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# Towards an Urban Resilience Index: A Case Study in 50 Spanish Cities

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**Abstract:** Urbanization is a major driver of land use change and global environmental decline. With accelerated urbanization worldwide, it is essential to put in place new policies to conserve urban ecosystems, species and the services these provide in order to secure more sustainable, resilient and livable cities for the 21st century. In urban planning, the concept of resilience has broadly replaced the word sustainability. In recent years, resilience indicators have been gradually developed, but few address urban resilience from a social-ecological systems perspective. We develop a methodological framework to measure urban resilience, define an urban resilience index and apply it to Spanish province capitals as a case study. Results show that most Spanish province capitals are far from being resilient. We conclude that increased efforts to measure urban resilience should be in place, and we offer the urban resilience index as a theoretical framework for measuring resilience in urban social-ecological systems that can be gradually improved as more data become available.

**Keywords:** urban resilience; sustainability indicators; urban resilience index; Spanish province capitals

## 1. Introduction

Resilience has become a key concept underpinning the sciences concerned with sustainability [1–4], having gone as far as replacing the word sustainability in everyday discourses [2,3]. Over the last four decades, the term resilience has been used in many different ways [4–9] and in many different fields [3,9], to such an extent that some authors wonder if the concept has become meaningless or may be a bridging concept among disciplines [2]. At the local, national and international level, resilience has even become a priority in urban planning, having been included as a main objective in local strategies for climate change adaptation [8] or in the 2030 Agenda for Sustainable Development of the United Nations Development Programme [10].

Urban ecosystems, defined as those systems in which people live at high densities and where built structures and infrastructure cover much of the land surface [11], house the majority of the world's population [12]. Taking into account that humans are the major drivers of environmental change [13], it is a priority to introduce new paradigms in urban planning, not only to create more habitable, sustainable and resilient cities, but also to reduce their environmental and social impacts across the whole planet. However, there is not a consensus about what resilience means for urban areas [9] and how we can introduce resilience in urban planning [14].

Holling's paper [15] influenced ecologists' framing and shaped their understanding of the capacity of a system to absorb disturbances and remain stable. He distinguished two types of resilience: engineering and ecological. The former refers to the capacity of a system to return to equilibrium after disturbance [16], while ecological resilience recognizes that there are multiple equilibrium states, and the system can flip into a new one after the disturbance occurs [17]. Although the first one focuses on bouncing back and the second one on bouncing forward, both build up on the conception that any system can reach a stable equilibrium. More recently, a social-ecological perspective of resilience, also known as evolutionary resilience [2,4,8,14], has raised the recognition that complex systems are in constant change, and there is not any equilibrium state that systems can return to or move forward from following a disturbance. In this sense, resilience is the ability of complex social-ecological systems to change, adapt and, crucially, transform in response to stresses and strains [18].

A recurrent criticism in the literature is the constant use of engineering and ecological resilience in urban planning and policy making, especially in the field of risk management [3,8,14]. Efforts are made to return as fast as possible to a previous state after disturbance [4], assuming that it was a desirable state and ignoring the existence of social injustice and environmental problems [3]. Another criticism is that the urban literature often addresses resilience in relation to single types of disturbances, such as natural disasters. However, the higher levels of uncertainty brought about by climate change have meant that there is a growing need to build resilience to a broader range of disturbances [19]. Disturbances threatening cities include environmental extremes, such as hurricanes or heat waves, but also a broader variety of unexpected shocks, such as technological failures, water shortages or the depletion of fisheries, forests, oil or other essential resources for the supply of cities [20,21].

The framework of social-ecological resilience applied to urban systems focuses not only on the system's persistence, but also on the capacity of learning, being innovative and being flexible. It assumes that human beings can make conscious interventions into the process, diminishing, sustaining or enhancing resilience [8]. It is a continuous process towards a desirable state in response to the constant internal and external urban pressures [3], so it better adjusts to the characteristics of urban systems.

After a disturbance, we can observe empirically if a system is resilient or not, but how can we know if a city is resilient if we want to be prepared for any kind of pressures and before a disturbance occurs? Social-ecological resilience is a property of complex systems that may not be directly created. However, it can be fostered through factors that have been proven to increase resilience, such as diversity [5,19,22–28], modularity [19,22–24], tightness of feedbacks [19,22–24,26,29], social cohesion [5,19,20,22,23,26,30–32] and innovation [20,22,26,33,34] (an explanation of these factors is provided in Section 2.2). If we find indicators to measure these factors, we could know the system's resilience. These indicators may be used for research purposes, but also for decision-making and public communication [35–38], since they condense the complexity of any system into a compact and manageable amount of information [39]. If we improve our capacity to measure urban resilience, policy makers and society could make informed decisions in order to increase the resilience of cities.

Our work builds on various bodies of literature in the field of sustainability science, resilience and vulnerability. These include the literature on indicators and indexes to measure the sustainability of cities, countries and regions [36,37,40,41]; the literature on vulnerability assessment [42,43], considered by many authors as an antonym for resilience [6,44–46]; and the literature addressing resilience and risk reduction to known threats [19], such as earthquakes [45], floods [47–50] or heat waves [51], or broader ranges of natural hazards [38,46,52–56]. Most of these indicators are composed of social, economic, institutional and physical dimensions [38,45–47,53–55]. The social and the economic dimensions are measured through a compilation of socio-demographic data, such as household income, employment, health coverage, age or educational level. For example, inhabitants having health assurance or higher educational level are supposed to be more resilient than those inhabitants who do not. The physical or infrastructure dimension refers to the resilience of houses and infrastructures, such as electricity, water and communication systems [38,46,47,55], but also to the role of urban green infrastructure [57].

The institutional dimension takes into account the risk policies of governments and their financial capacity. Some indicators introduce variables related to social-ecological resilience, such as social cohesion [38,45,46,50,54] or ecosystem services [53,54], but other terms related to the concept of resilience, from a non-equilibrium view, are not considered. Few indicators have been developed to measure urban resilience for non-specific risks [58–62], and these have mostly focused on single parts of the urban system, such as energy [60,62], water provision [58] and urban drainage systems [61]. These methodologies attempt to analyze the continuity of the service and the future access to it for urban population, and they incorporate resilience-related characteristics, such as diversity [60,62], redundancy [61,62] or self-organization [62]. To the best of our knowledge, only Pierce et al. [59] have proposed a methodological framework to measure aggregate urban resilience.

Despite important progress in recent years, the existing methodologies to measure urban resilience only analyze it for specific disturbances or specific urban services from an engineering or ecological perspective. With the aim to fill this knowledge gap, we propose a methodological framework to measure social-ecological urban resilience and define an urban resilience index that we test with Spanish province capitals. We discuss its limitations, weaknesses, strengths and applicability. We conclude that major efforts to increase urban resilience are required and propose the urban resilience index as an open theoretical framework to measure social-ecological resilience that can be gradually improved as more data become available.

## 2. Methods

We followed Nardo et al.'s [63] approach to build composite indicators. This methodology was adapted to the objectives of the resilience index proposed in this paper along the following steps: (i) selecting an appropriate spatial scale of analysis; (ii) identifying key factors for sustaining resilience; (iii) selecting indicators; (iv) normalizing data; and (v) weighting and aggregating data.

### *2.1. Spatial Scale and Sample*

Municipalities were selected as the spatial scale because they are the minimum spatial scale with centralized statistical data and because they are the smallest administrative units with normative competencies. With the objective of building a broadly-applicable index and obtaining a representative sample of the urban variability in a country, we chose the 50 Spanish province capitals as sample units. Some socio-demographic and urban characteristics of the cities are detailed in Table S1.

### *2.2. Key Factor for Sustaining Resilience in Urban Systems*

Since the existing resilience indicators measure urban resilience from an ecological or engineering perspective [38,45,52,55,56] for specific disturbances [38,45–56] or for only a part of the system [58,60–62], we have developed a new conceptual framework to measure social-ecological urban resilience. In order to select indicators, we first identified key factors that affect urban resilience and how they affect the system's resilience [39] as variables of our index. For this purpose, we have conducted a review of: (i) reference works on social-ecological resilience; (ii) the literature on urban resilience; and (iii) case studies and reviews of the specific resilience factors (Table 1).

We selected the most salient factors addressed in the literature with a focus on those we deemed most relevant for urban ecosystems from a social-ecological point of view. In order to make the selection, we listed all factors found in the reviewed literature, selected the most repeated ones and removed those that were synonyms or that have a direct relationship with another factor, in order to avoid redundancy. We conclude that the most important factors contributing to foster urban resilience include diversity, modularity, tightness of feedbacks, social cohesion and innovation (Table 1). These factors are also valid for non-urban ecosystems, although the way they are revealed in urban systems and how they can be promoted is different, since in urban systems, human beings have a major influence. We further identified how they increase or diminish resilience, how they influence each other and how they can be promoted (Figure 1). Possible indicators coincide with urban characteristics that foster each factor. We explain each factor and how they are related below.

**Table 1.** Urban resilience factors and indicators.

| Core Urban Resilience Factors | Definition | Effect on Resilience | Possible Indicators | References |
|---|---|---|---|---|
| Diversity | Variety of urban system components. | Positive | Diversity of:<br>• organized citizen groups<br>• businesses<br>• institutions<br>• people<br>• species<br>• land uses<br>• food sources | [5,19,22,23,26] [1]<br>[24,28] [2]<br>[25,27] [3] |
| Modularity | The way that the system's components are linked with one another. A modular system is composed of subgroups of components (modules) with strong internal connections, but weak relationships with other subgroups. | Positive | Self-sufficiency<br>Diversity of:<br>• organized citizen groups<br>• businesses<br>• institutions | [19,22,23] [1]<br>[24] [2] |
| Tightness of feedbacks | Mechanisms that control ecosystems. Tightness of feedbacks is necessary to respond quickly and appropriately to shocks. | Positive | Self-sufficiency<br>Diversity of institutions<br>Social networks | [5,22,23,26,29] [1]<br>[24,64] [2] |
| Social cohesion | Trust, social networks and leadership. It increases the capacity of people to respond collectively to a disturbance. | Positive | Social trust<br>Social networks<br>Leadership<br>Diversity of organized citizen groups<br>Spaces for citizen participation facilitated by institutions<br>Degree of citizen participation | [5,19,22,23,26,32] [1]<br>[38,45,46,50,54,55] [2]<br>[20,30,31,65–67] [3] |
| Innovation | Collective learning and experimentation. It allows creating new ways to respond to changes. | Positive | Diversity of organized citizen groups<br>Spaces for citizen participation<br>Degree of citizen participation | [22,26] [1]<br>[34] [2]<br>[20,33,68] [3] |

[1] Reference works on social-ecological resilience; [2] urban resilience literature; [3] case studies and reviews of the specific resilience factors.

### 2.2.1. Diversity

In ecosystems, there are groups of organisms with specific functions, often called functional groups. Functional groups are important for ecosystem performance. Ecosystem functions can be supported by one or more species [28]. If all of the species sustaining a function disappear, the ecosystem can flip to a different regime [25], affecting ecosystem services that are essential for human well-being [27]. Moreover, if each functional group is composed of more than one species, the capacity to absorb shocks is higher than if they are made up of only one species, as the function can still be performed in the absence of the species that may have been affected by a given shock [22,28]. This kind of diversity is named response diversity [27]. In other words, functional diversity provides for different kinds of functions, and response diversity provides for components that have similar functions, but different responses to disturbance, so the function can be maintained if a component is damaged [19]. Both functional and response diversity increase resilience [5]. Expanding this framework beyond ecosystem functions, in an urban ecosystem, the diversity of species, people, businesses, institutions, land uses and food sources can be all important to sustain urban resilience [24]. Furthermore, social-ecological systems with redundant institutions are more resilient [22,26].

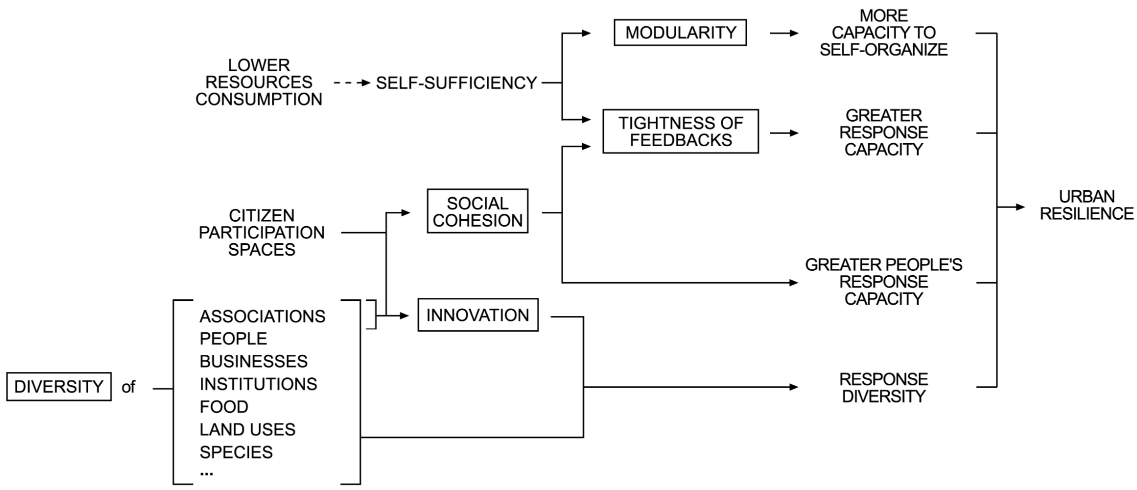


**Figure 1.** Factors that have an influence on urban resilience. The solid arrows mean a direct influence. The core factors that influence urban resilience are framed.

### 2.2.2. Modularity

Modularity refers to the way that the system's components are linked with one another [19]. The systems with subgroups of components (modules) and strong internal connections, but weak relationships with other subgroups have more capacity to self-organize after a shock [22]. For example, an urban ecosystem where there are many small organizations—associations, businesses, cooperatives, social movements—will be more resilient than that one where only a few big organizations—government, large businesses and social organizations—strongly linked with one another control the whole system. In the first case, the organizations collaborate, but work autonomously, and if one of them suffers a crisis, the rest of them will be able to continue to function. In the second case, the decisions made by the organizations or whatever happens to them will affect the system as a whole. In social-ecological systems, a degree of self-sufficiency and decentralization of production, consumption, economics and governance is necessary for modularity [24].

### 2.2.3. Tightness of Feedbacks

Ecosystems are controlled by feedbacks. The speed at which the effects of a change in a part of the system are sensed in the remaining parts of the system is influenced by these feedbacks [22]. Today's cities consume much more energy and materials than decades ago [64,69], and economic globalization has made cities increasingly dependent on ecosystem services, resources and pollution sinks from remote areas [70,71]. With globalized trade and economic activity, when something happens, it is difficult to find the cause and to respond appropriately. Consequently, several authors suggest that maintaining resilience involves increasing the tightness of feedbacks, which requires increasing the self-sufficiency of the urban system [24,29]. Institutions and social networks play a very important role, as well. It has been proposed that a centralized government and globalization cause a lack of connection between causes and consequences [22], while local institutions and social networks allow a quick response, since they are nearer the resources and there is a higher level of communication [26].

#### 2.2.4. Social Cohesion

Resilience in social-ecological systems is highly related to the capacity of people to respond collectively to a disturbance [31,32]. Trust, social networks and leadership, that is social cohesion or social capital, are important factors for the capacity of the response of communities [19,22,30]. Civil and social advocacy organizations promote social cohesion [38]. Some authors suggest that sustaining and strengthening social cohesion requires the connection between citizens and the government [65,67]. To nurture social cohesion, therefore, linking structures is required. This may be done through platforms and mechanisms for the active participation of citizens and their organizations [30,66]. These platforms offer a space for the collective construction of solutions to afford present problems and facilitate the interrelationship between government and citizen groups through an open process that promotes trust and a sense of belonging, strengthening social cohesion [20,26].

#### 2.2.5. Innovation

Innovation and learning are also important factors for a system's resilience, as they allow one to create new ways to respond to changes [22,34]. Social innovation cannot be planned directly, but it can be stimulated [33]. A higher diversity of organized citizen groups, such as cooperatives and associations, are important for the exchange of knowledge and, consequently, for social innovation [68]. Platforms for citizen participation allow communication and information transfer among stakeholders, including citizens and governments. This promotes collective learning and a better understanding of problems [20], which in turn leads to experimentation and innovation [34].

### *2.3. Indicator Selection*

As we mentioned in Section 1, most urban resilience indexes are composed of social, economic, institutional and physical resilience dimensions [38,45–47,53–55], measured in turn by several indicators. However, these indexes do not apply a social-ecological framework, and most indicators refer to the capacity to persist or return to a previous state in the face of a specific disturbance, usually natural disasters. Measuring urban resilience from a social-ecological perspective in a constantly changing urban system is a difficult task. Without the existence of equilibrium, resilience is not a static characteristic, and therefore, it cannot be directly measured. Hence, we followed a different approach to construct our index, identifying factors that foster urban resilience (Figure 1) and indicators to measure them (Table 1).

Following Schuschny and Soto [72], we have selected indicators based on relevance, quality, frequency of sampling and availability to the general public. We also took into account the synthesis capacity of the indicator and the homogeneity of the units of measure with regard to other indicators that can measure the same item. In addition, the indicators were re-elaborated to adjust them to our objectives. In order to select indicators, we conducted a review of urban resilience literature, statistical databases and municipality reports.

In Table 1, we have offered a list of possible indicators to measure resilience factors based on the literature. However, we have only included in the urban resilience index the following: business diversity, land use diversity, food sources diversity, self-sufficiency and spaces for citizen participation. Due to the lack of accessible data for the 50 Spanish province capitals, we could not include the diversity of organized citizen groups, the diversity of energy sources, the diversity of species, the degree of citizen participation, social networks, social trust and leadership. The diversity of institutions and that of people were not selected because of the absence of clarity on how to measure their influence on urban resilience. Details on how these indicators were selected, the calculation methods and the units of measurement are provided below. A summary of this information is provided in Table 2.

**Table 2.** Indicators that make up the urban resilience index.

| Indicator | Factors that Measure | Calculation | Effect on Resilience | Units of Measure | Source | Year |
|---|---|---|---|---|---|---|
| Business diversity | Diversity and modularity | Shannon diversity index with 4 categories | Positive | Dimensionless | Caja España-Duero [73]. | 2007 |
| Land use diversity | Diversity | Shannon diversity index with 9 categories | Positive | Dimensionless | Ministry of Public Works and Transport (Spain) [74]. | 2005 |
| Food diversity | Diversity | Shannon diversity index with 37 categories | Positive | Dimensionless | INE [a] [75]. | 2009 |
| Self-sufficiency | Modularity and tightness of feedbacks | Carrying capacity excess: ecological footprint (gha)/municipal area (ha) | Negative | Dimensionless | OSE [b] [76] and INE [75]. | 2004 and 2014 |
| Spaces for citizen participation | Social cohesion and innovation | Local Agenda 21 progress: the total of the milestones that have been completed or are being carried out. Scale from 0 to 10 | Positive | Dimensionless | OSE [76]. | - |

[a] Instituto Nacional de Estadística (Spanish Statistical Office); [b] Observatorio de la Sostenibilidad en España (Spanish Observatory of Sustainability).

### 2.3.1. Diversity

The literature mentions the diversity of species, people, businesses, institutions, land use and food sources as important sources of functional and response diversity in social-ecological systems [24]. However, which ones are more relevant for urban ecosystems remains unclear. Land use and food diversity seem to be critically relevant factors. The former defines the different ecosystems in the municipality and their capacity to provide ecosystem services to the local population [77], whereas the latter reflects the capacity to maintain food supply in the face of disturbance [78]. Social diversity also has a direct impact on urban social-ecological systems. This diversity can be measured by educational and acquisitive level, or ethnicity [79], but doing so can lead to incorrect results at the city level, since a high diversity can correspond to different groups segregated along the city, which affects resilience negatively by undermining cohesion [80]. Hence, the option followed here was to measure the diversity of social groups and entities: businesses that reflect the diversification of the economy and organized citizen groups, such as associations, that also measure social cohesion and innovation. In the case of institutions, there is not a consensus about the optimal degree of diversity or redundancy that maximizes resilience [26], and hence, this indicator was not included in the urban resilience index.

Diversity could be measured by four indicators: land use, food, businesses and organized citizen groups' diversity. However, we found no aggregated data for organized citizen groups, and hence, we focused on business diversity, land use diversity and food diversity.

We measured the indicator business diversity from the number of businesses by economic sectors—primary, production, construction and tertiary sector—using data obtained from Caja España-Duero [73] for 2007. Following Rueda [80], we used the Shannon diversity index to calculate the indicator business diversity. The Shannon diversity index reflects the probability of contact, regulation, exchange and communication among the different stakeholders in urban systems using the following equation:

$$H = \left[-\sum_{i=1}^{n} P_i Log_2 P_i\right], \quad (1)$$

where "$H$" is diversity and "$P_i$" is the probability of occurrence, that is the proportion of the type of business "$i$" in relation to the total of the businesses. Businesses have been divided into the four sectors of activity mentioned above. With this index, we measured functional diversity (number of sectors) and response diversity or redundancy (number of businesses per sector). Using this equation and the classification of businesses into four sectors, the minimum value of diversity is 0, while the maximum diversity is 2.

To calculate the indicator land use diversity, we used data from the report *Ciudades & Capitales + 100* [74]. For this research, we focused on 9 of the 20 land use classes covered in the report, joining crops and family allotments together, and the classes concerning urban and artificial land. The reason for this choice is that, although each type of urban land use may perform one or several functions, the segregation of land uses on the territory has a negative influence on urban resilience, while a mixture of uses in the same area has been noted to influence resilience positively [80]. For example, if we took into account residential, tertiary and non-residential land independently in the diversity indicator, we would be including a segregation of uses as a positive factor on diversity. The division of urban land into old quarter, peripheral and discontinuous would have a similar effect on the indicator.

Each land use within an urban ecosystem performs different functions and provides different ecosystem services to urban people, such as air filtration, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment and recreational and cultural services [77,81].

As for the indicator business diversity, the Shannon diversity index was also used to calculate the indicator land use diversity, where "$P_i$" is the proportion of the type of land use "$i$" in relation to the total municipal area. Since we used 9 classes of land use, the minimum value is 0, and the maximum is 3.17.

We obtained data for the indicator food diversity from the Spanish Statistical Office (INE) [75] for 2009. It was also calculated with the Shannon diversity index using 37 types of crops and cattle, where "$P_i$" is the proportion of the type of crop or cattle "$i$" in relation to the total size of the production. The minimum value for this indicator is 0, and the maximum is 5.21.

### 2.3.2. Self-Sufficiency

Self-sufficiency is critical to increase modularity and the tightness of feedbacks in urban social-ecological systems [24]. We used carrying capacity excess to measure self-sufficiency, which in turn is calculated from the city's ecological footprint [70] in relation to the municipal area. The ecological footprint includes all agricultural and farming lands, forests and fisheries needed to: (i) produce the food, fiber and wood consumed in a given area; (ii) absorb the waste it produces; and (iii) provide space for infrastructure. Hence, the ecological footprint is calculated from the sum of the above three areas [76]. The ecological footprints for Spanish province capitals have been obtained from the Spanish Observatory of Sustainability (OSE) [76], which calculated the above-mentioned variables following the methodology of the Global Footprint Network, recommended for smaller areas than countries and which accounts for approximately 90% of consumption.

The measurement unit for the ecological footprints of Spanish province capitals is global hectares per person (ghp). A global hectare represents the productive capacity of one hectare of land in relation to the world average productivity [82]. We multiplied the ecological footprint per person by municipality population and divided it by its area. If the result is 1, it means that the consumption adjusts to the carrying capacity of the municipality, while a result higher than one indicated that the carrying capacity is overstepped. Population and the definition of municipal areas were obtained from INE [75] for 2014.

### 2.3.3. Spaces for Citizen Participation

*Spaces for citizen participation* were measured through an indicator of progress in Local Agenda 21 (LA21). LA21 is a citizen participation space where local stakeholders work on an Action Plan for sustainable development following the principles of the United Nations Agenda 21 and taking into account environmental, social and economic dimensions [83]. Although it is not centered on building urban resilience, the LA21 provides a space for communication between local government and citizen associations, creating networks, promoting learning, getting local problems closer to the government and getting local population involved in problem solving, so it fosters social cohesion and innovation.

The degree of development of LA21 was evaluated with OSE [76] data, which analyses the 11 main milestones of the Agenda: signing of the Aalborg Charter, signing of the Aalborg +10 Commitments, setting up a Local Agenda 21 Forum or another representative group of social participation, setting up institutional support structures, joining the Agenda 21 Network, preparing an assessment report, designing a system of indicators, designing an Action Plan, implementing the Action Plan, evaluating and revising the Action Plan and setting up participatory budgeting. The first two milestones were merged since both represent local government's commitment to LA21. Therefore, the indicator consists of a scale ranging from 0 to 10, where 0 means there is no Local Agenda 21 at all, and 10 indicates that the process has been fully implemented.

### *2.4. Normalization of Data, Weighting and Aggregation*

Our final indicator of urban resilience is composed of two sub-indexes, each measured by one or several indicators (Figure 2). The indicators were aggregated into sub-indices according to their positive or negative influence on urban resilience. In this way, we obtained a sub-index named self-sufficiency and another sub-index made up of the other four indicators—spaces for citizen participation, business diversity, land use diversity and food diversity—named capacity and diversity of response (Figure 2).

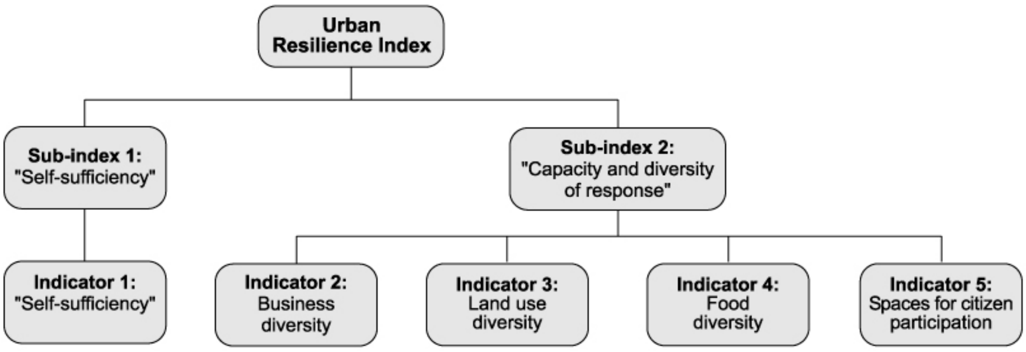


**Figure 2.** Urban resilience index structure.

In order to aggregate these four indicators into one sub-index, each indicator was re-scaled from 0 to 1 according to the following equation [63,72]:

$$\text{Indicator} = \frac{\text{real value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \quad (2)$$

Since we did not have information about which one of the indicators compounding the sub-index capacity and diversity of response has more influence on resilience, the convention adopted here for their aggregation was to give them the same weight [38,63,72]. Finally, the sub-indices were aggregated as a fraction, where the numerator consists of the sub-index capacity and diversity of response and the denominator consists of the sub-index self-sufficiency. In this way, the highest values of the urban resilience index are expected to match up with the most resilient municipalities. The equation used for the index is the following:

$$Resilience = \frac{H_{business} + H_{land\ use} + H_{food} + LA21}{EF/area} \quad (3)$$

where "$EF$" is the ecological footprint of the municipality in global hectares, "$area$" is the area measured in hectares, "$H_{business}$" is business diversity, "$H_{land\ use}$" is land use diversity, "$H_{food}$" is food diversity and "$LA21$" is Local Agenda 21 progress.

## 3. Results

The urban resilience index was applied to the 50 Spanish province capitals. The resilience values were re-scaled from 0 to 100 for a better comparison, in relation to the minimum and maximum values obtained (Table 3, Figure 3).

Our results show that most of the Spanish province capitals present low values of resilience, (Figure 3). According to our results, Cáceres, Cuenca, Albacete and Badajoz with resilience values over 50 are the most resilient province capitals in Spain (Table 2), followed by Córdoba, Teruel, Jaén and Ávila, whose resilience values are 48, 34, 27 and 23, respectively. The remaining Spanish province capitals present values lower than 20%, and 60% of the municipalities obtained values below 10.

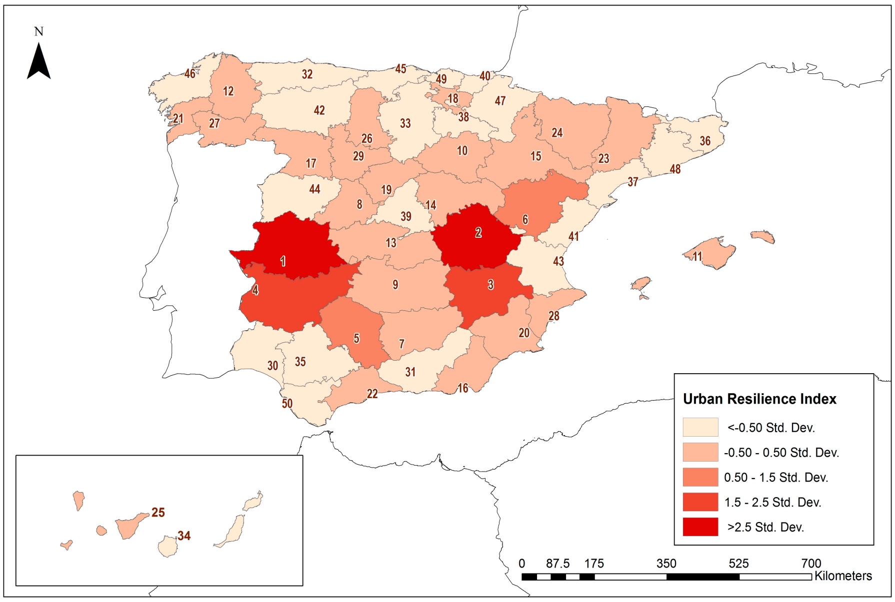


**Figure 3.** Urban resilience index results. The results have been classified following the standard deviation methodology from ArcGIS. Dark colors show high resilience, while light colors show weak resilience. Numbers on the map represent the Spanish province capitals' locations and their position in the resilience ranking (Figure 3).

**Table 3.** Urban resilience index and indicators' results.

| | Municipality | Resilience Index Value | Carrying Capacity Excess | Business Diversity (0–1) [a] | Land Use Diversity (0–1) [a] | Food Diversity (0–1) [a] | Local Agenda 21 Progress (0–1) [a] |
|---|---|---|---|---|---|---|---|
| 1 | Cáceres | 100 | 2 | 1.09 (0.54) | 1.51 (0.48) | 2.21 (0.42) | 0 (0.0) |
| 2 | Cuenca | 79 | 3 | 1.00 (0.50) | 0.64 (0.20) | 2.03 (0.39) | 3 (0.3) |
| 3 | Albacete | 64 | 7 | 1.15 (0.57) | 1.64 (0.52) | 3.52 (0.68) | 10 (1.0) |
| 4 | Badajoz | 56 | 5 | 1.06 (0.53) | 1.13 (0.36) | 3.91 (0.75) | 0 (0.0) |
| 5 | Córdoba | 48 | 9 | 1.11 (0.56) | 1.80 (0.57) | 2.71 (0.52) | 8 (0.8) |
| 6 | Teruel | 34 | 7 | 1.07 (0.53) | 1.50 (0.47) | 2.45 (0.47) | 0 (0.0) |
| 7 | Jaén | 27 | 9 | 1.30 (0.65) | 1.16 (0.36) | 1.60 (0.31) | 2 (0.2) |
| 8 | Ávila | 23 | 10 | 0.96 (0.48) | 1.29 (0.41) | 1.57 (0.30) | 1 (0.1) |
| 9 | Ciudad Real | 19 | 14 | 0.85 (0.42) | 1.27 (0.40) | 2.32 (0.45) | 3 (0.3) |
| 10 | Soria | 18 | 12 | 1.03 (0.51) | 0.75 (0.24) | 2.29 (0.44) | 1 (0.1) |
| 11 | Palma de Mallorca | 16 | 19 | 0.91 (0.46) | 1.65 (0.52) | 3.38 (0.65) | 3 (0.3) |
| 12 | Lugo | 16 | 18 | 0.90 (0.45) | 1.69 (0.53) | 1.64 (0.31) | 4 (0.4) |

**Table 3.** *Cont.*

| | Municipality | Resilience Index Value | Carrying Capacity Excess | Business Diversity (0–1) [a] | Land Use Diversity (0–1) [a] | Food Diversity (0–1) [a] | Local Agenda 21 Progress (0–1) [a] |
|---|---|---|---|---|---|---|---|
| 13 | Toledo | 15 | 21 | 0.85 (0.43) | 1.62 (0.51) | 3.22 (0.62) | 4 (0.4) |
| 14 | Guadalajara | 15 | 20 | 0.96 (0.48) | 1.24 (0.39) | 2.11 (0.41) | 5 (0.5) |
| 15 | Zaragoza | 13 | 32 | 0.98 (0.49) | 1.56 (0.49) | 3.54 (0.68) | 8 (0.8) |
| 16 | Almería | 16 | 22 | 1.21 (0.61) | 1.19 (0.38) | 2.14 (0.41) | 2 (0.2) |
| 17 | Zamora | 11 | 26 | 0.98 (0.49) | 1.62 (0.51) | 3.18 (0.61) | 2 (0.2) |
| 18 | Vitoria-Gasteiz | 11 | 38 | 1.00 (0.50) | 1.69 (0.53) | 2.83 (0.54) | 9 (0.9) |
| 19 | Segovia | 11 | 23 | 0.93 (0.47) | 1.42 (0.45) | 2.59 (0.50) | 1 (0.1) |
| 20 | Murcia | 10 | 41 | 1.15 (0.57) | 1.70 (0.54) | 2.73 (0.52) | 8 (0.8) |
| 21 | Pontevedra | 10 | 28 | 0.95 (0.48) | 1.52 (0.48) | 2.70 (0.52) | 2 (0.2) |
| 22 | Málaga | 9 | 46 | 0.90 (0.45) | 1.62 (0.51) | 2.92 (0.56) | 9 (0.9) |
| 23 | Lleida | 8 | 41 | 1.01 (0.50) | 1.44 (0.46) | 2.40 (0.46) | 7 (0.7) |
| 24 | Huesca | 8 | 25 | 1.11 (0.55) | 1.27 (0.40) | 1.59 (0.31) | 0 (0.0) |
| 25 | Santa Cruz de Tenerife | 6 | 36 | 0.68 (0.34) | 2.00 (0.63) | 1.94 (0.37) | 1 (0.1) |
| 26 | Palencia | 6 | 46 | 0.87 (0.43) | 1.58 (0.50) | 2.65 (0.51) | 3 (0.3) |
| 27 | Ourense | 5 | 58 | 0.86 (0.43) | 1.50 (0.47) | 2.28 (0.44) | 5 (0.5) |
| 28 | Alicante/Alacant | 4 | 54 | 0.83 (0.42) | 1.19 (0.38) | 2.81 (0.54) | 2 (0.2) |
| 29 | Valladolid | 4 | 87 | 0.86 (0.43) | 1.66 (0.52) | 2.74 (0.53) | 8 (0.8 |
| 30 | Huelva | 4 | 75 | 0.97 (0.49) | 2.06 (0.65) | 2.75 (0.53) | 1 (0.1) |
| 31 | Granada | 3 | 97 | 0.78 (0.39) | 1.71 (0.54) | 2.48 (0.48) | 8 (0.8) |
| 32 | Oviedo | 3 | 56 | 0.70 (0.35) | 1.74 (0.55) | 0.78 (0.15) | 2 (0.2) |
| 33 | Burgos | 3 | 105 | 0.92 (0.46) | 0.83 (0.26) | 2.49 (0.48) | 7 (0.7) |
| 34 | Las Palmas de Gran Canaria | 2 | 91 | 0.76 (0.38) | 1.22 (0.39) | 2.52 (0.48) | 1 (0.1) |
| 35 | Sevilla | 2 | 158 | 0.69 (0.34) | 1.62 (0.51) | 3.46 (0.67) | 8 (0.8) |
| 36 | Girona | 2 | 97 | 0.80 (0.40) | 1.66 (0.52) | 1.55 (0.30) | 2 (0.2) |
| 37 | Tarragona | 2 | 133 | 0.91 (0.46) | 1.72 (0.54) | 2.49 (0.48) | 3 (0.3) |
| 38 | Logroño | 2 | 126 | 1.02 (0.51) | 1.68 (0.53) | 2.67 (0.51) | 0 (0.0) |
| 39 | Madrid | 2 | 166 | 0.66 (0.33) | 1.47 (0.46) | 2.79 (0.54) | 6 (0.6) |
| 40 | Donostia/San Sebastián | 1 | 168 | 0.63 (0.31) | 1.43 (0.45) | 1.81 (0.35) | 8 (0.8) |
| 41 | Castellón de la Plana/Castelló de la Plana | 1 | 139 | 1.05 (0.53) | 1.32 (0.42) | 2.21 (0.42) | 2 (0.2) |
| 42 | León | 1 | 180 | 0.76 (0.38) | 1.88 (0.59) | 2.25 (0.43) | 6 (0.6) |
| 43 | Valencia | 1 | 195 | 0.82 (0.41) | 2.10 (0.66) | 3.21 (0.62) | 1 (0.1) |
| 44 | Salamanca | 1 | 225 | 0.90 (0.45) | 1.05 (0.33) | 2.64 (0.51) | 5 (0.5) |
| 45 | Santader | 1 | 261 | 0.73 (0.37) | 1.58 (0.50) | 0.31 (0.06) | 7 (0.7) |
| 46 | A Coruña | 0 | 308 | 0.79 (0.39) | 0.94 (0.30) | 2.06 (0.39) | 5 (0.5) |
| 47 | Pamplona/Iruña | 0 | 441 | 0.69 (0.34) | 1.61 (0.51) | 2.93 (0.56) | 8 (0.8) |
| 48 | Barcelona | 0 | 617 | 0.68 (0.34) | 1.56 (0.49) | 2.99 (0.57) | 8 (0.8) |
| 49 | Bilbao | 0 | 526 | 0.71 (0.36) | 1.62 (0.51) | 1.43 (0.27) | 7 (0.7) |
| 50 | Cádiz | 0 | 429 | 0.70 (0.35) | 1.79 (0.56) | 0.00 (0.00) | 2 (0.2) |

[a] The values in brackets are the values obtained after re-scaling.

Population density has a very strong influence on the obtained measures of resilience. Municipalities with the highest population density, such as Cádiz, Bilbao or Barcelona, are also the least resilient. Their municipal areas are almost completely urbanized [74], so, due to the lack of other ecosystems, their carrying capacity is highly exceeded. At the other end, the most resilient cities are those with the largest municipal areas, so population density is very low and they exceed their carrying capacity less than ten-times their municipal area. There are exceptions, and these include Zaragoza, Murcia and Madrid. Therefore, as a result of the great variation found in carrying capacity excess, resilience values have been determined by self-sufficiency. The most resilient province capitals largely correspond to those that exceed their carrying capacity less, due to their low population densities. The least resilient cities are those with high population densities and, hence, those that exceed their carrying capacity most strongly. The remaining indicators become useful when comparing municipalities that have similar carrying capacity limits.

Our results also show that Local Agenda 21 progress has greater influence on resilience than the diversity indicators, since its values range is higher. Hence, municipalities, such as Albacete, Córdoba, Zaragoza, Vitoria-Gasteiz, Murcia, Málaga, Lleida, Valladolid, Granada, Burgos, Sevilla, Donostia or Barcelona, climb in their positions in the resilience ranking due to the values of this indicator. Among the diversity indicators, food diversity values have a major variability than business and land use diversity and, therefore, a major influence on resilience values.

The most resilient municipalities are inland cities located in southern rural Spain [76], whereas all of the coastal municipalities have low values of resilience. We have not identified any other socio-demographic characteristics that could explain resilience results.

## 4. Discussion

### *4.1. Data Gaps and Methodological Limitations*

There is no single indicator, or set of indicators, that measures sustainability or resilience universally. Methodological assumptions and adopted conventions have a major influence on the results. Hence, our results should be interpreted in light of a number of data limitations and methodological assumptions.

The first limiting factor concerns the selected scale and sample of the urban resilience index. While for bigger areas, such as provinces, countries, statistical datasets are generally available, this is not always the case for municipalities. Having built the index to measure urban resilience for 50 Spanish cities, the urban resilience index is broadly applicable to the Spanish context, and it may be translatable to other geographical context, if the index is simplified. If we construct the index for a few case studies and some data are obtained through questionnaires or interviews, in the same way that some authors have measured social cohesion [44,50], then more indicators could be added. The lack of relevant information to feed the indicators is one of the biggest difficulties faced when we build composite indicators [72] and one of the main challenges we met while conducting this research. Factors that the literature identifies as influencing resilience, such as organized citizen groups, were omitted from the index when no information was available, potentially biasing the result. As this information becomes available, the proposed indicator of resilience could be gradually developed and refined, and the obtained ranking could change.

The development of the theoretical framework was based on what is desirable to measure and not what indicators are available [63]. Nonetheless, research on urban social-ecological resilience is a relatively new field in ecology [6,9], and hence, a consensus has not yet been reached about which factors have the most influence on resilience. Therefore, identifying and connecting the different factors that influence urban resilience proved a challenging task, potentially biased by the reach of the authors' knowledge and the reviewed literature.

A further limiting factor concerns the selection of the variables making up the urban resilience index and the indicators we used to measure such variables. Firstly, the scarcity of data about associations' diversity for a part of the sample, the low level of detail in the data of business diversity and the heterogeneity of their units of measure forced us to simplify the index. This was also the case for the indicator self-sufficiency. In the absence of data about biocapacity, that is the available biologically-productive land [84], at the local level, it was replaced by municipal area. Furthermore, the indicator spaces for citizen participation was limited by data availability. Here, we measured it by the indicator Local Agenda 21 process because it is a space for participation for which we have data. However, there are other programs and spaces that can also be relevant for urban resilience that we do not have taken into account, including, and often decisively, various informal networks compounded by numerous social movements that do not have even a legal entity and, hence, do not appear in statistical data. In addition, we lacked important data, such as the degree of participation, the number of stakeholders involved, the achievement of the objectives of the Action Plan or the effect of the communication campaign [76].

Decisions at the stage of developing diversity indicators also affect the results. If we modify the number of classes of each of the diversity indicators, we also modify the diversity values. In the case of business diversity, we have calculated the Shannon diversity index taking the four existing economic sectors: primary, production, construction and tertiary. This coarse level of detail involves limited variation of the obtained values. Hence, future research could consider a greater number of types of businesses. At the other end of the scale, when considering the indicator food diversity, we had access to data on a greater range of classes. This meant that we obtained a larger variability of results. Moreover, the Shannon diversity index assumes that the ideal situation, in the case of land use diversity, is that all of the land uses have the same area in the municipality, which is not necessarily the case. While diversity in land uses is beneficial for landscape resilience [27], the degree to which different relative weights of land classes within each municipality affect resilience depends on other factors, such as the availability of the specific needs of the municipality, the availability of those land classes in close areas and their interconnectedness with other areas, e.g., through trade. Built-up land, mines or quarries, crops, forests and wooded grasslands or wetlands all perform a function in the ecosystem and are the source of different ecosystem services. However, at what proportion each one is needed is something that is difficult to determine and depends, among other things, on the characteristics of the area.

The decisions made at the normalization, weighting and aggregation step also have a significant effect on the index and the results [63]. The four indicators that make up the sub-index capacity and diversity of response were re-scaled according to the minimum and maximum possible values. This allowed us to analyze the diversity values in the same way regardless of the number of classes of each one. Hence, the Local Agenda 21 progress indicator is responsible for the great variations of the sub-index capacity and diversity of response, since some of the values obtained for Local Agenda 21 match up with the minimum and maximum values, whereas this does not happen for diversity indicators because of their own characteristics. The way we made the re-scaling affects this result, but we believe that it is a realistic outcome, since the diversity variability among cities is really low, except for food diversity, whereas there is a huge difference between having developed all of the steps of the LA21 and not having even signed the Aalborg Charter. With regard to weighting, we adopted the convention that all of the indicators of the sub-index capacity and diversity of response have the same weight. Frequently, as in this paper, equal weighting is applied, especially when there are no solid arguments justifying the need to assess the indicator differently [38,63,72].

### *4.2. Interpretation of Results and Future Challenges*

Resilience is a major challenge for cities around the world [10], and as our results show, Spanish cities must make great efforts to increase their resilience. If urban resilience is to be enhanced, governments and societies should promote diversity, modularity and the tightness of feedbacks, reduce resource consumption, increase self-sufficiency and foster social cohesion and innovation.

However, due to the data gaps and methodological limitations exposed above, we must interpret the resilience results cautiously. A critical aspect is the influence of each of the sub-indices on the final values. The least resilient municipalities are those whose ecological footprint compared to their area is very big, while the most resilient largely correspond to those that less exceed their carrying capacity. This means that the sub-index self-sufficiency has a great effect on the urban resilience index, while the sub-index capacity and diversity of response is useful to distinguish municipalities with a similar carrying capacity excess. These results lead to the following question: is the ecological footprint indicator, when compared to the municipal area, the best indicator to measure the self-sufficiency of the urban ecosystem? To answer this question, it would be necessary to make clear if the administrative borders are a good indicator for this variable. Some authors argue that a city cannot be self-sufficient and resilient without acknowledging and accounting for their dependence on ecosystems from nearby or distant regions [28,85–87]. We measured resilience for municipalities, which include not only the urbanized area. However, administrative borders lack environmental meaning, and a better choice to measure urban resilience would be to consider the urban system embedded in a bioregion [88]. Comparing the ecological footprint of the city with the bioregion's biocapacity, taking into account other urban settlements in the area, allows us to analyze the urban rural-interface [76] and self-sufficiency of the urban system in a more realistic manner [85]. Furthermore, our indicator for carrying capacity excess did not take into account ecosystem services, taking for granted that if the city does not exceed its carrying capacity, it will not import or export any materials, and all of the ecosystem services it needs will be provided by itself, when regions are usually specialized and import materials, energy and resources from other regions or countries [89]. Nevertheless, no matter what method we are using to measure carrying capacity excess, some results would not vary too much. For example, big cities like Madrid or Barcelona would also obtain low values of resilience due to fact that their metropolitan areas are largely urbanized, while Cáceres, Cuenca, Albacete or Badajoz would still obtain high levels of resilience due to their rural context.

Diversity could also have a major influence on index results if we obtain data for organized citizen groups, but to what extent it would change our results is unclear. A possible hypothesis is that it would capture a high diversity of social organizations, but be weak in cities located in rural regions.

The geographical distribution of our results partially matches up with the results obtained through the urban vulnerability index developed by Méndez et al. [43]. A major part of the most vulnerable cities, following urban vulnerability index results, and some of the least resilient, following our results, are located in the Mediterranean coastal area, the metropolitan area of Madrid and the Galician west coast, while the least vulnerable and the most resilient are located in rural regions. Although the urban vulnerability index only takes into account the social-economical characteristics of the urban settlements [43], this result suggests that urbanization processes, linked to tourism and housing sectors and the bursting of the housing market bubble, had reduced urban resilience.

In spite of the limitations of the urban resilience index discussed above, the indicator to measure the resilience of urban ecosystems presented here offers an important basis for future methodological developments that can build on this work. Details in the methodological description and transparency regarding methodological assumptions in the calculation of the composite indicators make our study reproducible in the same or other areas, and the potential users can evaluate the strengths and weaknesses of the indicator [39,63]. The proposed urban resilience index could be gradually improved as the theoretical framework is refined and available data increase [63]. The proposed index can be improved by applying sensitivity and robustness tests [63,72] and using participative methods involving experts, politicians and users in defining the methodological assumptions to bring points of view closer, increase robustness and reduce biases [39,63]. This could broaden the acceptance and legitimacy of the indicator [35,72].

## 5. Conclusions

Maurice Strong, Secretary General of the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, stated that "the battle for sustainability will be won or lost in the cities of the world". Cities cause a big impact on the environment [28,71]. Promoting sustainability and resilience in human settlements must be a priority [6]. Indicators are a valuable tool to evaluate if we are progressing in a desirable way or we are pulling back from our objectives. It has been widely demonstrated that they are a useful tool to design public policies and support decisions [35,36]. Despite important progress in recent years, the existing methodologies to measure urban resilience only analyze it for specific disturbances or specific urban services from an engineering or ecological perspective, and in this paper, we have attempted to partially fill this knowledge gap.

We built a composite indicator to measure the resilience of urban ecosystems from a social-ecological perspective, a core concept of sustainability [22] that does not usually feature in sustainability indicators [58]. The urban resilience index proposed has been applied to the Spanish province capitals. The results show that most cities are far from being resilient, so a major effort to increase resilience must be done in urban areas. Measures such as reducing resource consumption, promoting local trade, creating citizen participation spaces or diversifying the local economy are needed to promote urban resilience.

The proposed index provides a first attempt to measure the resilience of Spanish cities. On the one hand, it offers a baseline against which the resilience of the selected Spanish cities can be assessed in the future in order to detect increases or decreases in resilience. On the other hand, it puts on the table a methodological proposal to measure urban resilience that can be used as the basis for future studies that can improve it in light of the methodological assumptions and data limitations discussed in this paper. For this reason, the methodology has been documented in detail so that it can be reproducible, applicable and modifiable according to the specific objectives of the user. We propose to evolve the urban resilience index as the theoretical framework of social-ecological resilience is improved and there is more quality data, as well as including experts and potential users in the building process, in order to develop ownership and relevance.

**Supplementary Materials:** The following are available online at www.mdpi.com/2071-1050/8/8/774/s1, Table S1: Socio-demographic and urban characteristics of the 50 Spanish province capitals.

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**Author Contributions:** Marta Suárez conceived of and designed the study, performed the research, analyzed the data and wrote the paper. Marta Suárez, Erik Gómez-Baggethun and Javier Benayas worked on the interpretation of the results and the discussion. Erik Gómez-Baggethun, Javier Benayas and Daniella Tilbury carried out the proofreading and restructured the paper. All authors read and approved the final manuscript.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| OSE | Observatorio de la Sostenibilidad en España (Spanish Observatory of Sustainability) |
| INE | Instituto Nacional de Estadística (Spanish Statistical Office) |
| LA21 | Local Agenda 21 |

## References

1. Brand, F.S.; Jax, K. Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. *Ecol. Soc.* **2007**, *12*, 23.
2. Davoudi, S. Resilience: A bridging concept or a dead end? *Plan. Theory Pract.* **2012**, *13*, 299–307. [CrossRef]
3. Vale, L. The politics of resilient cities: Whose resilience and whose city? *Build. Res. Inf.* **2014**, *42*, 191–201. [CrossRef]

4. Kim, D.; Lim, U. Urban resilience in climate change adaptation: A conceptual framework. *Sustainability* **2016**, *8*, 405. [CrossRef]
5. Folke, C. Resilience: The emergence of a perspective for social-ecological systems analyses. *Glob. Environ. Chang.* **2006**, *16*, 253–267. [CrossRef]
6. Chelleri, L. From the "resilient city" to urban resilience. A review essay on understanding and integrating the resilience perspective for urban systems. *Doc. Anàl. Geogr.* **2012**, *58*, 287–306. [CrossRef]
7. Blewitt, J.; Tilbury, D. *Searching for Resilience in Sustainable Development: Learning Journeys in Conservation*, 1st ed.; Routledge: London, UK, 2013.
8. Davoudi, S.; Brooks, E.; Mehmood, A. Evolutionary resilience and strategies for climate adaptation. *Plan. Pract. Res.* **2013**, *28*, 307–322. [CrossRef]
9. Meerow, S.; Newell, J.P.; Stults, M. Defining urban resilience: A review. *Landsc. Urban Plan.* **2016**, *147*, 38–49. [CrossRef]
10. UNDP. Sustainable Development Goals (SDGs). Available online: http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda/ (accessed on 5 May 2016).
11. Pickett, S.T.A.; Cadenasso, M.L.; Grove, J.M.; Boone, C.G.; Groffman, P.M.; Irwin, E.; Kaushal, S.S.; Marshall, V.; McGrath, B.; Nilon, C.H.; et al. Urban ecological systems: Scientific foundations and a decade of progress. *J. Environ. Manag.* **2011**, *92*, 331–362. [CrossRef] [PubMed]
12. UN. *World Urbanization Prospects: The 2014 Revision*; United Nations: New York, NY, USA, 2014.
13. IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Core Writing Team, Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014.
14. Mehmood, A. Of resilient places: Planning for urban resilience. *Eur. Plan. Stud.* **2016**, *24*, 407–419. [CrossRef]
15. Holling, C.S. Resilience and stability of ecological systems. *Ann. Rev. Ecol. Syst.* **1973**, *4*, 1–23. [CrossRef]
16. Pimm, S.L. *The Balance of Nature? Ecological Issues in the Conservation of Species and Communities*; University of Chicago Press: Chicago, IL, USA, 1991.
17. Gunderson, L.H. Ecological resilience—In theory and application. *Annu. Rev. Ecol. Syst.* **2000**, *31*, 425–439. [CrossRef]
18. Folke, C.; Carpenter, S.; Walker, B.; Scheffer, M.; Chapin, T.; Rockstrom, J. Resilience thinking: Integrating resilience, adaptability and transformability. *Ecol. Soc.* **2010**, *15*, 20.
19. Carpenter, S.R.; Arrow, K.J.; Barrett, S.; Biggs, R.; Brock, W.A.; Crépin, A.; Engström, G.; Folke, C.; Hughes, T.P.; Kautsky, N.; et al. General resilience to cope with extreme events. *Sustainability* **2012**, *4*, 3248–3250. [CrossRef]
20. Goldstein, B.E. Resilience to surprises through communicative planning. *Ecol. Soc.* **2009**, *14*, 33.
21. Spanish National Ecosystem Assessment. *Ecosystems and Biodiversity for Human Wellbeing. Synthesis of the Key Findings*, 1st ed.; Biodiversity Foundation of the Spanish Ministry of Agriculture, Food and Environment: Madrid, Spain, 2013.
22. Walker, B.; Salt, D. *Resilience Thinking. Sustaining Ecosystems and People in a Changing World*, 1st ed.; Island Press: Washington, DC, USA, 2006.
23. Levin, S.A. *Fragile Dominion: Complexity and the Commons*, 1st ed.; Perseus Books: Reading, MA, USA, 1999.
24. Hopkins, R. *The Transition Handbook. From Oil Dependency to Local Resilience*, 1st ed.; Green Books: Totnes, UK, 2008; pp. 54–57.
25. Scheffer, M.; Carpenter, S.; Foley, J.A.; Folke, C.; Walker, B. Catastrophic shifts in ecosystems. *Nature* **2001**, *413*, 591–596. [CrossRef] [PubMed]
26. Berkes, F.; Colding, J.; Folke, C. *Navigating Social-Ecological Systems. Building Resilience for Complexity and Change*, 1st ed.; Cambridge University Press: Cambridge, UK, 2003.
27. Elmqvist, T.; Folke, C.; Nystrom, M.; Peterson, G.; Bengtsson, J.; Walker, B.; Norberg, J. Response diversity, ecosystem change and resilience. *Front. Ecol. Environ.* **2003**, *1*, 488–494. [CrossRef]
28. Andersson, E. Urban landscapes and sustainable cities. *Ecol. Soc.* **2006**, *11*, 34.
29. Walker, B.; Holling, C.S.; Carpenter, S.R.; Kinzig, A. Resilience, adaptability and transformability in social-ecological systems. *Ecol. Soc.* **2004**, *9*, 5.
30. Adger, W.N. Social capital, collective action and adaptation to climate change. *Econ. Geogr.* **2003**, *79*, 387–404. [CrossRef]

31. Pretty, J. Social capital and the collective management of resources. *Science* **2003**, *302*, 1912–1914. [CrossRef] [PubMed]
32. Gómez-Baggethun, E.; Reyes-García, V.; Olsson, P.; Montes, C. Traditional ecological knowledge and community resilience to environmental extremes. A case study in Doñana, SW Spain. *Glob. Environ. Chang.* **2012**, *22*, 640–650. [CrossRef]
33. Biggs, R.; Westley, F.R.; Carpenter, S.R. Navigating the back loop: Fostering social innovation and transformation in ecosystem management. *Ecol. Soc.* **2010**, *15*, 9.
34. Ernstson, H.; van der Leeuw, S.E.; Redman, C.L.; Meffert, D.J.; Davis, G.; Alfsen, C.; Elmqvist, T. Urban transitions: On urban resilience and human-dominated ecosystems. *Ambio* **2010**, *39*, 531–545. [CrossRef] [PubMed]
35. Parris, T.M.; Kates, R.W. Characterizing and measuring sustainable development. *Ann. Rev. Environ. Resour.* **2003**, *28*, 13. [CrossRef]
36. Hezri, A.A.; Dovers, S.R. Sustainability indicators, policy and governance: Issues for ecological economics. *Ecol. Econ.* **2006**, *60*, 86–99. [CrossRef]
37. Singh, R.K.; Murty, H.R.; Gupta, S.K.; Dikshit, A.K. An overview of sustainability assessment methodologies. *Ecol. Indic.* **2009**, *9*, 189–212. [CrossRef]
38. Cutter, S.L.; Burton, C.G.; Emrich, C.T. Disaster resilience indicators for benchmarking conditions. *J. Homel. Secur. Emerg. Baseline Cond.* **2010**, *7*, 51. [CrossRef]
39. Bossel, H. *Indicators for Sustainable Development: Theory, Method, Applications*, 1st ed.; International Institute for Sustainable Development: Winnipeg, MB, Canada, 1999.
40. Briassoulis, H. Sustainable development and its indicators: Through a (planner's) glass darkly. *J. Environ. Plan. Manag.* **2001**, *44*, 409–427. [CrossRef]
41. Science for Environment Policy. *Indicators for Sustainable Cities. In-Depth Report 12*, 1st ed.; European Commission DG Environment by the Science Communication Unit, UWE: Bristol, UK, 2015.
42. Tonmoy, F.N.; El-Zein, A.; Hinkel, J. Assessment of vulnerability to climate change using indicators: A meta-analysis of the literature. *Clim. Chang.* **2014**, *5*, 775–792. [CrossRef]
43. Méndez, R.; Abad, L.D.; Echaves, C. *Atlas de la Crisis. Impactos Socioeconómicos y Territorios Vulnerables en España*, 1st ed.; Tirant Humanidades: Valencia, Spain, 2015. (In Spanish)
44. Adger, W.N. Social and ecological resilience: Are they related? *Prog. Hum. Geogr.* **2000**, *24*, 347–364. [CrossRef]
45. Ainuddin, S.; Routray, J.K. Earthquake hazards and community resilience in Baluchistan. *Nat. Hazards* **2012**, *63*, 909–937. [CrossRef]
46. Hiete, M.; Merz, M.; Comes, T.; Schultmann, F. Trapezoidal fuzzy DEMATEL method to analyze and correct for relations between variables in a composite indicator for disaster resilience. *OR Spectr.* **2012**, *34*, 971–995. [CrossRef]
47. Chan, S.-L.; Wey, W.-M.; Chang, P.-H. Establishing disaster resilience indicators for Tan-sui river basin in Taiwan. *Soc. Indic. Res.* **2014**, *115*, 387–418. [CrossRef]
48. Scarelli, A.; Benanchi, M. Measuring resilience on communalities involved in flooding Ombrone river. *Procedia Econ. Financ.* **2014**, *18*, 948–958. [CrossRef]
49. Siebeneck, L.; Arlikatti, S.; Andrew, S.A. Using provincial baseline indicators to model geographic variations of disaster resilience in Thailand. *Nat. Hazards* **2015**, *79*, 955–975. [CrossRef]
50. Wickes, R.; Zahnow, R.; Taylor, M.; Piquero, A.R. Neighbourhood structure, social capital, and community resilience: Longitudinal evidence from the 2011 Brisbane flood disaster. *Soc. Sci. Q.* **2015**, *96*, 330–353. [CrossRef]
51. Zaidi, R.Z.; Pelling, M. Institutionally configured risk: Assessing urban resilience and disaster risk reduction to heat wave risk in London. *Urban Stud.* **2015**, *52*, 1218–1233. [CrossRef]
52. Deshkar, S.; Hayashia, Y.; Mori, Y. An alternative approach for planning the resilient cities in developing countries. *Int. J. Urban Sci.* **2011**, *15*, 1–14. [CrossRef]
53. Prashar, S.; Shaw, R.; Takeuchi, Y. Assessing the resilience of Delhi to climate-related disasters: A comprehensive approach. *Nat. Hazards* **2012**, *64*, 1609–1624. [CrossRef]
54. Joerin, J.; Shaw, R.; Takeuchi, Y.; Krishnamurthy, R. The adoption of a Climate Disaster Resilience Index in Chennai, India. *Disasters* **2014**, *38*, 540–561. [CrossRef] [PubMed]

55. Kusumastuti, R.D.; Husodo, Z.A.; Suardi, L.; Danarsari, D.N. Developing a resilience index towards natural disasters in Indonesia. *Int. J. Disaster Risk Reduct.* **2014**, *10*, 327–340. [CrossRef]
56. Bozza, A.; Asprone, D.; Manfredi, G. Developing an integrated framework to quantify resilience of urban systems against disasters. *Nat. Hazards* **2015**, *78*, 1729–1748. [CrossRef]
57. Green, T.L.; Kronenberg, J.; Andersson, E.; Elmqvist, T.; Gómez-Baggethun, E. Insurance Value of Green Infrastructure in and Around Cities. *Ecosystems.* **2016**, in press. [CrossRef]
58. Milman, A.; Short, A. Incorporating resilience into sustainability indicators: An example for the urban water sector. *Glob. Environ. Chang.* **2008**, *18*, 758–767. [CrossRef]
59. Pierce, J.C.; Budd, W.W.; Lovrich, N.P., Jr. Resilience and sustainability in US urban areas. *Environ. Politics* **2011**, *20*, 566–584. [CrossRef]
60. Kuznecova, T.; Romagnoli, F.; Rochas, C. Energy metabolism for resilient urban environment: A methodological approach. *Procedia Econ. Financ.* **2014**, *18*, 780–788. [CrossRef]
61. Mugume, S.N.; Gomez, D.E.; Fu, G.; Farmani, R.; Butler, D. A global analysis approach for investigating structural resilience in urban drainage systems. *Water Res.* **2015**, *81*, 15–26. [CrossRef] [PubMed]
62. Sharifi, A.; Yamagata, Y. A conceptual framework for assessment of urban energy resilience. *Energy Procedia* **2015**, *75*, 2904–2909. [CrossRef]
63. Nardo, M.; Saisana, M.; Saltelli, A.; Tarantola, S.; Hoffman, A.; Giovanni, E. *Handbook on Constructing Composite Indicators: Methodology and User Guide*; OECD Statistics Working Papers 2005/03; OECD Publishing: Paris, France, 2005.
64. Krausmann, F.; Gingrich, S.; Eisenmenger, N.; Erb, K-H.; Haberl, H.; Fischer-Kowalski, M. Growth in global materials use, GDP and population during the 20th century. *Ecol. Econ.* **2009**, *68*, 2696–2705. [CrossRef]
65. Alguacil, J. La Ciudad Emergente y Sus Síntomas. Available online: http://habitat.aq.upm.es/boletin/n24/ajalg.html (accessed 20 February 2015). (In Spanish)
66. Camagni, R. Incertidumbre, capital social y desarrollo local: Enseñanzas para una gobernabilidad sostenible del territorio. *Investig. Reg.* **2003**, *2*, 31–47. (In Spanish)
67. Alguacil, J. Política nacional y políticas locales: Los supuestos de la solidaridad. *Polis Rev. Univ. Boliv.* **2004**, *7*, 239–263. (In Spanish)
68. Mulgan, G.; Tucker, S.; Ali, R.; Sanders, B. *Social Innovation. What It Is, Why It Matters and How It Can Be Accelerated*, 1st ed.; The Young Foundation: London, UK, 2007.
69. Wiedmann, T.O.; Schandl, H.; Lenzen, M.; Moran, D.; Suh, S.; West, J.; Kanemoto, K. The material footprint of nations. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 6271–6276. [CrossRef] [PubMed]
70. Rees, W.; Wackernagel, M. Urban ecological footprints: Why cities cannot be sustainable—And why they are a key to sustainability. *Environ. Impact Assess. Rev.* **1996**, *16*, 223–248. [CrossRef]
71. Folke, C.; Jansson, A.; Larsson, J.; Costanza, R. Ecosystem appropriation by cities. *Ambio* **1997**, *26*, 167–172.
72. Schuschny, A.; Soto, H. *Guía Metodológica. Diseño de Indicadores Compuestos de Desarrollo Sostenible*, 1st ed.; United Nations: Santiago de Chile, Chile, 2009. (In Spanish)
73. Caja España-Duero. Obra Social. Available online: http://www.cajaespana-duero.es/obrasocial/asistencia-social-y-sanitaria/estudios-sociales/index.aspx (accessed on 20 April 2016). (In Spanish).
74. Ministerio de Fomento. *Capitales & Ciudades +100. Información Estadística de las Ciudades Españolas 2010*, 1st ed.; Ministerio de Fomento: Madrid, Spain, 2011. (In Spanish).
75. Instituto Nacional de Estadística (Spanish Statistical Office). Available online: http://ine.es/en/welcome.shtml (accessed on 20 April 2016).
76. Observatorio de la Sostenibilidad en España. *Sostenibilidad Local: Una Aproximación Urbana y Rural*, 1st ed.; Mundi-Prensa: Madrid, Spain, 2008. (In Spanish).
77. Bolund, P.; Hunhammar, S. Ecosystem services in urban areas. *Ecol. Econ.* **1999**, *29*, 293–301. [CrossRef]
78. Barthel, S.; Isendahl, C. Urban gardens, agricultures and waters management: Sources of resilience for long-term food security in cities. *Ecol. Econ.* **2013**, *86*, 215–225. [CrossRef]
79. Pickett, S.T.A.; Cadenasso, M.L.; Grove, J.M. Resilient cities: Meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landsc. Urban Plan.* **2004**, *69*, 369–384. [CrossRef]
80. Rueda, S. *El Urbanismo Ecológico*, 1st ed.; Agencia de Ecología Urbana de Barcelona: Barcelona, Spain, 2011. (In Spanish)

81. Gómez-Baggethun, E.; Gren, Å.; Barton, D.; Langemeyer, J.; McPhearson, T.; O'Farrell, P.; Andersson, E.; Hamstead, Z.; Kremer, P. Urban ecosystem services. In *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*, 1st ed.; Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P.J., McDonald, R.I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K.C., et al., Eds.; Springer: Dordrecht, The Netherlands, 2013; pp. 175–251.
82. WWF. *Living Planet Report 2010*, 1st ed.; WWF: Gland, Switzerland, 2010.
83. Casares, J.J.; Arca, J.C. Gestión estratégica de la sostenibilidad en el ámbito local: La Agenda 21 Local. *Rev. Galega Econ.* **2002**, *11*, 1–18. (In Spanish)
84. Ministerio de Medio Ambiente y Medio Rural y Marino. *Análisis de la Huella Ecológica de España*, 1st ed.; Ministerio de Medio Ambiente y Medio Rural y Marino: Madrid, Spain, 2007. (In Spanish)
85. Doughty, M.R.C.; Hammond, G.P. Sustainability and the built environment at and beyond the city scale. *Build. Environ.* **2004**, *39*, 1223–1233. [CrossRef]
86. Elmqvist, T.; Fragkias, M.; Goodness, J.; Güneralp, B.; Marcotullio, P.J.; McDonald, R.I.; Parnell, S.; Schewenius, M.; Sendstad, M.; Seto, K.C.; et al. Stewardship of the biosphere in the urban era. In *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*, 1st ed.; Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P.J., McDonald, R.I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K.C., et al., Eds.; Springer: Dordrecht, The Netherlands, 2013; pp. 719–746.
87. Montes, C.; Gutiérrez, M.D. Ciudades resilientes en el atropoceno: Mito o realidad. *Ciudad Territorio* **2015**, *183*, 9–22. (In Spanish)
88. Van den Bergh, J.C.J.M.; Verbruggen, H. Spatial sustainability, trade and indicators: An evaluation of the "ecological footprint". *Ecol. Econ.* **1999**, *29*, 61–72. [CrossRef]
89. Sastre, S.; Carpintero, O.; Lomas, P.L. Regional material flow accounting and environmental pressures: The Spanish case. *Environ. Sci. Technol.* **2015**, *49*, 2262–2269. [CrossRef] [PubMed]