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# Fostering the Resiliency of Urban Landscape through the Sustainable Spatial Planning of Green Spaces

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**Abstract:** Background: It has been recognized that urban green spaces play a crucial role in providing many landscape services. The research aimed at identifying the main knowledge gaps in this framework and to support urban planning, taking into account the spatial configuration of green areas through a pilot study area, and mapping urban landscape services. Methods: In this research, (1) a systematic review, analyzed through a network analysis; (2) an urban pilot study to map the Urban Green Index and, jointly, the spatial composition and configuration of urban green areas, through the integration of three landscape metrics; and (3) the mapping of Urban Landscape Services Index have been carried out. Results: The 37% of the reviewed articles focused on regulating services, while the network analysis identified four clusters. The total Urban Green Index was 26%, and some districts showed a percentage that surpassed it. The total overall Green Connectivity Index was 21%. Some districts were the best providers of landscape services. Conclusions: This research was in line with the EU Joint Science for Policy Report suggesting giving emphasis to the spatial pattern map of green spaces in European cities to provide spatial data available for decision-makers in relation to GI deployment.

**Keywords:** urban green areas; green connectivity index; landscape services; urban spatial planning

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## 1. Introduction

It is widely recognized that most of the world's population will live in cities in the near future [1–3]. The problem of urbanization is particularly alarming since it represents a complex process of land use transformation (from rural to urban), which involves a profound change of landscape structure, function, and dynamics [4], causing urban landscape degradation and loss of urban biodiversity. This continuous urbanization of the planet, with effects on citizens' quality of life, has led to the identification of the local (urban) level as the right scale to achieve the 11th UN Sustainable Development Goal (SDG) [5]. This goal is focused on "sustainable cities and communities" and, through innovative urban planning choices, it aims at making cities resilient. The key element for achieving the SDG in cities is certainly represented by urban green areas [6] usually composed of natural or semi-natural components of the urban landscape such as forests, grasslands, street trees, public and private gardens, vertical gardens etc., which ensure crucial urban landscape services [7–9] that depend on the resilience of urban landscapes. Sustainable cities require innovative urban planning strategies, based on new ecological knowledge and perspectives that are sometimes missing at urban scale. In this context, there is an explicit call for more green spaces in cities, and the European policy as well as the US New Urban Agenda ask to

include urban green areas into urban planning challenges for improving societal quality of life. It has been recognized that urban green space plays a crucial role in providing many landscape services [10–16]. More in detail, urban green areas provide cultural services, such as aesthetics, recreation, tourism, etc. [17–20], and regulatory services [10,21] such as reduction of air pollution, through carbon storage and sequestration [22–24], reduction of water pollution [25–27], water regulation [17,18,28], noise reduction [19,26], micro-climate regulation [29–31]. Urban green spaces provide habitats for different species and are, therefore, essential for maintaining biodiversity in urban landscapes [26,28,32]. Finally, as recognized by the Millennium Ecosystem Assessment [33] urban landscape services support the quality of life [34,35] and the well-being of citizens [36]. However, the challenge is to design a strategically planned network of green areas able to deliver a wide range of Landscape Urban Services (LS) within a city, through a spatial approach. Very often, the contribution of green areas to the provision of LS is related to their presence and amount, by using green area type (gardens, street trees, urban parks) as proxies of service flow [37,38]. However, the naturalness degree, diversity, size, shape, and above all the spatial pattern of urban green areas also play a crucial role in determining the contribution of green areas to the provision of urban landscape services [39–41]. The last point is of particular importance as urban green spaces are, often, increasingly fragmented because of urban development [42,43] and there is still a lack of research on the role of their spatial pattern in guaranteeing equal social access. Landscape ecology theory has strongly recognized that spatial composition (amount) and configuration (spatial arrangement) of urban green areas are two interplaying landscape components that can affect urban landscape heterogeneity, given by the complexity and variability of the properties of a landscape in space and time [44–52]. Therefore, both landscape properties influence the way landscape services are provided [53–56], since they depend on the abundance and variety of green area types, and on their spatial distribution in terms of spatial connectivity and/or fragmentation [57–60]. Even if most green spaces are public, access depends on distance [61]. Therefore, their spatial configuration plays an important role in the equal distribution of environmental benefits among people living in different suburban areas. In this context, the aims of this research are:

1. a systematic review through a network analysis approach to identify the main research items and knowledge gaps related to urban green areas and landscape services, and to analyze how these concepts are interrelated to each other and to the spatial configuration of green spaces;
2. to better focus the research on urban green area planning: (a) a pilot study has been carried out in the municipality of Lecce to analyze the amount of urban green areas at urban and suburban (district) scale through the use of a simple Urban Green Index; and (b) the joint analysis of the spatial composition and configuration of urban green spaces has been carried out through the integration of three landscape metrics; and the Urban Landscape Services Index has been estimated and mapped at urban and suburban scale as a support urban green areas planning to foster the resilience of urban landscape.

## 2. Materials and Methods

### *2.1. Systematic Review*

To carry out the systematic review, Web ISI and Scopus were used to collect potentially relevant papers to analyze the connection among alternative terms: "Green Infrastructure" or "Urban Green Areas" and "Natural Capital" or "Ecosystem Services". These four terms have been selected for two main reasons: (1) to analyze the main temporal trend of publications focused on these interlinked concepts as well as the typology of landscape services (supporting, provisioning, regulating, and cultural) taken into account, using descriptive statistics. (2) to investigate the role played by the spatial connotations, the keywords collected from the systematic review have been analyzed in terms of co-occurrence network, underlying the possible relationships among them. Network analysis has been carried out

using the open-source VOSviewer software. The size of the labels and nodes is determined by "total link strength", the number of documents linking the keywords, and the thickness of the lines connecting the nodes depends on "link strength" between two keywords [30].

The output of the analysis allowed the identification of possible clusters, whose number usually depends on the resolution parameter: the higher its value, the higher the level of detail [30]. In this study, 9 was the set as the minimum cluster size, therefore the minimum cluster is made up of at least 9 keywords.

### *2.2. Spatial Analysis of Urban Green Spaces and Assessment of the Landscape Services Index (LSI)*

Focusing on urban green area planning, a pilot study was carried out in the urbanized area of the municipality of Lecce (Apulia Region—southern Italy) (Figure 1) to analyze the amount of urban green areas at urban and suburban (district) scale through the use of a simple Urban Green Index, and then a spatial configuration was carried out.

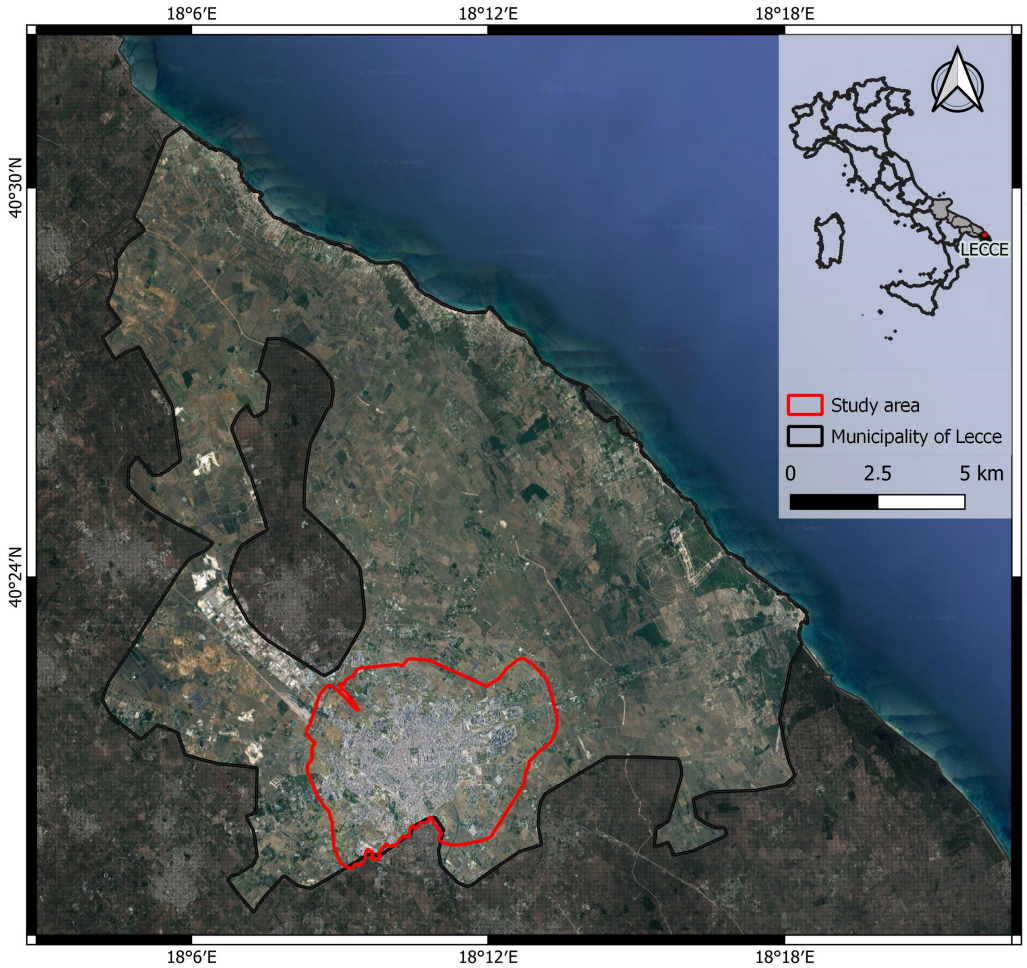


**Figure 1.** Study area.

More in detail, the study area has an extension of 30.16 km$^2$ over the total area of the municipality of Lecce 238.82 km$^2$ and presents the number of inhabitants as 95,037. Urban green planning is a priority for the municipal administration of the city of Lecce with four priority actions included in the purposes of green plan drafting: the census of the green areas, the proposal of a green area regulation, a programmatic framework for urban forestry interventions and the elaboration of the tree balance. In this perspective, interventions are planned to increase the presence of new green areas, and to improve the maintenance of the existing ones. This pilot study helps in testing some landscape indices that can support more effective strategies for implementing green areas to enhance their connectivity.

In the study area, spatial analysis was carried out through the following steps:

- identifying and mapping the public green areas using high-spatial-resolution satellite imagery using the QuickMapServices in QGIS 3.20.2 software.
- measuring and mapping the Urban Green Index (UGI) through the PLAND landscape metric, using the FRAGSTATS 4.2 software. This index measures the amount of green area over the whole urban landscape under study, and the districts' green index.
- measuring and mapping the Green Connectivity Index (GCI) through the integration of three landscape metrics: Class Area (CA), Aggregation Index, and COHESION index [62–64]. More specifically, Class Area, given by the number of green patches in the study area, has been used to quantify the spatial composition of green areas. On the other side, Aggregation Index, given indications on the spatial aggregation among green patches, and COHESION, quantifying the connectivity among green patches in an urban landscape, have been innovatively integrated to measure the spatial configuration of green areas in an urban landscape. Their use has been tested in the pilot study area, taking into account that $CA$ can assume values $> 0$, Aggregation Index and COHESION range from 0 and 100. Thus, the GCI allows analysis of the urban green landscape taking into consideration not only the quantity of green areas (amount) but also their spatial aggregation and connectivity. The GCI is always $> 0$ and is given by:

$$Green \quad Connectivity \quad Index \quad (GCI) = CA \times AI \times COHESION \tag{1}$$

- measuring and mapping the urban Landscape Service Index (LSI), though a new classification of the urban green areas of the study area into two sub-classes—Forest and Non-Forest—and by considering three main urban landscape services associated with these sub-classes: carbon sequestration, temperature regulation, and runoff regulation. The LSI has been calculated as follows:

$$Landscape \quad Services \quad Index \quad (LSI) = aGCI_{Forest} + bGCI_{Non-Forest} \tag{2}$$

  where "$a$" and "$b$" are the weighting factors in terms of broad contribution of each class to each selected landscape service: green areas classified as Forest contribute more to each landscape services than green areas classified as Non-Forest, with the exception of runoff regulation (Table 1), while $GCI_{Forest}$ is the green connectivity index for class Forest, and $GCI_{Non-Forest}$ is the green connectivity index for class Non-Forest.
- Finally, the LSI has been normalized.

**Table 1.** Weighting factors in terms of contribution of each sub-class to each selected landscape service (adapted from [65]).

| Weighting Factors | Carbon Sequestration | Temperature Regulation | Runoff Regulation |
|---|---|---|---|
| $a$ (Forest) | 1 | 1 | 1 |
| $b$ (Non-Forest) | 0.5 | 0.5 | 1 |

## 3. Results

### *3.1. Systematic Review*

The systematic review resulted in the collection of 671 articles published over a period ranging from 2006 to 2020. The trend of the number of articles per year has highlighted the growing interest of the scientific literature towards the interlinked topics "Green Infrastructure" and "Urban Green Areas", with "Natural Capital" and "Ecosystem Services" (Figure 2a).

The articles were analyzed by their content to understand which categories of urban landscape services have been mainly associated with green infrastructures/areas. The results showed that some articles did not deal with one or more specific categories of

landscape services, while others have been more focused on specific landscape services that in 37% of the articles have been represented by regulating services followed by cultural services (32%) (Figure 2b).

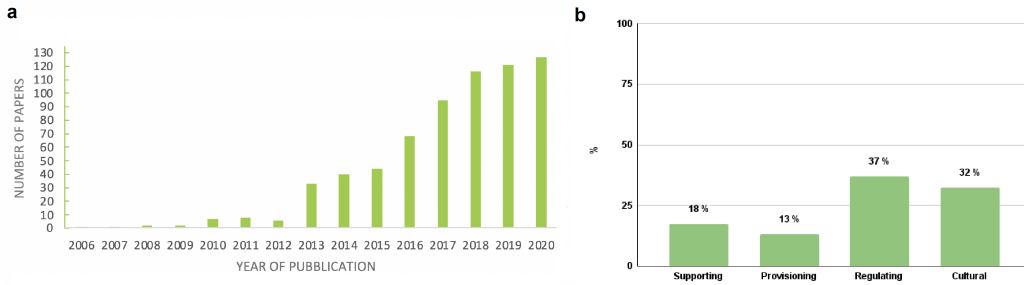


**Figure 2.** (**a**) Temporal trend of the papers collected in the systematic review. (**b**) The landscape services most investigated in the Review.

Most of the study areas were in Europe, China, and the United States. The results of the Network Analysis are shown in Figure 3. The sample used in the Network Analysis consisted of 1895 keywords.

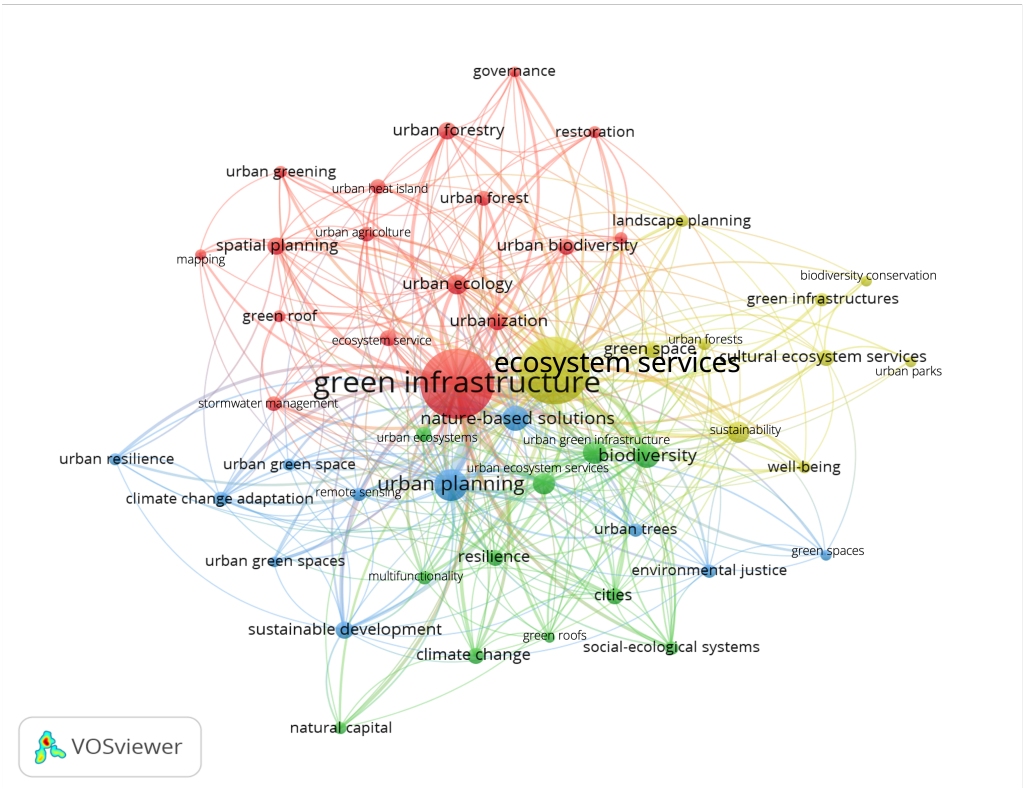


**Figure 3.** Network Analysis Map.

The size of the label and node of a keyword was determined by its weight: the greater its weight, the larger its label and node. The color of each keyword was dependent on belonging to a specific cluster. The lines among the keywords, on the other hand, represent the interlinks among them [66].

The results showed that four clusters were identified with the following central nodes: green infrastructures, ecosystem services, urban planning, and biodiversity. The most frequent keyword was "green infrastructures" (red cluster), which was, together with "ecosystem services", one of the central topics of the systematic review. It showed a great weight, evident from the size of the node, and the greatest number of elements (keywords)

nearby (Figure 3). The terms "green space" and "nature-based solutions" in adjacent positions to "green infrastructures", was highlighted as all these terms are often used in an interchangeable way to indicate urban green spaces.

Another important keyword is "ecosystem services" (yellow cluster), a transversal topic associated with several research items such as well-being, landscape planning, and green spaces (Figure 3).

Finally, "urban planning" and "biodiversity" represents the last two clusters, less important than "green infrastructures" and "ecosystem services". In particular, "urban planning" (blue cluster) was more related to "urban green spaces", "climate change adaptation", "nature-based solutions", and "environmental justice" at urban scale, while "biodiversity" (green cluster) was more related to "resilience", "climate change", and "natural capital".

### *3.2. Spatial Analysis of Urban Green Areas*

For the spatial analysis of urban green areas, it has been an expedient to take into consideration the relationship between spatial composition and configuration of urban green areas and the related provision of landscape services. A map of Lecce public urban greenery is shown in Figure 4.




**Figure 4.** (**a**) Urban greenery map of the municipality of Lecce; (**b**) Districts' Urban Green Index (UGI) Map; (**c**) Districts' Green Connectivity Index (GCI) Map.

It is possible to notice that the green areas are found mainly in the districts around Lecce old town, as well as the areas characterized by more recent urban sprawl. The urban green index (UGI) of the municipality of Lecce is 26% of the total area. When this index is estimated at the district scale (Figure 4b), it is possible to highlight that Districts 1, 6, 7, 9, 10, and 11 show a percentage of UGI higher than 26%.

The high value of UGI in the case of District 6 (historic center) is linked to the presence of two green areas in a district that has shown a very small extent in comparison with others with the same amount of green areas but with a higher extent, as with District 4 and District 3, showing, the lowest UGI. The result is in line with other studies focused on other urban contexts [67,68]. However, these districts are characterized by private urban gardens and green roofs that are not included in the results of the present research.

To take into consideration jointly the spatial composition and configuration of the urban green areas, the Green Connectivity Index (GCI) has been elaborated and mapped (Figure 4c). The GCI for the whole study area is about 21%, and Districts 1, 5, 9, 10, 11, and 13 shows values of GCI higher than 21%. These higher values of GCI could be related

to the presence of green areas more aggregated in these districts in comparison with the whole study area.

### *3.3. Urban Landscape Services*

The Landscape Services Index is based on the reclassification and mapping of urban green spaces in "Forest" and "Non-Forest" green areas (Figure 5a), showing a greater extent of "Non-Forest" areas than "Forest" areas (Figure 5b). More specifically, the "Non-Forest" areas are predominant in the peri-urban areas, as a ring outside the most urbanized area, and are more aggregated than "Forest" areas.

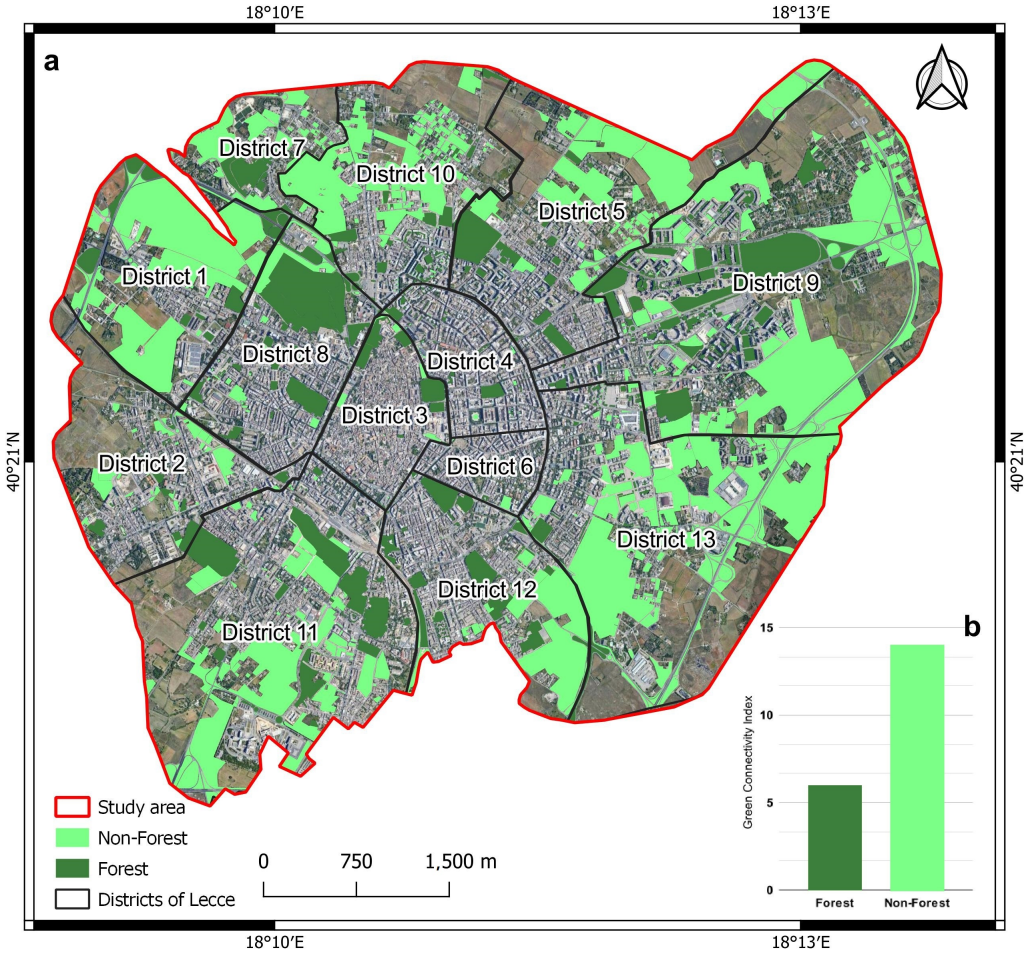


**Figure 5.** (**a**) Map of Forest and Non-Forest Area; (**b**) Green Connectivity Index for Forest and Non-Forest areas.

District 9 shows high performance in the provision of all landscape services. On the contrary, the other districts highlight high performance only in one or two landscape service provisions. Finally, District 8 has a high contribution in terms of Carbon Sequestration but a medium contribution in terms of Temperature and Runoff Regulation. Furthermore, District 13 contributes more in Runoff and Temperature Regulation but not in terms of Carbon Sequestration. Other districts, such as 5 and 3, show the same level of landscape service provision.

From the analysis of the Landscape Services Index, however, it has emerged that the districts that best provide the three urban landscape services analyzed in this study are 1, 8, 9, 11 and 13 (Figure 6a), while Figure 6b–d show the districts that mostly provide each landscape service (Carbon Sequestration, Temperature Regulation and Runoff Regulation).

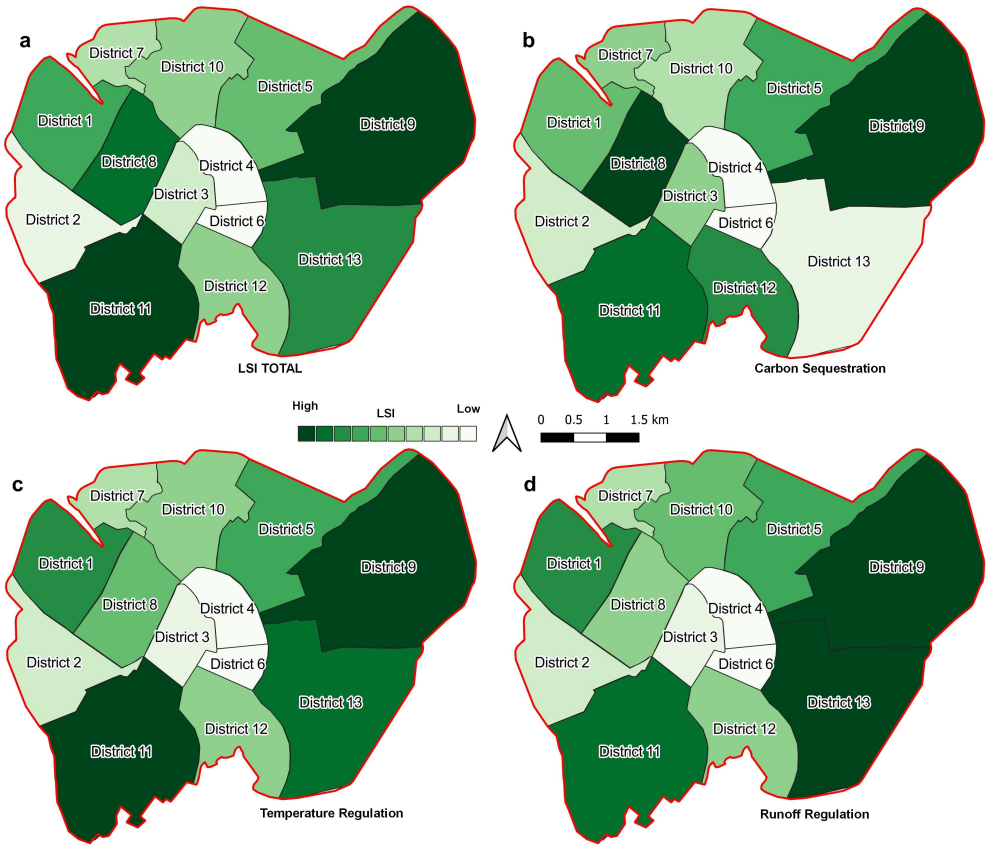


**Figure 6.** (**a**) Map of the Landscape Services Index (LSI) at the District scale, (**b**) Map of the provision of Carbon sequestration at the District scale, (**c**) Map of the provision of Temperature Regulation at the District scale, and (**d**) Map of Runoff Regulation at the District scale.

## 4. Discussion

Today, urban areas represent a fundamental tool to support and promote sustainable development within urban contexts [69]. As highlighted by the systematic review, the scientific literature has shown a growing interest in urban green areas from 2006 to 2020 (Figure 2a). Furthermore, the worldwide interest in this theme has also been noticed in a recent review by Chatzimentor and colleagues in 2020 [70] but probably the greatest interest towards green areas in Europe is related to the economic support given to their implementation in European countries.

The regulated landscape services provided by urban green areas have played a key role in building healthy, livable cities that are resilient to natural disasters [71], and this is the reason these services have been the most frequently analyzed services in the investigated literature (Figure 2b). It has been also observed that the regulating services have been followed by cultural services, therefore most of the studies have also been tackled from a social perspective, probably because urban landscape services that foster cultural diversity and social relations comply with the Sustainable Development Goal on Sustainable Cities and Communities (SDG11) [72]. This has been further confirmed in the four clusters resulting from the Network Analysis (Figure 3), where among the main scientific research topics it has been possible to notice that cultural ecosystem services are part of the ecosystem service cluster (yellow cluster). The deep knowledge of urban green areas could represent a useful support for appropriate and sustainable urban planning that supports both natural capital and human well-being. The systematic review has noticed the strong interdisciplinarity of the topic, as demonstrated by the interrelations between red and yellow clusters among the terms planning, biodiversity, well-being, and services. This

could mean that urban green planning should be able to integrate ecological and social values. Urban green spaces can therefore provide landscape services which, by affecting the constituents of human well-being, produce several social and cultural benefits. Another interconnection has been highlighted between blue and green clusters, where the terms urban planning, climate change and natural capital are of particular interest. Part of the scientific literature on green spaces has focused on the role of biodiversity and urban tree coverage in supporting the resilience of cities [72,73].

However, the systematic review has highlighted that there are few keywords focused on spatial aspects such as spatial planning and landscape planning. This represents a knowledge gap that it is crucial to fill, since the connectivity of a landscape, intended as a "spatial characteristic of systems that supports the occurrence of specific processes and functions, through adjacency, proximity or connection and functional connection" [74], must be taken into account when planning urban green areas for landscape services. In this perspective, the spatial analysis of green areas in the municipality of Lecce was intended to highlight how crucial it is to analyze the amount of green areas together with their spatial arrangement (configuration) to foster landscape services at urban scale. Planning for improving the spatial connectivity of urban landscapes is therefore fundamental for contrasting the serious consequences related to climate change, by implementing the provision of landscape services as shown in Figure 6, as well as the equal distribution of environmental benefits among people living in different districts. For instance, Districts 3, 4, and 6 need new planning strategies to guarantee the implementation of carbon sequestration, and temperature and runoff regulation. The only consideration of the amount of urban green areas do not help in planning for enhancing urban landscape services. The correct implementation of urban greenery will move cities towards the enhancement of human well-being and urban sustainability [75].

The research needs further development implemented through the inclusion of private green areas that could modify the results mainly in those districts where built-up areas do not leave available space for the increasing of new urban greenery, as in the case of the old town.

In addition, given the recognized role of green areas in regulating the urban microclimate, this research will be developed by analyzing the effects of green areas on the mitigation of the heat island, by measuring in situ the climate regulation service. All this information will be used to better plan the urban and peri-urban green areas for enhancing the provision of urban landscape services and the resiliency of the city.

## 5. Conclusions

The role of urban green spaces in producing urban landscape services is fundamental for the resilience of a city [76]. The link between the provision of landscape services and urban green areas has been the focus of several studies, revealing a positive correlation between the amount of green space and the services they provide [22,77,78]. However, the spatial configuration of green areas plays an important role, since it helps in understanding if a single large green area (SL) is better than several small (SS) interlinked green areas or vice versa. The so-called SLOSS debate, very well known in nature conservation theory, can be of relevance also in the case of green area planning. This is a typical ecological concept to discuss if it is better to protect a single large or several small protected areas to enhance biodiversity conservation. In this perspective, the contribution of urban green areas to the provisioning of landscape services should be analyzed in terms of spatial composition and the configuration of green spaces [8].

In the context of ever-increasing urban sprawl, it is necessary to evaluate the impact of this expansion on the configuration of the urban landscape, and on its connectivity. The design of a network of green areas can improve the connectivity of highly urbanized landscapes by building green corridors to protect biodiversity, improve the quality of life, and enhance the resilience of the cities [79]. Characteristics such as the proportion between

green areas of the different areas of the city, the complexity of their spatial configuration and, consequently, their connectivity, can affect the role of green areas in urban contexts.

The European Commission, in one of its most recent Joint Science for Policy Reports (2019), suggested giving emphasis to the spatial pattern map of green spaces in European cities to provide spatial data available for decision-makers in relation to GI deployment.

The Green Infrastructure concept is better known and applied in the urban local context, particularly for its benefits in regulating landscape services, as demonstrated in this study. Planning that develops connected green areas can solve several urban challenges and contributes significantly to the creation of resilient future cities that support landscape services and human well-being in facing climate change.

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