in the average values of Tmrt is due to the location of the greening scenarios, mainly concentrated in the most urbanized areas, where the highest values of Tmrt can be found due to the presence of impermeable surfaces and buildings. Similar values have been reported in the same metropolitan area of Catania (Italy) by [39]. The reduction of Tmrt may also seem more limited than in other studies [40], but this is mainly because of the small spatial extent of the two greening scenarios. However, it must be highlighted that the scenarios were identified by taking into consideration the actual physical and socio-economic constraints present of the urban environment: such constraints limit the possible choice for the areas to be included in the greening scenarios but return planning options that are closer to reality. This relationship with the actual urban environment and socio-economic condition represents the main element of novelty of this research.

5.2. Proposal of General Planning Criteria for New Urban Greening Based on the Performed Simulations

The results from the simulations of the current and new scenarios of urban greening indicate some useful planning criteria that can be generalized to different urban contexts with similar climatic characteristics and greening objectives. These criteria are about the type, location, and extent of the greening and the choice of the species that can be used.

First, simulations highlight that trees represent the most effective type of green elements in terms of cooling capacities, while the contribution of other types of greenery (shrubs, grass, and herbaceous vegetation) is more limited because of the reduced height and canopy volume. This is in line with other studies [40,41] and suggests that shrubs and grass can be used for ornamental or ecological purposes, i.e., for completing vegetation levels in parks or public spaces or to generate other important functions such as noise reduction or carbon sequestration [42].

Prior choices for the location of new trees should select public areas (sidewalks, streets, and public areas) with permeable land cover for the easier suitability and economic viability of tree planting. Areas at lower priority can include private areas, where landowners must be convinced or supported economically with specific incentives for planting trees [13]. Moreover, impervious land cover represents areas with lower suitability due to the higher costs for planting new trees. This highlights an important trade-off for current impervious street sideways between the maximization of the benefits that can be obtaining and the costs for planting new trees. Furthermore, areas close to buildings with aspects to the south and/or west can be chosen to maximize the shading potential of new trees [43,44].

The extent of new greenery is a variable depending on the cooling objectives assumed by the greening scenarios as well as the available economic resources. The extent of new greenery should be large enough to cover all areas of the urban environment under thermic stress (i.e., with Tmrt higher than an assumed threshold). The extent of the greenery should also include highly used portions of the city, such as streets and public areas, so as to maximize thermal comfort for people.

Given a specific climate and overall water availability, the most suitable species should have some characteristics in order to maximize their climate regulation potential: high-density canopy, deciduous species for hot climates, evergreen for cold climates, and fast-growing, cheap to plant and manage, and able to maximize the ecological heterogeneity of the urban context. However, in some cases, not-autochthonous species can be accepted as suitable species, as demonstrated by the widespread presence of Australian species in southern Italian urban contexts [45]. Possible suitable species for Mediterranean climates include, among others, *Pinus pinaster, Ficus benjamina,* and *Quercus ilex* [16,45].

5.3. Economical Viability

It is widely acknowledged that investments in urban greening can ensure positive returns on the quality of urban environments and human health and in economic terms [46–48]. However, specific political and economic factors might hamper the actual implementation of greening projects. The most common of these factors is the need for public acquisition of the land where the greening scenarios should implemented because, often, public administrations do not own such land. The availability of economic resources required to buy land from private landowners thus represents a strong constraint for the final implementation and maintenance of greening projects. To face this lack of economic resources, public administration must find alternative sources of funding or design incentive-based mechanisms, compensations for land acquisition, and payment for ecosystem services [49,50].

For this reason, public areas (i.e., streets, sidewalks, and open spaces) represent high-priority areas in which to concentrate economic resources for the implementation of greening scenarios because they do not need to be acquired.

As already stated, the greening scenarios have been identified with the main objectives of improving the outdoor thermal comfort of the urban environment, but it must be underlined that these scenarios are able to generate many other positive contributions to an urban environment and its residents. For example, in terms of regulation of urban water run-off and pluvial flooding reduction, new trees located along streets would be crucial elements [10,51].

5.4. Limitations

There are some limitations that can be acknowledged in this research. First, the scenarios of reduced values of Tmrt are missing a ground validation, which can be very useful for better tuning the model results to the actual conditions of the urban environment under analysis and therefore identifying more reliable and effective greening scenarios. However, this process can be long and complex, as it would require identifying existing green elements in specific parts of cities (i.e., street trees or trees on sidewalks) to be used as a reference configuration for the ground measurement of Tmrt with radiometers. Results from these measurements of Tmrt can then be compared with the values of simulated Tmrt for scenarios with similar configuration of green elements. With this approach, it would be possible to better understand the difference between the simulated and measured values of Tmrt.

The SOLWEIG module has specific characteristics and simplifications. In its formulation, it does not evaluate the contribution of evapotranspiration of vegetation, which is a relevant benefit that can be directly perceived by people who are walking or moving close to trees. It makes use a single value for the albedo for all the facades of buildings, and it also does not allow the modelling of the contribution of shrubs but only of trees and grass, so other forms of urban greenery such as green roofs and walls, which are important options for urban planners and designers, cannot be included in simulations.

Finally, the results of the simulations used to identify urban areas with high levels of thermal stress referred to the hottest hour of the day (3 p.m.) (see Figure 6). In other times, different areas can show high values of thermal stress so that different greening scenarios can be identified. However, from our analysis, the total amount of areas with high levels of thermal stress were at their maximum at 3 p.m., so this hour can be considered as a reliable reference condition because it represents the worst thermal situation to be addressed with greening scenarios.

6. Conclusions

This paper proposes a spatially explicit method to identify planning scenarios to maximize the cooling benefits of urban vegetation for people and local residents, which represent the main beneficiaries of any public policy and action for climate regulation. Built on high-resolution simulations of mean radiant temperature and modelling of physical and socio-economic factors acting as spatial constraints, two greening scenarios were designed.

The case studies are three peri-urban areas located in the Catania metropolitan areas in Sicily, characterized by a hot and dry Mediterranean climate and exposed to several extreme hot days during the summer.

The proposed greening scenarios represent feasible and viable planning options, where the positive contribution of trees in reducing the values of Tmrt is concentrated to the areas where the trees can be planted. This outcome highlights the importance of developing greening projects targeting the highly used areas of the built environment, such as sideways and other public spaces. This is very relevant, especially for public administrations with limited economic resources to implement these scenarios.

The integration of the actual physical and socio-economic conditions of the urban environment and the high resolution of the analysis in identifying the greening scenarios represent the main elements of novelty of this research.

Based on the results obtained, the general planning and design criteria were proposed with regards to the type, location, and extent of the new greening and the choice of the tree species. Such criteria can be used to maximize the benefits of climate regulation while at the same time ensuring the actual socio-economic viability of the identified options of urban greening.

Further research can be oriented toward the integration of the contribution of evapotranspiration in the evaluation of outdoor comfort by using other spatially explicit models and economic valuations of the greening scenarios to dynamically understand the correct return of public investments over a designed period of time.

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References

1. Butera, F.M.; Palme, M. The City as a Complex Thermodynamic System. In *Urban Microclimate Modelling for Comfort and Energy Studies*; Palme, M., Salvati, A., Eds.; Springer: Cham, Switzerland, 2021. [CrossRef]
2. Hammond, M.J.; Chen, A.S.; Djordjević, S.; Butler, D.; Mark, O. Urban Flood Impact Assessment: A State-of-the-Art Review. *Urban Water J.* **2013**, *12*, 14–29. [CrossRef]
3. Escobedo, F.J.; Kroeger, T.; Wagner, J.E. Urban Forests and Pollution Mitigation: Analyzing Ecosystem Services and Disservices. *Environ. Pollut.* **2011**, *159*, 2078–2087. [CrossRef] [PubMed]
4. Filho, W.L.; Balogun, A.-L.; Olayide, O.E.; Azeiteiro, U.M.; Ayal, D.Y.; Muñoz, P.D.C.; Nagy, G.J.; Bynoe, P.; Oguge, O.; Yannick Toamukum, N.; et al. Assessing the Impacts of Climate Change in Cities and Their Adaptive Capacity: Towards Transformative Approaches to Climate Change Adaptation and Poverty Reduction in Urban Areas in a Set of Developing Countries. *Sci. Total Environ.* **2019**, *692*, 1175–1190. [CrossRef]
5. Aguiar, F.C.; Bentz, J.; Silva, J.M.N.; Fonseca, A.L.; Swart, R.; Santos, F.D.; Penha-Lopes, G. Adaptation to Climate Change at Local Level in Europe: An Overview. *Environ. Sci. Policy* **2018**, *86*, 38–63. [CrossRef]
6. Tucker, J.; Daoud, M.; Oates, N.; Few, R.; Conway, D.; Mtisi, S.; Matheson, S. Social Vulnerability in Three High-Poverty Climate Change Hot Spots: What Does the Climate Change Literature Tell Us? *Reg. Environ. Chang.* **2014**, *15*, 783–800. [CrossRef]
7. Eigenbrod, F.; Bell, V.A.; Davies, H.N.; Heinemeyer, A.; Armsworth, P.R.; Gaston, K.J. The Impact of Projected Increases in Urbanization on Ecosystem Services. *Proc. R. Soc. B Biol. Sci.* **2011**, *278*, 3201–3208. [CrossRef]
8. Liberalesso, T.; Oliveira Cruz, C.; Matos Silva, C.; Manso, M. Green Infrastructure and Public Policies: An International Review of Green Roofs and Green Walls Incentives. *Land Use Policy* **2020**, *96*, 104693. [CrossRef]
9. Wolch, J.R.; Byrne, J.; Newell, J.P. Urban Green Space, Public Health, and Environmental Justice: The Challenge of Making Cities "Just Green Enough". *Landsc. Urban Plan.* **2014**, *125*, 234–244. [CrossRef]

10. Berland, A.; Shiflett, S.A.; Shuster, W.D.; Garmestani, A.S.; Goddard, H.C.; Herrmann, D.L.; Hopton, M.E. The Role of Trees in Urban Stormwater Management. *Landsc. Urban Plan.* **2017**, *162*, 167–177. [CrossRef]
11. Donovan, G.H. Including Public-Health Benefits of Trees in Urban-Forestry Decision Making. *Urban For. Urban Green.* **2017**, *22*, 120–123. [CrossRef]
12. Ma, B.; Zhou, T.; Lei, S.; Wen, Y.; Htun, T.T. Effects of Urban Green Spaces on Residents' Well-Being. *Environ. Dev. Sustain.* **2018**, *21*, 2793–2809. [CrossRef]
13. Privitera, R.; Evola, G.; La Rosa, D.; Costanzo, V. Green Infrastructure to Reduce the Energy Demand of Cities. In *Urban Microclimate Modelling for Comfort and Energy Studies*; Palme, M., Salvati, A., Eds.; Springer: Cham, Switzerland, 2021; pp. 485–503. [CrossRef]
14. Ministero della Salute. Sistema di Sorveglianza Mortalità Giornaliera. Available online: https://www.salute.gov.it/portale/caldo/dettaglioContenutiCaldo.jsp?id=4547&area=emergenzaCaldo&menu=vuoto (accessed on 2 April 2023).
15. Hwang, W.H.; Wiseman, P.E.; Thomas, V.A. Enhancing the Energy Conservation Benefits of Shade Trees in Dense Residential Developments Using an Alternative Tree Placement Strategy. *Landsc. Urban Plan.* **2017**, *158*, 62–74. [CrossRef]
16. Palme, M.; Privitera, R.; La Rosa, D. The Shading Effects of Green Infrastructure in Private Residential Areas: Building Performance Simulation to Support Urban Planning. *Energy Build.* **2020**, *229*, 110531. [CrossRef]
17. Konarska, J.; Uddling, J.; Holmer, B.; Lutz, M.; Lindberg, F.; Pleijel, H.; Thorsson, S. Transpiration of Urban Trees and Its Cooling Effect in a High Latitude City. *Int. J. Biometeorol.* **2015**, *60*, 159–172. [CrossRef] [PubMed]
18. Kántor, N.; Chen, L.; Gál, C.V. Human-Biometeorological Significance of Shading in Urban Public Spaces—Summertime Measurements in Pécs, Hungary. *Landsc. Urban Plan.* **2018**, *170*, 241–255. [CrossRef]
19. Lai, D.; Liu, W.; Gan, T.; Liu, K.; Chen, Q. A Review of Mitigating Strategies to Improve the Thermal Environment and Thermal Comfort in Urban Outdoor Spaces. *Sci. Total Environ.* **2019**, *661*, 337–353. [CrossRef]
20. Lachapelle, J.A.; Scott Krayenhoff, E.; Middel, A.; Coseo, P.; Warland, J. Maximizing the Pedestrian Radiative Cooling Benefit per Street Tree. *Landsc. Urban Plan.* **2023**, *230*, 104608. [CrossRef]
21. Turner, V.K.; French, E.M.; Dialesandro, J.; Middel, A.; Hondula, D.M.; Weiss, G.B.; Abdellati, H. How Are Cities Planning for Heat? Analysis of United States Municipal Plans. *Environ. Res. Lett.* **2022**, *17*, 064054. [CrossRef]
22. Coutts, A.M.; White, E.C.; Tapper, N.J.; Beringer, J.; Livesley, S.J. Temperature and Human Thermal Comfort Effects of Street Trees across Three Contrasting Street Canyon Environments. *Theor. Appl. Climatol.* **2015**, *124*, 55–68. [CrossRef]
23. Millward, A.A.; Torchia, M.; Laursen, A.E.; Rothman, L.D. Vegetation Placement for Summer Built Surface Temperature Moderation in an Urban Microclimate. *Environ. Manag.* **2014**, *53*, 1043–1057. [CrossRef]
24. Li, X.; Li, X.; Ma, X. Spatial Optimization for Urban Green Space (UGS) Planning Support Using a Heuristic Approach. *Appl. Geogr.* **2022**, *138*, 102622. [CrossRef]
25. Park, C.Y.; Lee, D.K.; Krayenhoff, E.S.; Heo, H.K.; Hyun, J.H.; Oh, K.; Park, T.Y. Variations in Pedestrian Mean Radiant Temperature Based on the Spacing and Size of Street Trees. *Sustain. Cities Soc.* **2019**, *48*, 101521. [CrossRef]
26. Werbin, Z.R.; Heidari, L.; Buckley, S.; Brochu, P.; Butler, L.J.; Connolly, C.; Houttuijn Bloemendaal, L.; McCabe, T.D.; Miller, T.K.; Hutyra, L.R. A Tree-Planting Decision Support Tool for Urban Heat Mitigation. *PLoS ONE* **2020**, *15*, e0224959. [CrossRef] [PubMed]
27. Morakinyo, T.E.; Ouyang, W.; Lau, K.K.-L.; Ren, C.; Ng, E. Right Tree, Right Place (Urban Canyon): Tree Species Selection Approach for Optimum Urban Heat Mitigation—Development and Evaluation. *Sci. Total Environ.* **2020**, *719*, 137461. [CrossRef]
28. Xu, Y.; Ren, C.; Ma, P.; Ho, J.; Wang, W.; Lau, K.K.-L.; Lin, H.; Ng, E. Urban Morphology Detection and Computation for Urban Climate Research. *Landsc. Urban Plan.* **2017**, *167*, 212–224. [CrossRef]
29. Salet, W.; Vermeulen, R.; Savini, F.; Dembski, S.; Thierstein, A.; Nears, P.; Vink, B.; Healey, P.; Stein, U.; Schultz, H.; et al. Planning for the New European Metropolis: Functions, Politics, and Symbols/Metropolitan Regions: Functional Relations between the Core and the Periphery/Business Investment Decisions and Spatial Planning Policy/Metropolitan Challenges, Political Responsibilities/Spatial Imaginaries, Urban Dynamics and Political Community/Capacity-Building in the City Region: Creating Common Spaces/Which Challenges for Today's European Metropolitan Spaces? *Plan. Theory Pract.* **2015**, *16*, 251–275. [CrossRef]
30. Lindberg, F.; Grimmond, C.S.B.; Gabey, A.; Huang, B.; Kent, C.W.; Sun, T.; Theeuwes, N.E.; Järvi, L.; Ward, H.C.; Capel-Timms, I.; et al. Urban Multi-Scale Environmental Predictor (UMEP): An Integrated Tool for City-Based Climate Services. *Environ. Model. Softw.* **2018**, *99*, 70–87. [CrossRef]
31. Lindberg, F.; Holmer, B.; Thorsson, S. SOLWEIG 1.0—Modelling Spatial Variations of 3D Radiant Fluxes and Mean Radiant Temperature in Complex Urban Settings. *Int. J. Biometeorol.* **2008**, *52*, 697–713. [CrossRef]
32. Chen, L.; Yu, B.; Yang, F.; Mayer, H. Intra-Urban Differences of Mean Radiant Temperature in Different Urban Settings in Shanghai and Implications for Heat Stress under Heat Waves: A GIS-Based Approach. *Energy Build.* **2016**, *130*, 829–842. [CrossRef]
33. Privitera, R.; La Rosa, D. Reducing Seismic Vulnerability and Energy Demand of Cities through Green Infrastructure. *Sustainability* **2018**, *10*, 2591. [CrossRef]
34. *Urban Atlas—Copernicus Land Monitoring Service*. Available online: https://land.copernicus.eu/local/urban-atlas (accessed on 2 April 2023).
35. Azcarate, I.; Acero, J.Á.; Garmendia, L.; Rojí, E. Tree Layout Methodology for Shading Pedestrian Zones: Thermal Comfort Study in Bilbao (Northern Iberian Peninsula). *Sustain. Cities Soc.* **2021**, *72*, 102996. [CrossRef]

36. Agarwala, R.; Vasudevan, V. Relationship between Mobility and Pedestrian Traffic Safety in India. *Transp. Dev. Econ.* **2020**, *6*, 15. [CrossRef]
37. De Gruyter, C.; Zahraee, S.M.; Young, W. Understanding the Allocation and Use of Street Space in Areas of High People Activity. *J. Transp. Geogr.* **2022**, *101*, 103339. [CrossRef]
38. ArcGIS Online Directions and Routing Services. traffic.arcgis.com. Available online: https://traffic.arcgis.com/arcgis (accessed on 2 April 2023).
39. Evola, G.; Costanzo, V.; Marletta, L.; Nocera, F.; Detommaso, M.; Urso, A. An Investigation on the Radiant Heat Balance for Different Urban Tissues in Mediterranean Climate: A Case Study. *J. Phys. Conf. Ser.* **2021**, *2042*, 012046. [CrossRef]
40. Guo, F.; Guo, R.; Zhang, H.; Dong, J.; Zhao, J. A Canopy Shading-Based Approach to Heat Exposure Risk Mitigation in Small Squares. *Urban Clim.* **2023**, *49*, 101495. [CrossRef]
41. Nice, K.A.; Coutts, A.M.; Tapper, N.J. Development of the VTUF-3D V1.0 Urban Micro-Climate Model to Support Assessment of Urban Vegetation Influences on Human Thermal Comfort. *Urban Clim.* **2018**, *24*, 1052–1076. [CrossRef]
42. Zhang, R. Cooling Effect and Control Factors of Common Shrubs on the Urban Heat Island Effect in a Southern City in China. *Sci. Rep.* **2020**, *10*, 17317. [CrossRef]
43. Kántor, N.; Gál, C.V.; Gulyás, Á.; Unger, J. The Impact of Façade Orientation and Woody Vegetation on Summertime Heat Stress Patterns in a Central European Square: Comparison of Radiation Measurements and Simulations. *Adv. Meteorol.* **2018**, *2018*, 2650642. [CrossRef]
44. Calcerano, F.; Martinelli, L. Numerical Optimisation through Dynamic Simulation of the Position of Trees around a Stand-Alone Building to Reduce Cooling Energy Consumption. *Energy Build.* **2016**, *112*, 234–243. [CrossRef]
45. Bartoli, F.; Savo, V.; Caneva, G. Biodiversity of Urban Street Trees in Italian Cities: A Comparative Analysis. *Plant Biosyst. Int. J. Deal. All Asp. Plant Biol.* **2021**, *156*, 1–14. [CrossRef]
46. Mell, I.C.; Henneberry, J.; Hehl-Lange, S.; Keskin, B. Promoting Urban Greening: Valuing the Development of Green Infrastructure Investments in the Urban Core of Manchester, UK. *Urban For. Urban Green.* **2013**, *12*, 296–306. [CrossRef]
47. Wild, T.C.; Henneberry, J.; Gill, L. Comprehending the Multiple "Values" of Green Infrastructure—Valuing Nature-Based Solutions for Urban Water Management from Multiple Perspectives. *Environ. Res.* **2017**, *158*, 179–187. [CrossRef] [PubMed]
48. Chazdon, R.L.; Guariguata, M.R. *Decision Support Tools for Forest Landscape Restoration: Current Status and Future Outlook*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2018. [CrossRef]
49. Grant, G. Incentive-based approaches. In *Nature Based Strategies for Urban and Building Sustainability*; Perez, G., Perini, K., Eds.; Elsevier: Amsterdam, The Netherlands, 2018; pp. 29–41. [CrossRef]
50. Bryan, B.A. Incentives, Land Use, and Ecosystem Services: Synthesizing Complex Linkages. *Environ. Sci. Policy* **2013**, *27*, 124–134. [CrossRef]
51. Gonzalez-Sosa, E.; Braud, I.; Becerril Piña, R.; Mastachi Loza, C.A.; Ramos Salinas, N.M.; Chavez, C.V. A Methodology to Quantify Ecohydrological Services of Street Trees. *Ecohydrol. Hydrobiol.* **2017**, *17*, 190–206. [CrossRef]

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Article

Italy vs. Poland: A Comparative Analysis of Regional Planning System Attitudes toward Adaptation to Climate Changes and Green Infrastructures

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Abstract: European spatial planners deal with two major concerns: adaptation to climate changes (ACC) and the design and management of green infrastructures (GIs). ACC calls for the renewal of spatial planning with constant appeals to the need to adequately prepare for extreme climate events. GIs deliver ecosystem services (ES), which consist of beneficial functions to living beings in terms of, for example, helping people adapt to climate change. An effective implementation of adaptation measures at the regional and sub-regional scale is based on an efficient and prompt spatial planning system and GIs management. In this paper, we aim at comparing the attitudes of Italian and Polish spatial planning systems with respect to the integration of concepts related to ACC and GIs. We describe commonalities and differences between the two spatial planning frameworks by scrutinizing regional plans adopted in Sardinia (Italy) and Wielkopolska (Poland). We found out a scarce consideration of both ACC and GIs planning and management. The findings suggest that the regional spatial planning tools need to be updated to be fully satisfactory in terms of ACC and GIs concepts.

Keywords: planning systems; spatial planning; regional plans; climate resilience; green infrastructures; assessment criteria

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1. Introduction

The European Union (EU) has emphasized the need to adapt to climate change by adopting in 2013—and updating in 2021—the EU strategy (EU strategy) on adaptation to climate change (ACC) [1,2]. While there are many definitions of ACC, here we mean ACC as the “adjustment of human and natural systems to climatic actual or expected events, in order to minimize damage or maximize benefit” (after [3,4]). The EU strategy aims at making the European member states more climate-resilient, remarks on the need to adopt adaptation measures from national to regional levels, and stresses the urgency to “achieve coordination and coherence at the various levels of planning and management through national adaptation strategies” [2]. In 2013, the Polish government published the “Strategic adaptation plan for sectors and areas sensitive to climate changes in Poland by 2020, with an outlook by 2030” (SPA 2020, developed as a part of the Klimada Project [5]). The SPA 2020 was the first document dealing with adaptation to climate changes in Poland. In 2015, the Italian Ministry of the Environment and Protection of Land and Sea adopted the National Climate Change Adaptation Strategy [6]. Italy is also developing a National Climate Change Adaptation Plan (December 2022, latest update; [7]).

According to the EU strategy, the Mediterranean basin is vulnerable to climate change [2]. In this regard, in February 2019, the Autonomous Region of Sardinia adopted the Regional Strategy for Adaptation to Climate Change (RSACC) with the purpose of paving the way for increasing the climate resilience of the region to extreme weather events [8]. Regional planning should be consistent with the RSACC: thus, spatial planning is crucial for the promotion of adaptation approaches from regional to local scale. Polish regional strategic documents are being drawn up to adapt cities to the climate change presented in global and regional climate scenarios. However, these documents take only a limited account of current knowledge on assumed climate change or the nature of this change for the quality of human life.

Spatial planning (SP) has been defined in a variety of ways. In this paper, we follow Davoudi's definition of SP: "actions and interventions that are based on 'critical thinking about space and place' [that] involve not only legislative and regulatory frameworks for the development and use of land, but also the institutional and social resources through which such frameworks are implemented, challenged and transformed" [9]. According to Busayo et al., lately, "spatial planning laws on the global scene have metamorphosed to cover broader areas and facets that call for the integration of planning systems into diverse sectors for addressing societal issues including climate change adaptation" [10]. Spatial planning is instrumental in fostering the integration of adaptation goals according to different institutional hierarchical levels to address budgetary constraints and develop synergies [4,11]. Developing a strategy at the regional and local level is of fundamental importance and is extremely difficult not only in Poland [12]. Regional planning tools are usually drafted through multi-actor collaboration and could be frameworks for defining successful adaptation measures sub-regionally, for example through municipal master plans [4]. According to Ledda et al. [4], "the regional plans are relevant to local planning and might be key to link national and regional adaptation principia and strategies to local adaptation measures". However, we found a certain lack of studies—a research gap—that deal with adaptation to climate change in regional spatial plans (or regional plans strictly related to spatial planning issues) in Italy and Poland and that consider results obtained from the comparative approach of two European regions.

According to Cortinovis and Geneletti (2018) and Lai et al. (2019) [13,14], the integration of green areas (including green infrastructures) in urban planning processes can contribute to provide ecosystem services and benefits for humankind, including adaptation to climate change solutions [15]. Therefore, a proper understanding of the usefulness of green infrastructures for enhancing environmental quality is both theoretically and practically relevant to local urban planners [16]. In this paper, we mean Green Infrastructure (GI) as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings" [17]. Scientific literature has scarcely addressed systematically the inclusion of GI in regional planning tools in Italy and Poland. De Montis et al. (2022) [18] state that the "scrutiny of green infrastructures related concepts integration patterns in planning documents would lead to a better understanding of the strengths and weaknesses of planning frameworks".

Thus, this study aims at filling two research gaps via two research questions (RQs) by scrutinizing a set of regional plans adopted in Sardinia (Italy) and Wielkopolska (Poland): (i) How do Sardinia and Wielkopolska consider adaptation to climate change and GI in regional spatial planning tools or regional plans closely related to spatial planning issues (RQ1)? Can the organization of the spatial planning system of Italy and Poland contribute at the integration of adaptation to climate change and GI in regional (and subregional) spatial planning tools (RQ2)?

RQ1 aims at investigating if—and to what extent—key concepts of adaptation to climate change and GI characterized the regional planning process and pointing out the main strengths and weaknesses of the tools. RQ2 has the purpose of stressing if and how the current organization of the spatial planning system of both the states has potential to ease the integration of adaptation issues and ecosystem services—delivered by GI—into practice.

The manuscript unfolds as follows. In Section 2, we provide the reader with an overview on the main elements that characterize the planning systems of Italy and Poland. In Section 3, we report on a brief literature review concerning spatial planning and ACC and spatial planning and GI. In Section 4, we exemplify the methodological approach. In Sections 5 and 6, we illustrate and discuss the results (Section 5) and, respectively, summarize the concluding remarks (Section 6).

2. Spatial Planning in Italy and Poland

Italy, in southern Europe (Figure 1), is a democratic republic, which belongs to the European Union. The state extends over a surface area of 302,073 square kilometers and is characterized by a predominantly hilly area (41.6% of the total area), while mountain and plains cover about 175,202 square kilometers (respectively, 35% and 23.2% of the total area; Italian National Institute of Statistics, 2014 [19]). The Italian peninsula consists of 20 administrative regions, which host about 60 million residents (Italian National Institute of Statistics, 2021 [20]) in 7904 municipalities (Italian National Institute of Statistics, 2022 [21]). The municipalities are clustered in—and administered by—80 Provinces, 2 Autonomous Provinces, 14 Metropolitan Cities, and 6 Free Municipal Consortia (Italian Republic, 2022 [22]).

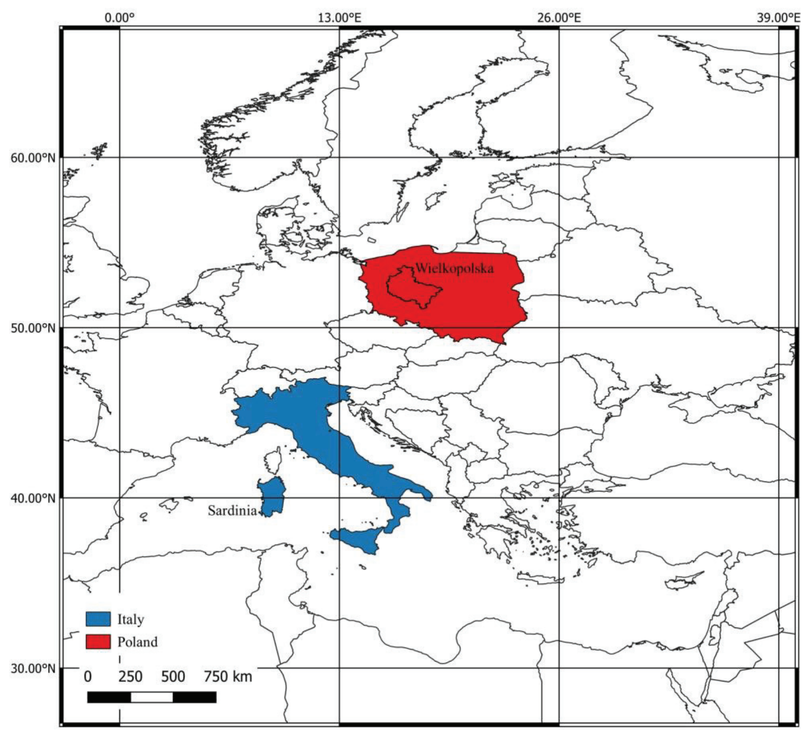

Figure 1. Geographical context.

Italy approved laws with the aim of regulating human behavior in a meticulous way (Italian Republic, [23–27]). We can recognize a juridical tradition of Italian law, which assumes that a correct behavior must constantly be referred to a written normative source. The tradition of Italian law has determined a planning system largely based on the so-called "command and control" scheme, according to which the regulatory apparatus requires a top–down approach, i.e., the public administrations promote territorial transformations that are conformed to certain characteristics and check that these transformations take place in accordance with the plans [28].

The Italian urban planning law [23] could be considered as one of the most innovative when it was enacted "as it introduced multi-level planning and urban development plans extended to entire municipal territories and limited the building activities of municipalities lacking urban development plans" [29]. The Italian urban planning law of 1942 was never repealed or replaced and is still in force. In the 1970s, the legislative activities concerning urban planning were delegated to the 20 administrative regions and were characterized by weak strategic regulation and strong heterogeneity [29–31], "thus easing forms of control and increasingly delegating decision-making to [also very small and demographically irrelevant] municipalities" [30].

While the urban planning law of 1942 [23] focused on the urban development, in the last decades in Italy, the processes of urban growth have undergone a drastic setback, and it has been understood that beyond certain limits the urban sprawl has negative effects for the economy and for the real estate market [32].

The plans can be classified by the function they perform or by their scale (national, regional, sub-regional, municipal scale). Table 1 summarizes the main spatial planning activities of Regions, Provinces, Metropolitan Cities, and municipalities according to Petroncelli [32].

Table 1. Main spatial planning activities of Regions, Provinces, Metropolitan Cities, and municipalities (after Petroncelli [32]).

Body	Spatial Planning Activities	Main Spatial Planning Tool	Type
Region	Urban planning, Social and territorial planning, Guidelines for local authorities, . . .	Regional landscape or territorial plan	Strategic
Province	Proposal of provincial multiannual programs of general and sectoral type, Coordination of municipal planning activities, Drafting and adoption of the spatial coordination plan, . . .	Provincial spatial coordination plan	Strategic
Metropolitan City	Spatial planning of the metropolitan area	Metropolitan plan	Strategic
Municipality	Local urban planning, Adoption of the municipal master plan, . . .	Municipal master plan	Operational

According to De Montis [28], the coordination plans (e.g., the provincial spatial coordination plans) refer to large portions of the territory (at least inter-municipal scale) and define a framework for the territorial transformations; the operational plans (e.g., the municipal master plans) are approved in accordance with the coordination plans usually at the municipal level and affect the local administrative area; the executive plans concern the implementation of measures—included in the operational plans—in practice.

Italy acknowledges four administrative levels: state, region, province, and municipality (Figure 2, after [33]; Larsson [34]). National sector plans adopted at the state level are very rare, as the "planning competences have been transferred to the lower-level administrative bodies" [4]. Regions, provinces, and municipalities adopt a plurality of instruments—coordination, operational regulation, and implementation instruments—to regulate their own development. Usually, regional and provincial governments draw up instruments (e.g., coordinator territorial plans) aimed at regulating the development of large areas through general provisions, while municipalities regulate changes to their land through municipal master plans [35–38].

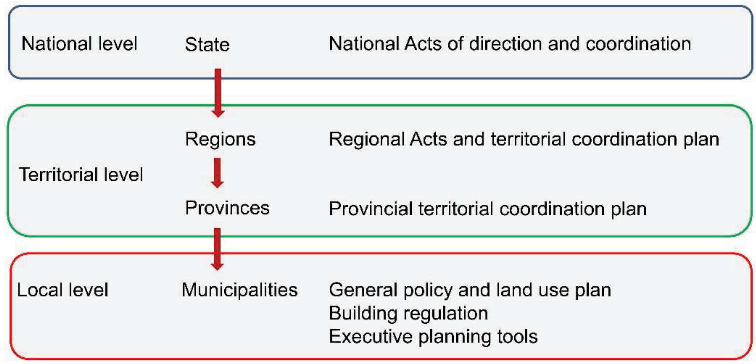

Figure 2. Organization of spatial planning system in Italy. Based on—and modified from—Bragagnolo et al. [33].

Poland, officially Republic of Poland, is a country in central Europe (Figure 1) and since 2004 is a member state of the EU. Poland covers an area of 312,696 km^2 and is the fifth-most populous member state with a population of over 38 million. The implementation of the spatial policy in Poland obeys the Spatial Planning and Development Act (SPDA) approved in 2003. The SPDA regulates the spatial planning system in Poland, including the development of spatial policies and spatial plans (concepts, plans, studies) and attributed different powers to the administrative tiers of government [39]. The Polish spatial planning and management system has changed a lot over the last 30 years. The most relevant transition occurred after the fall of socialism [40]. During the socialist era, planning and decision making were centralized so that local authorities had no influence and were mere executors of spatial transformations in their own area. Between 1989 and 2003, the Polish Government established and implemented a roadmap for building a new spatial planning and management system. Similarly, other central and eastern European countries restructured their spatial planning and management system. For most countries, this restructuration has been steered and eased by the process of adhesion to the European Union [41–43].

According to the Polish Constitution, the territorial system of the Republic of Poland ensures the decentralization of public power [39]. Governmental bodies operate in four hierarchical tiers (Figure 3): the state, at the national level; sixteen regions (Voivodeship), at the regional level; 379 provinces (Powiat), at the intermediate level; and 2477 municipalities (Gmina), at the local level. National, regional, and local level administrations are committed to land use planning. The national government steers spatial planning, according to the Long-term National Development Concept (Poland 2030), which has integrated and substituted the National Spatial Development Concept. These documents set out the conceptual framework and address the development of the whole country, by organizing the environmental and landscape protection system. Voivodeships play a limited role in spatial planning through the Regional Spatial Plans together with spatial development plans for urban functional areas. Powiats have only minor functions related to planning. The main actors in land-use planning are the municipalities, which elaborate mandatory studies on local planning scenarios for the whole communal area and the Local Spatial Development Plan for part of the community, the only legally binding zoning plan. The disadvantage of local plans is that they are recommended but not mandatory. According to a hierarchical scheme set out by the SPDA, the local plan is drafted in conformance with the spatial development plan of a voivodeship, which obeys to the National Spatial Development Concept and Long-term National Development Strategy (Figure 3).

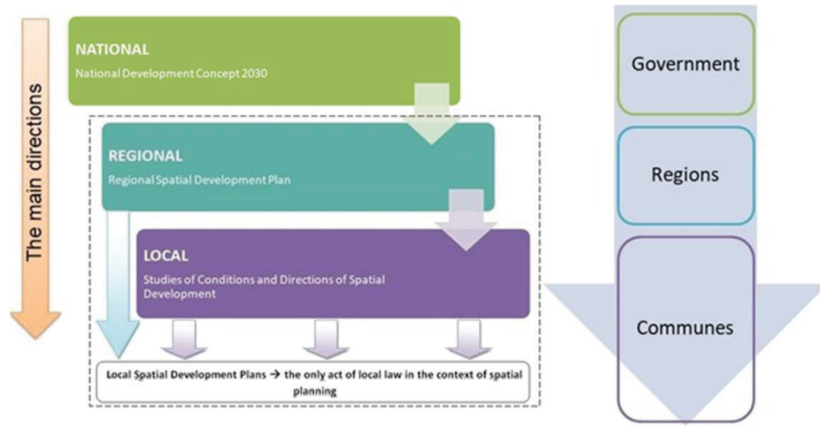

Figure 3. Organization of spatial planning system in Poland, according to the Spatial Planning and Development Act (SPDA) issued on 27 March 2003.

3. Literature Overview

The scientific cornerstones of this paper consist of the integration in spatial planning of adaptation to climate change and green infrastructures. We report on the literature review in the following two subsections.

3.1. Adaptation to Climate Change and Spatial Planning

Multi-level and multisectoral approaches can support effective adaptation to climate change [44,45]. However, in human—ecological systems, there is no guarantee that multi-level governance will be effective [4,46]. ACC can be addressed at supranational, national, regional, and sub-regional (local) scale, although scholars have been focused more on national and local than the regional scale [4,47]. ACC involves cascading decisions in which both public agencies and individuals act [48]. According to Lukat et al. [11], the connection between ACC and SP can promote the consideration and introduction of climate change adaptation objectives at both local and regional scales by fostering synergies, for example "for flood protection and biodiversity protection" [11]. Similar concepts are expressed by Carter et al. [49] quoted by Busayo et al. [10] (p. 5). SP has proven to be key in promoting ACC and resilience mainly in cities [10]. Bruneniece and Klavins [50] emphasize the critical importance of regional and local governmental agencies in terms of adaptation. Indeed, these institutions usually hold accurate information regarding both local contexts and conditions that can foster or hinder environmental change. Lazoglou and Serraos also emphasized that the Regional SP frameworks "of Western Macedonia [are] central to promote the adaptation to the expected impacts of climate change" [51]. Hurlimann and March [52] remark on the role of SP, in the context of adaptation and report on six reasons why SP can deal with adaptation. Wilson [53] focuses on adaptation to climate change and the task of SP and development plans in the UK. The author emphasizes the pivotal function of local SP as a means for promoting adaptation. Thus, the role of SP is crucial for ACC [4,50,52,53].

Ledda et al. [4] stress that the regional plans represent a framework for introducing adaptation concepts at a sub-regional scale, "i.e., for addressing municipal master plans to making local landscapes and territories more resilient to climate changes" [4]. Ledda et al. [4] stressed a certain lack of studies addressing ACC in regional SP tools adopted in Sardinia. Thus, they proposed and applied a set of criteria to assess the performance of the regional plans and programs in terms of ACC.

3.2. Green Infrastructure and Spatial Planning

The European Commission considers GI as strategic solutions for safeguarding biodiversity and ecosystem services and important adaptation and mitigation measures to address climate change effects [17,54,55]. Nature-based solutions, GIs, and ecosystem-based adaptation are strategic in the challenge to climate change and communities' resilience [56]. In this regard, GIs provide benefits, in terms of hydrological flow regulation, reduction in soil erosion phenomena, pollutant filtration, restoration of degraded biodiversity [57]. GIs can contribute at safeguarding ecosystems and communities that are vulnerable to extreme climate events and natural disaster such as flooding, storms, forest fires, and avalanches [17]. The negative effects of these events "can often be reduced using GIs solutions such as functional flood plains, riparian woodland, protection forests in mountainous areas, barrier beaches and coastal wetlands [. . .]" [17]. Green roofs, a special type of GIs, contribute to the reduction in stormwater runoff [58] and heat island effect [59,60].

Gill et al. [61] address green infrastructures (GIs) as a resource for adapting urbanized areas to climate change and remark on the need to emphasize the role of GI in terms of adaptation in planning and policy instruments at all levels. SP is key to promoting the use of GI as a solution to address climate change [62]. Irga et al. [63] analyzed the dissemination of policy instruments aimed at the design of GIs in Australia, which concerned green roofs and green walls. Irga et al. [63] claimed the importance of local spatial planning to favor GIs designs by developing strategies and adopting aimed policies. On the other hand, a better integration of GIs in spatial planning could be achieved through a multi-level approach: spatial multi-scale integration by improving connectivity; resources integration by detecting GIs components and related ecosystem services; social–economic integration, which can be achieved by updating current spatial planning methods [64]. The implementation of GI depends on: planning aspects, for example the availability of specific planning tools [63]; stakeholders' interest; institutional organization; participation and coordination [62]. A lack of financial resources hinders the planning of GIs at a local scale [65]. Matthews et al. [62] argued that the planning and successful implementation of GIs as climate adaptation measures depends on biophysical and social factors, i.e., areas available for greening, species characteristics and urban morphology, but also governance aspects and involvement of citizens in decisional processes. SP should involve the design of large-scale green infrastructure to enhance its function in adapting to climate change: e.g., a metropolitan area can be divided into more vulnerable climate zones and GIs could be planned for each zone and assessed by comparing different climate scenarios to make GIs planning more effective [66]. Ecosystem services mapping, with a focus on supply and demand at the municipal level, can promote actions concerning GIs implementation, including parks and urban ecosystems, and the updating of urban plans [62]. The integration of GIs in spatial planning could be eased through appropriate indicators [67–69]: institutions should expand the GIs database to determine more specific city-scale indicators that include social, ecological, and environmental factors suitable for GIs implementation and monitoring [68]. Some authors have addressed the role of GIs in flood protection and stormwater runoff mitigation by focusing on spatial planning and indicators to identify priority areas [70]. Italian institutional bodies dealt with adaptation to climate change by integrating GIs' regional or local policies. As an example, some Italian cities adopted the so-called Green City Guidelines [71], which include GIs as a measure for promoting adaptation to climate change. In 2020, the Metropolitan City of Genoa for GIs planning explicitly focused on adaptation to climate change [72]. In 2020, the Region of Umbria considered GIs in a guidance for drafting the Spatial Strategic Program mainly for reducing climate change effects [73]. Thus, in Italy, a certain interest in GI is growing for promoting adaptation to climate change in spatial planning processes.

4. Materials and Method

In this section, we describe the methodological approach. Firstly, we provide the reader with the list of regional plans considered in this study. Secondly, we introduce the criteria adopted to scrutinize the plans in terms of inclusion of adaptation to climate change and GI concepts.

4.1. Planning Tools Selection

We scrutinized the regional planning tools (including the strategic environmental assessment—SEA—report when available) described in Table 2.

Table 2. The pool of documents scrutinized in this study.

	Code	Name	References	Year of Approval	Main Mission	SEA Report
Sardinia (Italy)	RHP	Regional Hydrogeological Plan	Autonomous Region of Sardinia [74]	2006	Land defense and hydrogeological risk prevention	No
	RLP	Regional Landscape Plan	Autonomous Region of Sardinia [75]	2006	Protection and valorization of local landscapes	No
Wielkopolska (Poland)	EPP	Environmental Protection Programme	The Wielkopolska Regional Parliament [76]	2020	Undertaking activities in the field of landscape protection and shaping in the process of planning development	Yes
	SDP	Spatial Development Plan	The Wielkopolska Regional Parliament [77]	2019	Conducting spatial policy within the administrative boundaries of the region	Yes

As for Sardinia, the Regional Hydrogeological Plan (RHP) has been adopted in 2006 by the Autonomous Region of Sardinia. The plan provides guidelines, sectoral actions, technical standards, and general prescriptions for the prevention of hydrogeological hazards and risks in the regional river basin and hydrogeological hazard areas. RHP regulates areas of very high, high, medium, and moderate hydraulic and landslide hazard. The Regional Landscape Plan (RLP) aims to protect the landscape, with the dual purpose of preserving its quality elements and promoting its improvement through restoration and restructuring, even deep restoration when it appears degraded and compromised. RLP relies on three pillars, meaning 'environmental', 'historical and cultural' and 'settlement' settings, and it affects the regional territory, particularly twenty-seven coastal landscape units (LU). An LU consists of regional areas with similar environmental, historical and cultural, and settlement characteristics. The municipal master plans adopted in Sardinia must be consistent with RHP and RLP.

As for Wielkopolska, the Spatial Development Plan (SDP) has been adopted in 2019 by the Wielkopolska Regional Parliament. This is the most important strategic document for the Wielkopolska Region, which defines the spatial policy within the administrative border of the region. The plan defines the model of spatial development, the objectives of spatial policy and directions of spatial development of the region as well as the distribution of public purpose investments of supra-local importance. This document also contains a detailed analysis of development directions for the functional area of the voivodeship capital. The Environmental Protection Program (EPP) for the Wielkopolska Region until 2030 has been adopted in 2020 by the Wielkopolska Regional Parliament and implements an ecological policy for the region with the assumptions of the most important national and EU strategic documents. Conclusions and recommendations formulated in both documents should be reflected in planning documents at the regional and local level.

4.2. Adaptation to Climate Change: Assessment Criteria

We applied the criteria proposed by Ledda et al. [4]. Ledda et al. [4] focused on the regional plans adopted by the Autonomous Region of Sardinia (Italy), south European Mediterranean region, which is an area that will be negatively affected by climate change in the coming decades. Ledda et al. [4] aimed at proposing and applied a method rooted in the scientific literature and adaptation strategies with the purpose of scrutinizing a set of regional plans related to spatial planning issues. The authors performed a document analysis according to the following steps: (i) collection of the main strategic regional plans; (ii) scrutiny of the plans by using specific criteria (Table 3), to assess if, and to what extent, adaptation to climate change concepts were considered by the plans.

Table 3. Criteria applied to scrutinize the plans (after Ledda et al., 2020; [4]).

Criteria	Description	References
Reference to adaptation strategies	The plans refer to climate change adaptation strategies.	[2,78]
Inclusion of explicit or implicit adaptation measures	The plans include (i) explicit adaptation measures (i.e., measures specifically set as a response to climate change), or (ii) implicit measures (i.e., measures that have not been set as a response to climate change but can be effective in terms of adaptation to climate change).	[2,6,79–81]
Identification of responsible bodies for implementing Explicit adaptation measures	The plans clearly identified the responsible bodies for implementing Explicit adaptation measures.	[2,82]

The criteria were used to scrutinize if the plans: referred to adaptation strategies (regional, national, European, or international climate change adaptation strategies); included explicit (measures specifically defined in response to climate change) or implicit (that have not been defined as a response to climate change but are useful for adaptation) measures; identified the responsible bodies for implementing explicit adaptation measures.

4.3. Green Infrastructure and Spatial Planning: Assessment Criteria

De Montis et al. [18] focused on the integration of Green Infrastructure (GI) concepts in regional plans and programs and proposed and applied a complex index to do so. The study aimed at clarifying if—and to what extent—GI concepts were included in regional plans and programs adopted in Sardinia (Italy). De Montis et al. [18] defined and applied a quali–quantitative multicriteria method for selecting and scrutinizing regional plans and programs. This method was based on content analysis, inspired by similar criteria-based frameworks, and designed to enable a comparative assessment of Sardinian planning tools with respect to other countries and regions. The method included the use of a composite indicator—i.e., the Complex Index of Green Infrastructure Integration (CIGI)—for ascertaining the intensity of the consideration of GI themes and criticalities in plans and programs. While the methodologic details on the design of CIGI can be retrieved in De Montis et al. [18], here, we focus on the main elements: simple criteria (Table 4), scoring rule (Table 5), and criteria aggregation pattern (Equations (1)–(3)).

Table 4. Complex Index of Gi Integration: simple criteria (source: De Montis et al., 2022; [18]).

Domain	Code	Criteria
Explicit	EC1	Definition of GI
	EC2	Provisions concerning the design, valorization, management, maintenance of GI
	EC3	Indicators
Implicit	IC1	Strategies based on ecological networks, natural and semi-natural areas conservation
	IC2	Provision of actions for soil conservation and ecosystem/habitat/landscape protection
	IC3	Indicators

Table 5. Scoring system applied to assess the integration of Green Infrastructure (GI) concepts in the plans (after De Montis et al., 2022; [18]).

Score		Motivation
Quantitative	Qualitative	
1	No integration	GI concepts are not mentioned.
2	Barely acceptable	GI concepts are considered in a barely acceptable manner.
3	Acceptable	GI concepts are considered in an acceptable way.
4	Good	GI concepts are mentioned in a good way.
5	Excellent	GI concepts are satisfactorily considered.

The full expression of the composite indicator CIGI reads as follows (De Montis et al., [18]):

$$\mathrm{CIGI} = w_1 * \mathrm{CIGEI} + w_2 * \mathrm{CIGII} \quad (1)$$

where w_1 and w_2 (with $w_1 + w_2 = 1$) are the weights of the domain indicators Complex Index of GI Explicit Integration (CIGEI) and Complex Index of GI Implicit Integration (CIGII), which are calculated according to the following equations:

$$\mathrm{CIGEI} = \sum_1^3 w_{Ei} * \mathrm{EC}_{Ei} \quad (2)$$

$$\mathrm{CIGII} = \sum_1^3 w_{Ii} * \mathrm{IC}_{Ii} \quad (3)$$

where w_{Ei} and w_{Ii} are the weights of—respectively—the simple explicit (EC_{Ei}) and implicit (IC_{Ii}) criteria, with $\sum_1^3 w_{Ei} = 1$ and $\sum_1^3 w_{Ii} = 1$. Weight of CIGEI $= 2/3$; weight of CIGII $= 1/3$.

5. Results and Discussion

In this section, we describe and discuss the main findings.

5.1. Adaptation to Climate Change

Table 6 summarizes the scrutiny of the regional plans. The second column lists the plans, while from the third to the sixth column, a check mark (✓) indicates if the criterion is met.

Table 6. Scrutiny of the regional plans: findings (after Ledda et al. [4]).

	Plans	Criteria			
		Reference to ACC Strategy	Indication of Adaptation Measures		Indication of Responsible Bodies for Implementation of Explicit Measures
			Explicit	Implicit	
Sardinia	RLP			✓	
	HSP			✓	
Wielkopolska	EPP	✓	✓		✓
	SDP			✓	

On the one hand, the Sardinian regional plans are devoid of reference to adaptation to climate change strategies and explicit adaptation measures (and thus the responsible bodies for their implementation). On the other hand, RLP and HSP include measures that can be effective in terms of adaptation to climate change (implicit adaptation measures). The implicit measures include "gray and green [measures], such as environmental regeneration, drainage systems, safeguarding of watercourses, and preserving ecological connectivity" [4]. As an example, the RLP refers to: depollution and environmental regeneration; preservation of ecological connections between coastal and inland areas through river corridors; maintaining the functionality of watercourses flowing toward the coast by ensuring the natural flow of surface water; etc. Meanwhile, the HSP refers to: riverbank protection; adjustment or construction of river embankments; slope protection from runoff phenomena; protective barriers against rock falls and landslides; reconstitution of vegetation cover; etc.

In case of the Wielkopolska Region, only the Environmental Protection Program [76] implements rules from higher-level adaptation strategies and plans (national and EU). In addition, this strategic document includes explicit adaptation measures and identifies some responsible agencies for the implementation of explicit adaptation measures. For this reason, the Environmental Protection Program, due to the lack of regional strategy for adaptation to climate change, should play a role of guidance for mainstreaming adaptation in the current spatial planning practices. Recommended directions of adaptation activities for the Wielkopolska Region include: flood protection of areas located in floodplains; recognition of the possibility of growing thermophilic plants and preparation of programs to secure good quality water. The Spatial Development Plan [77] includes only some measures that can be effective in terms of adaptation to climate change, but much more should be undertaken in this aspect. For example, the Spatial Development Plan (2019) includes some general recommendations such as: maintenance and introduction of mid-field; roadside and waterside plantings to improve ecological and climatic function; reducing low pollutant emissions; introducing environmentally friendly sources of local and regional transport; or designation of green areas supporting the process of self-cleaning atmosphere, especially in urban areas. However, the main provisions of the Spatial Development Plan (2030) are consistent with the adopted concept of the Environmental Protection Program (2020).

Three out of four regional plans lack clear references to climate change and adaptation concepts. However, the plans set implicit adaptation measures that can increase the resilience of the regional contexts against the negative consequence due to climate change [4]. Implicit measures—such as roadside and waterside plantings improving ecological and climatic function (SDP, Wielkopolska Region) and drainage systems dealing with the excess of water and the design of green areas (RLP and HSP, Sardinia)—can have a key role as entry points for explicit adaptation measures [4,78]. However, the plans need to be updated to clearly introduce adaptation principles and guidance acknowledged at international [83] and European [1] levels. Furthermore, the two plans adopted in Sardinia will have to be consistent with the regional strategy for adaptation to climate change approved in 2019 [8] as they are the framework for sub-regional planning tools.

The EPP (Wielkopolska) met three criteria, which are the most relevant to adaptation. The plan clearly provides a reference to adaptation strategies, adaptation measures, and an indication of responsible bodies for implementation of the explicit measures. The reference to adaptation strategies can be considered as the first step to introduce adaptation principia from a higher (European or national) to sub-regional (provincial or municipal) scale [4]. According to England et al. [44], the consistency among policies is important in terms of increased efficiency and effectiveness and reduced competition for scarce budgets and resources. The definition of explicit adaptation measures should be considered the minimum to meet adaptation objectives consistent with adaptation strategies. However, adaptation measures have to be tailored to specific geographical and climate contexts to be effective [4,81]. Finally, the plan identifies the agencies for the implementation of explicit adaptation measures, and this is a key issue in terms of effective adaptation [84] partly because "[. . .] each node of the administrative network should be known, and alerted when needed, across horizontal and vertical levels. In such a network, the nodes are the actors, who are responsible for certain adaptation measures, while the links stand for the relationships and interactions between the actors" [4].

In the case of Sardinia, we analyzed documents approved 15 years ago. Therefore, the plans need to be updated to include the principles and objectives of the regional strategy for adaptation [8]. By contrast, the Wielkopolska region shows very recent (i.e., approved in 2019 and 2020) tools, even though they are still not sufficiently adapted to climate change issues. This is due to the lack of regional strategy for adaptation, which should be a starting point in this context. The Marshal Office of the Wielkopolska Region should prepare the Regional Strategy for Adaptation to Climate Change as soon as possible.

5.2. Green Infrastructures

Table 7 summarizes the outcomes. The criteria (columns 4–9) quantify the qualitative assessment on the performance of each plan.

Table 7. CIGI: scores assigned to the simple criteria and resulting values for domain and composite indicators plans (after De Montis et al., 2022; [18]). 'A' stands for the arithmetic mean of the scores assigned to RHP and RLP; as an example, for Sardinia, the arithmetic mean A of EC1 = (1 + 1)/2 = 1. 'B' stands for the arithmetic mean of the scores assigned to EPP and SDP; as an example, for Wielkopolska, the arithmetic mean B of IC2 = (3 + 4)/2 = 3.50. 'C' stands for the arithmetic mean of 'A' and 'B', i.e., (A + B)/2.

Regions (Code)	Plans	Calculation	EC1	EC2	EC3	IC1	IC2	IC3	CIGEI	CIGII	CIGI
Sardinia (A)	RHP		1	2	1	1	4	1	1.33	2.00	1.56
	RLP		1	1	1	2	3	1	1.00	2.00	1.33
		Mean A	1.00	1.50	1.00	1.50	3.50	1.00	1.17	2.00	1.45
Wielkopolska (B)	EPP		1	1	1	3	3	2	1.00	2.66	1.55
	SDP		1	1	1	4	4	1	1.00	3.00	1.67
		Mean B	1.00	1.00	1.00	3.50	3.50	1.50	1.00	2.83	1.61
		Mean C	1.00	1.25	1.00	2.50	3.50	1.25	1.08	2.42	1.53
Sardinia		(A-C)/C	0%	20%	0%	−40%	0%	−20%	8%	−17%	−5%
Wielkopolska		(B-C)/C	0%	−20%	0%	40%	0%	20%	−8%	17%	5%

RHP and RLP do not report any definition of GIs (EC1). The RHP suggests the use of GIs as a countermeasure to hydrogeological instability, such as landslides and floods (EC2 and IC2). The RHP refers to "green roofs, permeable flooring, grassy canals, plant strips, and buffer strips" [18] and includes both structural and not-structural naturalistic engineering measures. Indicators are not mentioned in the plan (EC3 and IC3). The RLP refers to GIs (IC2) in implicit terms such as "[. . .] urban green spaces, conservative farming for soil conservation, cover crops" [18]. The RLP aims at establishing, enhancing, restoring, and conserving natural areas through landscape and habitat connectivity (IC1). The plan does not mention any indicators (EC3).

In the case of the Wielkopolska Region, there is no national document or strategy in Poland which will implement GIs from the national to regional level. Furthermore, in the absence of a coherent spatial planning system, Poland is increasingly losing its natural potential to create GIs due to a growing fragmentation of ecosystems. Currently, one of the major barriers is the lack of effective legal instruments, regulations and guidelines. So, the level of GIs integration is barely acceptable because none of the scrutinized documents explicitly include definitions, provisions and indicators concerning GIs. They have implemented only some general recommendation: preventing ecosystem fragmentation; maintaining ecological connectivity; and re-naturalizing degraded and anthropogenically transformed areas.

According to the CIGI, the plans of the Wielkopolska Region show a better performance than the plans adopted in Sardinia. However, the regions show similar very low quality in terms of GIs concepts integration, excluding IC1 compared to which Wielkopolska has a significantly higher average score (+40%) than Sardinia. The Sardinian plans did not refer to the concept of GI: this because the plans are very old (2006) and cannot refer to strategies such as the EU Strategy to GIs [17].

Both Sardinia and Wielkopolska show a certain lack of consideration of GIs. The findings confirm the results of previous studies [18,85,86]. The plans did not explicitly refer to the definition of GI (EC1), provisions concerning the design, valorization, management, maintenance of GI (EC2), and indicators (EC3). In this regard, our results are similar to the output obtained by Di Marino et al. [85], who investigated the regional planning policy of the Uusimaa Region (Finland) and found that "the concept of GI has not been introduced yet" [18]. Grădinaru and Hersperger [86] also found comparable findings in a study concerning spatial plans adopted by European urban regions. As for EC2, the Sardinian RHP addressed GI implementation, management, and conservation, also implicitly (IC2) as EPP and SDP (Wielkopolska). GIs are implicitly integrated in the plans, and this could pave the way for an explicit consideration of GIs. However, this conjecture needs to be investigated with further research. The plans did not include any explicit reference to GI indicators (EC3), while EPP refers implicitly to them. According to De Montis et al. [18], "[the] inclusion of ecological indicators specifically defined for measuring the effectiveness of GIs would be desirable", as such indicators can be used to "measure climate and microclimatic modifications [. . .]" (De Montis et al., [18]; see also Pakzad et al., [87]). In addition, GI indicators are also useful in strategic environmental assessment procedures: for example, in the monitoring phase of plans and programs that may affect the environment [18].

6. Conclusions

Spatial planning has a key role in the promotion of adaptation to climate change (ACC) and green infrastructure (GI) concepts and principles as well as adequate planned measures. In this paper, we answered to two research questions (RQs). RQ1 aimed at investigating if—and to what extent—key concepts of ACC and GI characterized the regional planning process of Sardinia (Italy) and Wielkopolska (Poland) and pointing out the main strengths and weaknesses of the tools. RQ2 had the purpose of stressing if and how the current organization of the spatial planning system of both Italy and Poland has potential to ease the integration of ACC and ecosystem services—delivered by GI—into practice.

As for RQ1, we found out that the major regional spatial planning tools of both regions are deficient in terms of consideration of ACC and GI issues. The plans mainly met implicit performance criteria. Thus, future updates of the plans must integrate ACC and GI concepts according to European, national, and regional strategies (ACC) or provincial guidance (GIs).

As for RQ2, the multi-level and multi-actor planning system of Italy and Poland can contribute at the integration of adaptation to climate change and GI concepts at the regional and sub-regional scale. Italy has adopted a national adaptation strategy in 2015 [6]. Thus, Sardinia benefits from a national (and from 2019, regional) framework that promotes adaptation to climate change, i.e., the national [6] and regional adaptation strategy [8]. In this regard, the planning system of both states has a central role for the promotion of adaptation from a higher (state) level to lower (sub-regional) level. Neither Italy nor Poland have adopted a national GI yet, but some Italian public administrations adopted guidelines for the design and implementation of GI at the provincial level.

We might speculate that the regional plans show a weak attitude to integrating ACC and GI concepts because of the slowness of the regions to fully integrate such concepts into the regional legislative framework (see Wielkopolska) and to update the plans (see Sardinia). On the one hand, a satisfactory integration of the EU strategies on ACC and GI into regional regulations and guidance documents of Wielkopolska might be relevant to the mainstreaming of ACC, resilience and GI in plans related to SP issues. SP could promote the consideration of such concepts into planning processes, e.g., in the context of strategic environmental assessment. On the other hand, Sardinia needs to update the regional plans, according to the regional strategy for ACC and better include GI concepts into the SP processes. In Poland, there is a clear need to develop or update planning documents and adaptation strategies for regions and subregions, which undergo energy transformation processes relating to moving away from coal. These are strongly transformed areas, in which the processes of mitigation and ACC play a special role. In the case of the Wielkopolska region, this applies to the Konińskie Basin of Brown Coal.

We feel that this research can contribute to the scientific panorama as: (i) it provides the scholars with a methodological approach replicable in similar European geographical contexts; (ii) the study might be of inspiration for planners to assess the quality of regional plans and stress their strengths and weaknesses; (iii) the performance criteria proposed in this study have potential to be utilized as a checklist, i.e., a sort of list of criteria that need to be met in the context of planning processes; (iv) it emphasizes the role of adaptation to climate change and GI concepts in regional spatial planning and provides the regional administrations with reasons that support the need to increase the climate resilience of territories and population to preserve human (and non-human) life. European regions can be inspired by this study to promote the use of GIs for increasing territorial resilience.

The main limitations of this research regard: (i) the small set of regional plans scrutinized and (ii) the basic performance criteria adopted. We aim at increasing the sample of plans and considering additional performance criteria in future research. A further limitation concerns the need to investigate how regional plans are implemented in practice. Future research should investigate what barriers—regulatory or otherwise—hinder the implementation of the scrutinized plans in regard to ACC and promoting the use of GI.

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References

1. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Empty. Forging a Climate-Resilient Europe—The New EU Strategy on Adaptation to Climate Change. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0082&from=EN (accessed on 5 January 2022).
2. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—An EU Strategy on Adaptation to Climate Change. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52013DC0216 (accessed on 19 March 2021).
3. Salzmann, N.; Huggel, C.; Nussbaumer, S.U.; Ziervogel, G. Setting the Scene: Adapting to Climate Change—A Large-Scale Challenge with Local-Scale Impacts. In *Climate Change Adaptation Strategies: An Upstream-Downstream Perspective*; Salzmann, N., Huggel, C., Nussbaumer, S.U., Ziervogel, G., Eds.; Springer: Berlin/Heidelberg, Germany, 2016; ISBN 978-3-319-40771-5.
4. Ledda, A.; Di Cesare, E.A.; Satta, G.; Cocco, G.; Calia, G.; Arras, F.; Congiu, A.; Manca, E.; De Montis, A. Adaptation to Climate Change and Regional Planning: A Scrutiny of Sectoral Instruments. *Sustainability* **2020**, *12*, 3804. [CrossRef]
5. Ministry of Climate and Environment. *Strategic Adaptation Plan for Sectors and Areas Sensitive to Climate Changes in Poland by 2020, with an Outlook by 2030*; Ministry of Climate and Environment: Warsaw, Poland, 2020.
6. Ministry of the Environment and Protection of Land and Sea. *Strategia Nazionale Di Adattamento Ai Cambiamenti Climatici [National Strategy for Adaptation to Climate Change] (SNACC) Approvata Con Il Decreto Direttoriale n. 86 Del 16 Giugno 2015*; Ministry for Environment, Land and Sea: Rome, Italy, 2015.
7. Ministero dell'Ambiente e della Sicurezza Energetica Piano Nazionale Di Adattamento Ai Cambiamenti Climatici. Available online: https://www.mite.gov.it/pagina/piano-nazionale-di-adattamento-ai-cambiamenti-climatici (accessed on 24 December 2022).
8. ARS-Autonomous Region of Sardinia Strategia Regionale Di Adattamento. Available online: https://portal.sardegnasira.it/strategia-regionale-di-adattamento (accessed on 24 December 2022).
9. Davoudi, S.; Crawford, J.; Mehmood, A. *Planning for Climate Change: Strategies for Mitigation and Adaptation for Spatial Planners*; Routledge: London, UK, 2009; p. 319. ISBN 978-1-84977-015-6.
10. Busayo, E.T.; Kalumba, A.M.; Orimoloye, I.R. Spatial Planning and Climate Change Adaptation Assessment: Perspectives from Mdantsane Township Dwellers in South Africa. *Habitat Int.* **2019**, *90*, 101978. [CrossRef]
11. Lukat, E.; Tröltzsch, J.; Cazzola, G.; Kiresiewa, Z.; Blobel, D.; Terenzi, A.; Peleikis, J.; Latinos, V.; Purdy, R.; Hjerp, P. *Regional and Local Adaptation in the EU since the Adoption of the EU Adaptation Strategy in 2013*; European Union: Brussels, Belgium, 2016.
12. Nowak, M.J.; Śleszyński, P.; Legutko-Kobus, P. Theoretical and Legal Conditions of Spatial Management Systems. In *Spatial Planning in Poland: Law, Property Market and Planning Practice*; Nowak, M.J., Śleszyński, P., Legutko-Kobus, P., Eds.; SpringerBriefs in Geography; Springer International Publishing: Cham, Switzerland, 2022; pp. 1–20. ISBN 978-3-030-96939-4.
13. Cortinovis, C.; Geneletti, D. Ecosystem Services in Urban Plans: What Is There, and What Is Still Needed for Better Decisions. *Land Use Policy* **2018**, *70*, 298–312. [CrossRef]
14. Lai, S.; Leone, F.; Zoppi, C. Assessment of Municipal Masterplans Aimed at Identifying and Fostering Green Infrastructure: A Study Concerning Three Towns of the Metropolitan Area of Cagliari, Italy. *Sustainability* **2019**, *11*, 1470. [CrossRef]
15. Nakamura, F. (Ed.) *Green Infrastructure and Climate Change Adaptation: Function, Implementation and Governance*; Ecological Research Monographs; Springer Nature: Singapore, 2022; ISBN 9789811667909.
16. Malcevschi, S.; Cordara, P. *Buone Pratiche per Le Infrastrutture Verdi. Un Percorso*; Rivista Della Associazione Analisti Ambientali: Milano, Italy, 2013.
17. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Green Infrastructure (GI)—Enhancing Europe's Natural Capital*; European Commission: Brussels, Belgium, 2013.
18. De Montis, A.; Ledda, A.; Calia, G. Integrating Green Infrastructures in Spatial Planning: A Scrutiny of Regional Tools in Sardinia, Italy. *Eur. Plan. Stud.* **2022**, *30*, 251–268. [CrossRef]
19. Italian National Institute of Statistics Principali Dimensioni Geostatistiche e Grado di Urbanizzazione del Paese. Available online: https://www.istat.it/it/archivio/137001 (accessed on 24 December 2022).

20. Italian National Institute of Statistics Censimento Della Popolazione e Dinamica Demografica—Anno 2020. Available online: https://www.istat.it/it/archivio/264511#:~{}:text=Al%2031%20dicembre%202020%2C%20data,al%202019%20(-405.275%20individui) (accessed on 24 December 2022).
21. Italian National Institute of Statistics Codici Statistici Delle unità Amministrative Territoriali: Comuni, Città Metropolitane, Province e Regioni. Available online: https://www.istat.it/it/archivio/6789 (accessed on 24 December 2022).
22. *Italian Republic Relazione Sulla Gestione Finanziaria Degli Enti Locali. Comuni, Province e Città Metropolitane. ESERCIZI 2019–2021. Corte Dei Conti. DELIBERAZIONE N. 11/SEZAUT/2022/FRG 2022*; Corte Dei Conti: Rome, Italy, 2022.
23. Italian Republic Legge, n. 1150 Del 1942. Available online: https://www.bosettiegatti.eu/info/norme/statali/1942_1150.htm (accessed on 24 December 2022).
24. Italian Republic Legge, n. 167 Del 1962. Available online: https://www.bosettiegatti.eu/info/norme/statali/1962_0167.htm (accessed on 24 December 2022).
25. Italian Republic LEGGE 6 Agosto 1967, n. 765. Available online: https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:1967-08-06;765 (accessed on 24 December 2022).
26. Italian Republic Legge, n. 457 Del 1978. Available online: https://www.bosettiegatti.eu/info/norme/statali/1978_0457.htm (accessed on 24 December 2022).
27. Italian Republic Legge, n. 47 Del 1985. Available online: https://www.bosettiegatti.eu/info/norme/statali/1985_0047.htm#:~{}:text=47%20del%201985&text=Norme%20in%20materia%20di%20controllo%20dell%27attivit%C3%A0%20urbanistico-edilizia.&text=Legge%20quadro-,1.,principi%20definiti%20dalla%20presente%20legge (accessed on 24 December 2022).
28. De Montis, A. *Pianificare Il Paesaggio Rurale*; Università degli Studi di Sassari: Sassari, Italy, 2017; ISBN 978-88-907678-4-5.
29. Romano, B.; Zullo, F.; Fiorini, L.; Marucci, A. Molecular No Smart-Planning in Italy: 8000 Municipalities in Action throughout the Country. *Sustainability* **2019**, *11*, 6467. [CrossRef]
30. Romano, B.; Zullo, F.; Marucci, A.; Fiorini, L. Vintage Urban Planning in Italy: Land Management with the Tools of the Mid-Twentieth Century. *Sustainability* **2018**, *10*, 4125. [CrossRef]
31. Fiorini, L.; Zullo, F.; Marucci, A.; Di Dato, C.; Romano, B. Planning Tool Mosaic (PTM): A Platform for Italy, a Country Without a Strategic Framework. *Land* **2021**, *10*, 279. [CrossRef]
32. Petroncelli, E. *Pianificazione territoriale. Principi e fondamenti*; Liguori Editore: LiguoriNapoli, Italy, 2002; ISBN 88-207-3470-2.
33. Bragagnolo, C.; Geneletti, D.; Fischer, T.B. Cumulative Effects in SEA of Spatial Plans—Evidence from Italy and England. *Impact Assess. Proj. Apprais.* **2012**, *30*, 100–110. [CrossRef]
34. Larsson, G. *Spatial Planning Systems in Western Europe: An Overview*; Delft University Press: Delft, The Netherlands, 2006; ISBN 978-1-58603-656-0.
35. Gabellini, P. *Tecniche Urbanistiche*; Carocci: Roma, Italy, 2001; ISBN 978-88-430-1869-7.
36. Selicato, F.; Rotondo, F. *Progettazione Urbanistica: Teorie e Tecniche*; McGraw Hill Education: Milano, Italy, 2009; ISBN 978-88-386-6547-9.
37. Gaeta, L.; Rivolin, U.J.; Mazza, L. *Governo del Territorio e Pianificazione Spaziale*; CittàStudi: Novara, Italy, 2013; ISBN 978-88-251-7382-6.
38. Mercandino, A. *Urbanistica Tecnica. Pianificazione Generale*; Il Sole 24 Ore: Milano, Italy, 2006; ISBN 88-324-6187-0.
39. Wagner, M. Evading Spatial Planning Law-Case Study of Poland. *Land Use Policy* **2016**, *57*, 396–404. [CrossRef]
40. Rzasa, K.; Caporusso, G.; Ogryzek, M.; Tarantino, E. Spatial Planning Systems in Poland and Italy—Comparative Analysis on the Example of Olsztyn and Bari. *Acta Sci. Pol. Adm. Locorum* **2021**, *20*, 111–138. [CrossRef]
41. Dąbrowski, M.; Piskorek, K. The Development of Strategic Spatial Planning in Central and Eastern Europe: Between Path Dependence, European Influence, and Domestic Politics. *Plan. Perspect.* **2018**, *33*, 571–589. [CrossRef]
42. Nadin, V.; Maldonando, A.; Zonneveld, W.; Stead, D.; Dąbrowski, M.; Piskorek, K.; Sarkar, A.; Schmitt, P.; Smas, L.; Cotella, G.; et al. *ESPON COMPASS—Comparative Analysis of Territorial Governance and Spatial Planning Systems in Europe (Applied Research 2016–2018—Final Report)*; ESPON & TU Delft: Luxembourg, 2018; ISBN 978-99959-55-55-7.
43. Nowak, M.; Petrisor, A.-I.; Mitrea, A.; Kovács, K.F.; Lukstina, G.; Jürgenson, E.; Ladzianska, Z.; Simeonova, V.; Lozynskyy, R.; Rezac, V.; et al. The Role of Spatial Plans Adopted at the Local Level in the Spatial Planning Systems of Central and Eastern European Countries. *Land* **2022**, *11*, 1599. [CrossRef]
44. England, M.I.; Dougill, A.J.; Stringer, L.C.; Vincent, K.E.; Pardoe, J.; Kalaba, F.K.; Mkwambisi, D.D.; Namaganda, E.; Afionis, S. Climate Change Adaptation and Cross-Sectoral Policy Coherence in Southern Africa. *Reg. Environ. Change* **2018**, *18*, 2059–2071. [CrossRef]
45. Corfee-Morlot, J.; Kamal-Chaoui, L.; Donovan, M.G.; Cochran, I.; Robert, A.; Teasdale, P.-J. *Cities, Climate Change and Multilevel Governance*; OECD: Paris, France, 2009.
46. Di Gregorio, M.; Fatorelli, L.; Paavola, J.; Locatelli, B.; Pramova, E.; Nurrochmat, D.R.; May, P.H.; Brockhaus, M.; Sari, I.M.; Kusumadewi, S.D. Multi-Level Governance and Power in Climate Change Policy Networks. *Glob. Environ. Change* **2019**, *54*, 64–77. [CrossRef]
47. Dannevig, H.; Aall, C. The Regional Level as Boundary Organization? An Analysis of Climate Change Adaptation Governance in Norway. *Environ. Sci. Policy* **2015**, *54*, 168–175. [CrossRef]
48. Adger, W.N.; Arnell, N.W.; Tompkins, E.L. Successful Adaptation to Climate Change across Scales. *Glob. Environ. Change* **2005**, *15*, 77–86. [CrossRef]

49. Carter, J.G.; Cavan, G.; Connelly, A.; Guy, S.; Handley, J.; Kazmierczak, A. Climate Change and the City: Building Capacity for Urban Adaptation. *Prog. Plan.* **2015**, *95*, 1–66. [CrossRef]
50. Bruneniece, I.; Klavins, M. Normative Principles for Adaptation to Climate Change Policy Design and Governance. In *Climate Change Management*; Knieling, J., Filho, W.L., Eds.; Springer: Berlin/Heidelberg, Germany, 2013; pp. 41–65. [CrossRef]
51. Lazoglou, M.; Serraos, K. *Climate Change Adaptation through Spatial Planning: The Case Study of the Region of Western Macedonia*; IOP Publishing Ltd.: Bristol, UK, 2021; Volume 899.
52. Hurlimann, A.C.; March, A.P. The Role of Spatial Planning in Adapting to Climate Change. *Wiley Interdiscip. Rev. Clim. Change* **2012**, *3*, 477–488. [CrossRef]
53. Wilson, E. Developing UK Spatial Planning Policy to Respond to Climate Change. *J. Environ. Policy Plan.* **2006**, *8*, 9–26. [CrossRef]
54. European Commission Biodiversity Strategy-Environment—European Commission. Available online: https://ec.europa.eu/environment/nature/biodiversity/strategy_2020/index_en.htm (accessed on 22 January 2023).
55. European Commission Biodiversity Strategy for 2030—Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—EU Biodiversity Strategy for 2030—Bringing Nature Back into Our Lives. Available online: https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en (accessed on 19 September 2021).
56. Pauleit, S.; Zölch, T.; Hansen, R.; Randrup, T.B.; Konijnendijk van den Bosch, C. Nature-Based Solutions and Climate Change—Four Shades of Green. In *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*; Kabisch, N., Korn, H., Stadler, J., Bonn, A., Eds.; Theory and Practice of Urban Sustainability Transitions; Springer International Publishing: Cham, Switzerland, 2017; pp. 29–49. ISBN 978-3-319-53750-4.
57. García, A.M.; Santé, I.; Loureiro, X.; Miranda, D. Spatial Planning of Green Infrastructure for Mitigation and Adaptation to Climate Change at a Regional Scale. *Sustainability* **2020**, *12*, 10525. [CrossRef]
58. Vanuytrecht, E.; Van Mechelen, C.; Van Meerbeek, K.; Willems, P.; Hermy, M.; Raes, D. Runoff and Vegetation Stress of Green Roofs under Different Climate Change Scenarios. *Landsc. Urban Plan.* **2014**, *122*, 68–77. [CrossRef]
59. Santamouris, M. Cooling the Cities—A Review of Reflective and Green Roof Mitigation Technologies to Fight Heat Island and Improve Comfort in Urban Environments. *Sol. Energy* **2014**, *103*, 682–703. [CrossRef]
60. Griessler Bulc, T.; Ameršek, I.; Dovjak, M. Green Infrastructure in Settlements and Cities of the Future—Two Cases Studies; green roof and treatment wetland. *Sanit. Inženirstvo* **2014**, *8*, 67–80.
61. Gill, S.; Handley, J.; Ennos, R.; Nolan, P. Planning for Green Infrastructure:Adapting to Climate Change. In *Planning for Climate Change*; Davoudi, S., Crawford, J., Mehmood, A., Eds.; Routledge: London, UK, 2009; pp. 273–285. ISBN 978-1-84977-015-6.
62. Matthews, T.; Lo, A.Y.; Byrne, J.A. Reconceptualizing Green Infrastructure for Climate Change Adaptation: Barriers to Adoption and Drivers for Uptake by Spatial Planners. *Landsc. Urban Plan.* **2015**, *138*, 155–163. [CrossRef]
63. Irga, P.J.; Braun, J.T.; Douglas, A.N.J.; Pettit, T.; Fujiwara, S.; Burchett, M.D.; Torpy, F.R. The Distribution of Green Walls and Green Roofs throughout Australia: Do Policy Instruments Influence the Frequency of Projects? *Urban For. Urban Green.* **2017**, *24*, 164–174. [CrossRef]
64. Ramyar, R.; Ackerman, A.; Johnston, D. Adapting Cities for Climate Change through Urban Green Infrastructure Planning. *Cities* **2021**, *117*, 103316. [CrossRef]
65. Reu Junqueira, J.; Serrao-Neumann, S.; White, I. Developing and Testing a Cost-Effectiveness Analysis to Prioritize Green Infrastructure Alternatives for Climate Change Adaptation. *Water Environ. J.* **2022**. [CrossRef]
66. Emmanuel, R.; Loconsole, A. Green Infrastructure as an Adaptation Approach to Tackling Urban Overheating in the Glasgow Clyde Valley Region, UK. *Landsc. Urban Plan.* **2015**, *138*, 71–86. [CrossRef]
67. Heckert, M.; Rosan, C.D. Developing a Green Infrastructure Equity Index to Promote Equity Planning. *Urban For. Urban Green.* **2016**, *19*, 263–270. [CrossRef]
68. Niţă, M.R.; Pătroescu, M.; Badiu, D.L.; Gavrilidis, A.A.; Avram, M.-E. Indicators for Evaluating the Role of Green Infrastructures in Sustainable Urban Development in Romania. *Forum Geogr.* **2018**, *17*, 75–81. [CrossRef]
69. Pakzad, P.; Osmond, P. Developing a Sustainability Indicator Set for Measuring Green Infrastructure Performance. *Procedia-Soc. Behav. Sci.* **2016**, *216*, 68–79. [CrossRef]
70. Li, L.; Uyttenhove, P.; Van Eetvelde, V. Planning Green Infrastructure to Mitigate Urban Surface Water Flooding Risk—A Methodology to Identify Priority Areas Applied in the City of Ghent. *Landsc. Urban Plan.* **2020**, *194*, 103703. [CrossRef]
71. Fondazione per lo sviluppo sostenibile, and Green City Network Le Linee Guida per Le Green City 2018. Available online: https://www.greencitynetwork.it/un-pacchetto-di-15-linee-guida-green-per-le-citta-italiane/ (accessed on 20 December 2022).
72. Metropolitan City of Genoa and Universxity of Genoa. *Infrastrutture Verdi per l'adattamento Ai Cambiamenti Climatici*; Città Metropolitana di Genova e Università degli Studi di Genova—Dipartimento Architettura e Design—Scuola Politecnica: Genova, Italy, 2020; Available online: https://www.cittametropolitana.genova.it/it/aree/progetti/proterina-3%C3%A9volution (accessed on 20 December 2022).
73. Region of Umbria Linee Guida per la Redazione del pst Programma Strategico Territoriale. 2020. Available online: https://www.regione.umbria.it/documents/18/25260896/DGR+1350+2021+Allegato+Linee+Guida+per+la+redazione+del+Programma+Strategico+Territoriale.pdf/b94b85bb-ae60-4055-8fbc-65e4e6a85452 (accessed on 20 December 2022).
74. ARS-Autonomous Region of Sardinia Piano Stralcio per l'Assetto Idrogeologico. 2006. Available online: https://www.regione.sardegna.it/j/v/25?s=28677&v=2&c=8622 (accessed on 20 December 2022).

75. ARS-Autonomous Region of Sardinia Piano Paesaggistico Regionale. 2006. Available online: https://www.sardegnaterritorio.it/pianificazione/pianopaesaggistico/ (accessed on 20 December 2022).
76. The Wielkopolska Regional Parliament Envionmental Protection Program (EPP). 2020. Available online: https://bip.umww.pl/artykuly/2826771/pliki/20210126124350_programochronyrodiwskadlawojewdztwawielkopolskiegodoroku2030.pdf (accessed on 20 December 2022).
77. The Wielkopolska Regional Parliament Spatial Development Plan (SDP). 2019. Available online: https://bip.umww.pl/artykuly/2828419/pliki/20220524091745_planzagospodarowaniaprzestrzennegowojewodztwawielkopolskiegoiplanzagospodarowaniaprzestrzennegomiejskiegoobszarufunkcjonaln.pdf (accessed on 20 December 2022).
78. Eisenack, K.; Stecker, R. A Framework for Analyzing Climate Change Adaptations as Actions. *Mitig. Adapt. Strateg. Glob. Change* **2012**, *17*, 243–260. [CrossRef]
79. Donner, S.D.; Kandlikar, M.; Webber, S. Measuring and Tracking the Flow of Climate Change Adaptation Aid to the Developing World. *Environ. Res. Lett.* **2016**, *11*, 054006. [CrossRef]
80. Ricci, L. *Linking Adaptive Capacity and Peri-Urban Features: The Findings of a Household Survey in Dar Es Salaam*; Springer Climate; Springer: Berlin/Heidelberg, Germany, 2014; pp. 89–107. [CrossRef]
81. Dubois, C.; Cloutier, G.; Rynning, M.K.R.; Adolphe, L.; Bonhomme, M. City and Building Designers, and Climate Adaptation. *Buildings* **2016**, *6*, 28. [CrossRef]
82. Mees, H.; Driessen, P. A Framework for Assessing the Accountability of Local Governance Arrangements for Adaptation to Climate Change. *J. Environ. Plan. Manag.* **2019**, *62*, 671–691. [CrossRef]
83. Pörtner, H.-O.; Roberts, D.C.; Tignor, M.; Poloczanska, E.S.; Mintenbeck, K.; Alegría, A.; Craig, M.; Langsdorf, S.; Löschke, S.; Möller, V.; et al. *IPCC Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2022.
84. Reckien, D.; Petkova, E.P. Who Is Responsible for Climate Change Adaptation? *Environ. Res. Lett.* **2019**, *14*, 014010. [CrossRef]
85. Di Marino, M.; Tiitu, M.; Lapintie, K.; Viinikka, A.; Kopperoinen, L. Integrating Green Infrastructure and Ecosystem Services in Land Use Planning. Results from Two Finnish Case Studies. *Land Use Policy* **2019**, *82*, 643–656. [CrossRef]
86. Grădinaru, S.R.; Hersperger, A.M. Green Infrastructure in Strategic Spatial Plans: Evidence from European Urban Regions. *Urban For. Urban Green.* **2019**, *40*, 17–28. [CrossRef]
87. Pakzad, P.; Osmond, P.; Corkery, L. Developing Key Sustainability Indicators for Assessing Green Infrastructure Performance. *Procedia Eng.* **2017**, *180*, 146–156. [CrossRef]

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