Bridging the Gap: The Measure of Urban Resilience

Original
Bridging the Gap: The Measure of Urban Resilience / Brunetta, Grazia; Faggian, Alessandra; Caldarice, Ombretta. - In: SUSTAINABILITY. - ISSN 2071-1050. - ELETTRONICO. - (2019), pp. 1-112.

Availability:
This version is available at: 11583/2791414 since: 2020-02-11T16:43:50Z

Publisher:
MDPI

Published
DOI:

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Mapping Urban Resilience for Spatial Planning—A First Attempt to Measure the Vulnerability of the System

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Received: 21 March 2019; Accepted: 11 April 2019; Published: 18 April 2019

Abstract: The concept of ‘resilience’ breaks down silos by providing a ‘conceptual umbrella’ under which different disciplines come together to tackle complex problems with more holistic interventions. Acknowledging the complexity of Davoudi’s approach (2012) means to recognize that ‘spatial resilience’ is influenced by many phenomena that are difficult to measure: the adaptation and transformation of a co-evolutive system. This paper introduces a pioneering approach that is propaedeutic to the spatial measure of urban resilience assuming that it is possible to define a system as being intrinsically vulnerable to stress and shocks and minimally resilient, as described by Folke in 2006. In this sense, vulnerability is counterpoised to resilience, even if they act simultaneously: the first includes the exposure to a specific hazard, whereas the second emerges from the characteristics of a complex socio-ecological and technical system. Here we present a Geographic Information System-based vulnerability matrix performed in ESRI ArcGIS 10.6 environment as an output of the spatial interaction between sensitivities, shocks, and linear pressures of the urban system. The vulnerability is the first step of measuring the resilience of the system by a semi-quantitative approach. The spatial interaction of these measures is useful to define the interventions essential to designing and building the adaptation of the built environment by planning governance. Results demonstrate how mapping resilience aids the spatial planning decision-making processes, indicating where and what interventions are necessary to adapt and transform the system.

Keywords: urban resilience; spatial planning; vulnerability; measuring; mapping; decision-making

1. Introduction

If we look at the international scientific debate around the concept of resilience and its relation with urban planning, also considering some practical experiences, the term creates a “conceptual umbrella” that provides a flourishing perspective for urban planning with a slippery and ambiguous definition [1,2]. This is the limit but also the strength of this concept that represents a metaphor to develop spatial policies of mitigation, adaptation, and transformation to the turbulences of the system [3]. As to what concerns the most cited approaches on urban resilience, two concepts emerge as paradigmatic: the co-evolutive perspective [4] and the multidisciplinary integration of knowledge that is necessary to assess the vulnerable and resilient capacity of a system [5]. Both approaches share the common assumption that urban resilience is a driver capable of steering the policies and the urban agenda of institutions, organizations, and social groups [6,7] towards a multi-level governance of urban systems to a long-period perspective.

The evolutionary definition of resilience provided by Davoudi (2012) is the one that explicitly refers to a co-evolutive condition of a system, and a challenge for planning. Therefore, the dynamic
non-equilibrium of a system is an opportunity to create knowledge and intelligence through learning capacity, robustness, adaptation, and transformation [8,9].

Particularly, the perspective of dynamic co-evolution is an approach derived from social sciences [10], which considers the resilience of a complex system as an evolutionary process of adaptation [11]. The implication of this definition in the urban planning agenda is that resilience becomes a normative concept for territorial systems and mainly refers to how a new approach to spatial development supporting the adaptation and transformation of the system could be traced. At the same time, spatial resilience implies that territorial systems continually self-organize and adapt in the face of ongoing and unpredicted changes [12].

In this view, a recent reflection on the theoretical development of a common background on the meaning of spatial resilience in planning has been deepened in the paper written by the Responsible Risk Resilience Centre (R3C) research group of Politecnico di Torino (the manuscript—in press—is entitled “Territorial Resilience: Toward a Proactive Meaning for Spatial Planning”). The work concludes that “territorial resilience” is an emerging concept that supports the decision-making process, identifying vulnerabilities while improving the development of urban transformations coupled with nature-based solutions [13].

It is agreed that urban resilience is characterized by a co-evolution, self-adaptiveness, and learning capacity; the question on how to operationalize the concept into urban planning procedures remains unsolved to the lack of empirical knowledge of how to measure the degree of resilience in a specific context [14,15].

This paper wants to move a step forward from these theoretical works in the operationalization of this concept, and particularly it works toward the application of a pioneering empirical model to measure the degree of vulnerability in a specific study. The assumption here is that measuring urban resilience is necessary in order to operationalize the concept into a more normative approach for urban planning that shifts from the pure descriptive/analytical assessment to the definition of a spatial support system that aids the definition of the transformation of the system in a long-term and co-evolutive manner. Main findings are referred to the capacity to construct a spatial and measurable knowledge of the vulnerable dimension of territorial systems to design land use plans that generate a resilient adaptation [16]. Results indicate that a composite assessment can indicate ‘where’ and ‘what’ kind of urban planning measures are suitable to reduce the vulnerability achieving the resilience of the system. Urban transformations range from ‘grey’ to ‘green’ infrastructures, adopting an integrated view of nature-based and technological solutions [17,18] according to contemporary resilience frameworks [19].

2. Measuring Vulnerability as a First Step to Resilience

Urban resilience has been measured both quantitatively and qualitatively with a predominance of indicator-based measurements that constitute the most considerable part of the research framework [3,20–22].

Measurement is mainly grounded on pre-emptive assessment, with an integration of multi-risk analysis and the qualitative study of governance models [23,24]. This specific knowledge is constructed in a GIS environment that creates local datasets to deliver maps of climate and risk vulnerabilities accounting for social, environmental, and economic components of the system [24–26].

In attempting to understand the spatial distribution of vulnerability in a system, a set of indicators were chosen as a proxy of the different group of variables (e.g., environment, land use, economy, and society) [27]. We approached structuring the GIS project to map vulnerabilities, taking into account the numerous limitations of an indicator based on quantitative or semi-qualitative measurements of a resilient system:

- Oftentimes, resilience is measured as the counter position of vulnerabilities and therefore the indicator-based quantitative methods do not lend to capturing intangible elements such as the social capital, power relations, partnership, and self-sufficiency that contradistinguish urban resilience;
even when vulnerability is measured with different methodologies, indicators of the state of the system are mixed up with an indicator of response (coping capacity), generating confusion and misleading interpretations;

the neglecting of a more self-adapting and governance capacity of the system in a proper measurement approach, namely ‘resilience’, may lead to ignoring the most important determinants factors that can lower the vulnerability of a system;

indicators are, in the vast majority of cases, non-spatial but purely statistical and therefore useful for a cross-comparative analysis of different urban areas but unhelpful to construct a spatial support system that steers the urban agenda of local institutions.

However, even with the abovementioned limitations, quantitative approaches offer a systematic and reliable way to measure the different dimensions of resilience. Therefore, the methodology hereafter synthesized is composed with some warnings in mind.

First of all, vulnerability and resilience should be measured with different approaches since vulnerability is the predisposition of exposed elements to being impacted by hazard events [27]. While resilience includes the governance of the system, including planning regulation at different levels and the decision-making framework [28,29]. Resilience also deals with education and early communication: a well-educated and informed population could react coping with the disaster risk while using and disseminating the knowledge of hazardous effects [30].

Currently, in a great number of studies, ‘vulnerability’ overlaps with ‘resilience’ where the ‘resilience’ refers to what is properly claimed to be the coping capacity. Such an approach creates confusion and misleading interpretations since the resilience is not an endogenous character of the system (like the coping capacity) and is instead a dynamic and co-evolutive character that depends on the post-disaster effects on socio-ecological and technological systems (SETS) [16]. On the other side, what in most resilience frameworks is properly called ‘vulnerability’, is the sum of a linear or nonlinear relation between sensitivity, exposure, and the coping capacity. Independently of which indicator is, or is not, present in a spatial evaluation of the vulnerable dimension of the system, what emerges is that vulnerability is the product of a systematic analysis of the state and pressures of the system, while the resilience is a condition that is influenced by the vulnerable dimension but it is not a part of it.

This is why vulnerability and resilience should be measured separately, taking into account that a resilient system is one where vulnerable elements are less present and the adaptive capacity is strongly acknowledged. Therefore, methodologies of measurement should consider this theoretical distinction. If vulnerability is much more prone to be measured with semi-quantitative indicators using spatial indexes, the measurement of resilience should account for a more qualitative and documental-based approach mixed up with a certain knowledge of the governance and barriers that make the system capable of adapting and transforming the territory in an effective manner.

Secondly, vulnerability has to be spatially measured including the sensitivity, where sensitivity is the predisposition of the system’s components to be affected by potential damages suffering harm as a consequence of endogenous conditions [15,31,32].

In this paper, a first attempt into the spatial measurement of vulnerability is presented using a GIS-based framework performed in ESRI ArcGIS 10.6 (Environmental System Research Institute, Redlands, CA, USA) environment as an output of the spatial interaction between sensitivities, shocks, and linear pressures of the urban system. The area of investigation is the Municipality of Moncalieri, Turin (Italy) that represents an optimal context for this study.

The spatial assessment of vulnerability is considered just the first step of measuring resilience of the system by a semi-quantitative approach. The spatial interaction of these measures is useful to define the interventions essential to building the adaptation of the built environment by planning procedures [1,19,33]. In the second chapter of this paper, the methodology of measurement is presented along with the kind of indicators used, while the Discussion and Conclusion sections present the significant findings and implication of this study.
3. Materials and Methods

The spatial assessment of vulnerability is the product of an interaction between sensitivities, disturbances, and shocks analyzed by three different components of the system (environment and ecosystem services; land use, infrastructures and heritage; economy and population). Indicators are mapped by the spatial representation of composite values by raster images with pixel values of sensitivities, disturbances and shocks (see the list of indicators in the Table 1).

**Table 1.** List of indicators of vulnerability.

| State of the System | Sensitivity | Source | Year | Unit |
|---------------------|-------------|--------|------|------|
| IMP                 | Imperviousness | Existent 2012 | %    |
| IFI                 | Ecological Fragmentation | R3C 2016 | %    |
| HQ                  | Habitat Quality | (InVEST) 2010 | %    |
| CS                  | Carbon Sequestration | (InVEST) 2010 | num |
| WY                  | Water Yield | (InVEST) 2010 | num |
| SH                  | Landscape Diversity | R3C 2010 | %    |

| Pressures on the System | Disturbances | |
|-------------------------|--------------|
| NDR                     | Nutrient Contamination | Kg nutrients * pixel/year (InVEST) 2010 | % converted in num |
| SDR                     | Erosion      | Tons eroded * pixel/year (InVEST) 2010 | % converted in num |
| CDS                     | Land Take    | Built up areas between 1990 and 2016 R3C 2016 | %    |

The categorization of indicators into groups of ‘components’ follows what has been done by previously published works on territorial resilience. From its definition [34] to its practical implementation in planning [35] the measurement of the vulnerability of the system has been analyzed using different criteria. To our knowledge, indicators are grouped in ‘components’ when referring to the main categories of social, economic and environment [36], into ‘resources’ when referring to capacities to react of the system (connections, services, natural resources, physical assets, economic assets, environmental assets, human assets, and social assets) [37], whilst ‘dimension’ and ‘sub-dimensions’ refer to analytical criteria existing on the system (environmental, social and economic, and their sub-dimensions of dynamism, robustness, efficiency, transport, and urban design) [38]. Within this background, our choice was to develop a simple and easy-to-comprehend framework composed of at least three main components that cover the abovementioned fields. Therefore, we optimize these approaches using a pragmatic categorization that matches the most essential ‘dimension’ of SETS: social aspects including economy, technological aspects including the infrastructures and the built-up heritage, and the environmental ones including the ecosystem service provisioning of the system.

The work here conducted focuses on a single component of vulnerability that is environment and ecosystem services. This decision is the effect of a sharp selection of a specific component of the system that is the ones linked with the ecological and environmental characteristics of the selected urban area.
The selection of the indicators has been the output of an accurate study of the two main operational references of resilience framework. The first is the “100 Resilient Cities” program of the Rockefeller Foundation that aims to measure urban resilience working across government departments; the second is the “Smart Mature Resilience” framework that directs all available resources toward well-defined goals to ensure city resilience development and planning. Both programs provide working reports and documents with the list of indicators used to measure the resilience of the system.

At this stage, since the interaction between the components of the system are not well defined, it was decided to develop a simple and understandable methodology that links together different spatial indicators. Moreover, since the interaction between different groups of indicators is not codified by a standard algorithm, the selection of a few indicators was necessary to reach a comprehension of the framework.

As early mentioned, indicators are grouped into three categories: sensitivity (state of the system), disturbances, and shocks (pressures in the system).

Sensitivities are constituted by the spatial distribution of indicators (index or absolute values) in each part of the territory that are randomly distributed and describe the actual condition of the environment and ecosystem services.

The pressures of the system (divided into disturbances and shocks) are constituted by the areas that are affected by external agents of the environment the determined its slow or sudden modification under linear circumstances (land take) or unpredicted events (shocks such as floods or fires) (see Figure 1).

Figure 1. Visualization of the cartographic representation of spatial indicators: (a) State indicator covers all the system indicating existing sensitivities (municipality); (b) Pressure indicators are distributes where the system is subjected to hazards, in that case from light grey to black there are the areas subjected to flooding events.

The spatial assessment of vulnerability is a product of an unweighted overlay (ESRI ArcGIS) of sensitivities, disturbances, and shocks.

The presented indicators (Table 1) refers to the component of natural asset (environment and resources) [38] that includes ecosystem services monitoring, the quality of landscape, and ecological
resources. Here, the most common and diffuse supporting and regulative services are mapped [39] (HQ, CS, WY) while a sharp selection of landscape ecology indicators is provided (IMP, IFI, SH). The selection includes the different threats to which these resources are affected by: NDR, SDR, and CDS for linear disturbances and IBO, ALU, and ALA to shocks. The selection of every single indicator follows the recent approach proposed by McPherson [40,41] which indicates the pathway to apply the ecosystem service mapping approach to design resilient cities. The selected indicators resulted in the available work conducted on ecosystem service mapping done by InVEST, and the available GIS vector material shared with the technical office of the municipality.

In the sections that follow the structure of each indicator is deepened. Indicators are the output of three different kinds of elaborations:

- “R3C” elaborations, when indicators are autonomously created by the Research Group of the Responsible Risk Resilience Centre, Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino (This work is the first output of the project “Measuring Resilience” initiated in early 2018, which aims to develop an operational framework to address urban resilience. The R3C Project aims at design and operationalize an interdisciplinary research methodology to implement resilience in regional and urban systems. The project has been used to set up an in-depth discussion around the epistemological knowledge of resilience by different theoretical scientific approaches and their practical applications through the operational research carried out by urban and regional planners, social scientists, anthropologists, engineers, historicist and ecologists);
- “Existent” indicators, that are the ones that were applied to the context without any kind of elaboration (despite clipping the pixel value in the context of analysis);
- Indicators that are the output of other mapping software, and particularly Integrated Evaluation of Ecosystem Services and their trade-off—“InVEST, ver. 3.4.4” of the Natural Capital Project.

3.1. Context of the Study

The City of Moncalieri, directly south from Turin, is part of the Metropolitan area of Turin (northwest Italy—See Figure 2). The municipality is located in the south-east axis that from the main town follows the Po river course along both the Turin-Placenza-Brescia and Liguria directions, in line with Alessandria and Genoa. The town has a population of 57,234 inhabitants (ISTAT, 2017) and consists of about 6200 buildings (as pointed out by the BDTre Digital Topographical Database of Piedmont Region). The city has been chosen for two main reasons: the proximity respect to Turin (which is bordering Moncalieri in the north-west side) which has influenced the development of this district of the metropolitan area that is not an isolated and autonomous system but a dense conurbation of approximately 60 thousand inhabitants, and the topography of the city, which is composed by a heterogeneous hilly topography with particular flat part subject to flooding.

Moncalieri territory has a quite diverse orography and consists of a flat part that develops mainly in the southern and western sectors of the municipal boundaries, and of the Po river basin that from the City of Moncalieri enters in Turin along the Turin hill ridge [42]. The settlement system has developed transversely to the north–south axis of the river, approaching to the hill that contradistinguishes the city of Turin. However, Moncalieri has also extensively expanded in the sloping northern part of the municipal territory, where settlements mainly distribute along the main streets that provide access to the Turin hill, also with high-density land uses [43]. This high accessibility and infrastructure level is precisely what determines Moncalieri peculiarity: the city is located at the entrance of the northern-Italian highway system and directly linked to the Turin beltway network. For this reason, the city has historically seen the development of large industrial areas, as the Vadò quarter, one of the largest in the metropolitan area. On the other hand, the Po River has historically represented a limit to the development of settlements. Thus, in summary, the geological, morphological, and hydrographic characteristics of Moncalieri make its municipal territory naturally susceptible to high levels of vulnerability.
Figure 2. Location of the context of study.

The analysis on the macro categories of land use, according to the regional digital topographic database of 2018 (see Table 2), indicates that 34% of the territory consists of the anthropic system (including urban green spaces and urban free spaces), 39% comprises agricultural land, while the woodland occupies 14% of the territory. A remaining part of extra-urban green areas covers the 4% of the territory; the infrastructure system occupies the 6% while bodies of water represent the remaining 3%. The anthropic system, although not representing the majority of land uses, covers a significant ecological and landscape impact. The rate of impermeable soil, calculated with the spatial interpolation of data from the high-resolution database built up area imperviousness (2012), is about 26%, but the comparison with the anthropic system (permeability index of anthropic soil), shows that approximately 78% of urban land is impermeable. This percentage expresses a remarkable critical level considering that in the stock of 1638 hectares of urban land almost the 80% consists of impermeable material and therefore it is exposed to complete soil degradation, the consequent increase in hydrogeological risk and surface run-off, depletion of ecosystem functions, and an increase of heat islands. The current urban plan (approved in 1997 and upgraded with several variations until the 2016 final version) is an instrument that has almost finished its building capacity. As the document review shows, the urban plan still has few zones that need to be completed, either through direct interventions with built-up permissions, or through new built-up expansion zones to design with new masterplans.

Table 2. Land use composition in Moncalieri

| Land Use/Cover Type | Surface (ha) | Land Use Index (%) |
|---------------------|--------------|-------------------|
| Antropic            | 1638.87      | 34.48%            |
| Agricultural        | 1838.60      | 38.68%            |
| Natural and Seminatural | 654.44  | 13.77%            |
| Other (green)       | 173.21       | 3.64%             |
| Infrastructures     | 294.33       | 6.19%             |
| Water               | 153.54       | 3.23%             |
|                     | 4752.99      | 100.00%           |
| Permeable           | 4752.99      | 100.00%           |
| Impermeable         | 3476.05      | 73.13%            |
|                     | 1276.94      | 26.87%            |
3.2. Sensitivity

As introduced earlier, sensitivities are made up of indicators that range from the landscape ecology to ecosystem services. Notably, in this work, six different indicators were selected:

- three indicators refer to the landscape ecology approach on environmental planning (IMP, IFI, and SH);
- three indicators refer to ecosystem services dimension (HQ, CS, WY);

Sensitivity here is calculated as the predisposition of environment and ecosystem services to be sensible to events due to intrinsic conditions that lead the inclination to suffer if the available resource will be destroyed. Therefore, values increase where the environment presents a good quality (thus it can be damaged by disturbances and shocks) and its ecosystemic functions are well-provisioned, too (Figure 3).

3.3. Normalization of Variables

Each indicator has been normalized in values that range from 0 to 1 and distributed in a homogeneous spatial unit of a pixel (210 sqm) using the ArcGIS Create Fishnet (Data Management Tool) of the local digital topographic database. Each indicator has been homogenized statistically and stylistically harmonized with the same range of colors form low to a high value.

3.3.1. Environment (IMP, IFI, SH)

IMP—Impermeabilization, that is the permanent sealing of topsoil due by asphalt, concrete, and other non-permeable construction materials, is the most diffuse and degrading effect of the urbanization process [44,45]. The impermeable surface of an urban area does not correspond to its entire dimension since urban areas are not completely sealed, therefore some urban systems are more sustainable of others since the permeability of urban areas can be considered a good proxy for the environmental condition of a built-up system. For this indicator, it has been employed the national sealing map available at www.consumosuolo.isprambiente.it that is the result of Copernicus High-Resolution Layer-Imperviousness Degree (2012) data. The indicator distributes in a pixel area of 5 m the information of land cover, where pixels with 1 value indicates a sealed area, while pixels with 0 value indicates an unsealed area.

IFI—Ecological fragmentation is an important indicator of the healthy condition of the ecological system since the isolation and the creation of patches into the ecological mosaic is one of the prominent threats for the ecological processes that regulate the environment [46]. IFI has been conceived, assuming that there is a spatial well-detailed knowledge of the network system that cuts the landscape continuity interrupting or degrading the potential connectivity. The fragmentation caused by the road network can be weighted according to the magnitude of the road system, generating a spatial index that displays the effective fragmentation of the ecomosaic.
Figure 3. Cont.
IFI has been calculated as follows

$$IFI = \frac{\sum (L_i \times O_i)}{AU} \quad (1)$$

where

- $L_i$ = length of the infrastructure.
- $O_i$ = coefficient of ecosystemic occlusion according to road ranking.
- $AU$ = surface unit (pixel surface 210 sqm).

The coefficient $O_i$ has been set according with some national references in the field, giving higher weights to highways and motorways and lower values to local streets:

- $O_1 = 1$ Highways, motorways, and railways
- $O_2 = 0.7$ national and regional streets
- $O_3 = 0.5$ urban streets
- $O_4 = 0.3$ local streets

This indicator has been autonomously created by the research group distributing the IFI value in the minimum spatial unit of a pixel and using the two layers 001156_el_str_2016, 001156_el_fer_2016 of the local digital topographic database.

SH—the landscape diversity index reflects how many different kinds of land uses there are in a minimum detected unit (pixel of 220 sqm), providing a distribution of the different components of the landscape where higher values reflect a richer heterogeneity of landscape patches in the observed unit \([47,48]\). This indicator is heavily used in landscape ecology to assess the species diversity or the ecological diversity in a specific area of investigation. It reflects how the landscape is composed of different patches that correspond to the land use polygons. The assumption here is that a mixed composition of the land uses that includes also anthropic areas helps to increase the quality of the landscape in general.
Land uses where analyzed using the Land Cover Piemonte of 2010, and the pixel calculation of the index has been done using the ArcGIS dissolve function (coverage tool).

3.3.2. Ecosystem Services (HQ, CS, WY)

As introduced, ES sensitivity has been evaluated using supporting and regulative ES [39,49]

HQ—The map of habitat quality has been employed as a proxy of biodiversity since high quality of habitats supports the development of all ecological functions [50].

The supporting ES of habitat quality has been produced using InVEST software. Habitat quality combines information on LULC and threats to generate maps that includes the degradations due to sources of habitat disturbances.

The model works assuming three input data:

- the spatial representation of the Land Use Land Cover distribution, that is a GIS raster map which includes the area of analysis, as well as a buffer zone that include potential threats;
- the spatial distribution of intensity of each individual threat in a GIS raster file with values between 0 and 1;
- a .csv table with threats data. This table contains all threats considered in the landscape weighting their impact;
- a .csv table of the sensitivity of LULC to threats. This table contains the specific sensitivity of each habitat to the considered threats.

Concerning the threats, they have been considered as a source of disturbance to the anthropic system, agricultural areas and road network, with a weighting factor for different kinds of streets: principal, secondary, and local.

The output of this model is a relative index (0–1) of the habitat quality in each LULC pixel. This model has been then transformed into a sensitivity map where higher sensitivities correspond to the area where habitat quality is higher and therefore most vulnerable to potential damages.

CS—The carbon sequestration is an ES related to the capacity of the soil of storing in the biomass and dead mass above and below ground to store CO$_2$. Ones that soil is sealed it lost its capacity to store the atmospheric carbon and therefore the storing capacity of soil influences the quantity of carbon that is present in the atmosphere. This ES has been mapped to model carbon storage and sequestration of InVEST that maps carbon storage densities to a different kind of LULC. The model maps the quantity of carbon sequestration that are produced by a csv. table of the four carbon pools: above ground, below ground, necromass, and the litter. Input data were based on the Italian National Inventory of Forests and Carbon Pools (INFC).

The output is a map where each LULC pixel contains the absolute amount of carbon stored per pixel.

WY—The water yield is an ES that refers to the water storing capacity depending on the structure and the physical structure of the ground and the aboveground vegetation. Changes of land use profoundly affect hydrological cycles affecting the evapotranspiration that is a primary function that modifies the water availability and microclimate conditions.

Moreover, the water yield is of primary importance for run-off regulation since this ES influences the capacity of the landscape to retain water from the surface, subsurface, and baseflow, determining the amount of pixel’s run-off calculated as the precipitation less the fraction of the evapotranspired water.

Inputs of this model are:

- Root restricting layer depth: the land capability classification took soil depth data with a scale of representation of 150,000.
- Precipitation: data were collected from the regional department for environmental protection (ARPA Piemonte. http://www.arpa.piemonte.it/rischinatorali/tematismi/clima/confronti-storici/precipitazioni/introduzione.html)
• Plant available water content: data comes from the SPAW Model for Agricultural Field and Pond Hydrologic Simulation. To obtain the specific data required by the SPAW Model the original land capability map was integrated with additional soil texture information provided by The Regional Institute for Plant and Environment (IPLA) at a reference scale of 1:250,000.

• Average annual reference evapotranspiration: values for each watershed were collected from the regional department for the environmental protection (watershed boundary dataset) http://www.scia.isprambiente.it/Documentazione/report2006.pdf Watersheds:

• The biophysical values in the attributes table were taken from references collected in the InVEST user’s guide and supervised by the National Institute for Environmental research and Protection—ISPRA.

The output used in this model is the annual average evapotranspiration per pixel in the landscape.

3.4. Pressures on the System: Disturbances

Disturbances are linear and predictable trends that affects the system gradually altering its condition. Therefore, are areas of the system that are affected by slow modification due to particular processes that affect sensitivities (Figure 4). As to what concerns the component of Environment and Ecosystem Services, the selected disturbances are composed by three indicators:

• Two indicators depend on soil ES: nutrient contamination—NDR that is an output of the model nutrient retention of InVEST; and the Erosion—SDR, that is an output of the model sediment retention of InVEST;

• One indicator refers to the landscape transformation due by the process of urbanization: the land take indicator—CDS represents the areas where the process of urbanization has been concentrated in the last years.
Disturbances

Figure 4. Spatial per-pixel representation of each indicator of disturbances.
NDR—the nutrient retention model of InVEST calculates the areas where diffuse pollutants flow into streams. The model routes the nutrients path along the environment. Mapping nutrient retention make clear the effects of anthropic activities on water quality [51].

Concerning inputs, this model shares the vast majority of inputs with the nutrient delivery model, plus the following:

- Average annual precipitation was calculated using the regional climate report of ARPA;
- Digital elevation model (DEM) is a raster file provided by Regione Piemonte by aerophoto Ice 2009–2011. The DTM covers the entire regional territory and it has a 25 sqm grid resolution.

SDR—Sediment retention model works towards the interaction of the digital elevation model and the soil characteristics computing the amount of the annual soil loss in each pixel, therefore calculating the soil loss that reaches the stream. This ES is pivotal since its account for one of the most dangerous and pervasive kinds of degradations that affect soils at different scales. This model has been used to map one of the most influent systemic pressures on the system since Moncalieri is partially built-up in the Turin Hill and has experienced in the last years some debris flows events due to intense rainfalls.

This model shares the vast majority of inputs with the nutrient delivery model. The rainfall erosivity index (R) indexes in the attributes table of the software were calculated using the biophysical values computed using the references parameters collected in the InVEST user’s guide [50] and supervised by the National Institute for Environmental research and Protection—ISPRA.

CDS—The land take indicator indicates the amount of new impermeable surfaces due to new urban areas [52,53]. This phenomenon is associated to the loss of the non-renewable resource of soil that is caused by the substitution of agricultural and natural/seminal natural land to artificial land. This process generates expansion areas in the landscape degrading the landscape and generating several environmental consequences [54–56].

The indicator has been autonomously elaborated by the diachronic comparison of different built-up layers in the Municipality of Moncalieri. The addition of new buildings has been monitored from 1990 to 2015, each building has been transformed into a point file, and using the ArcGis kernel density function (Spatial Analyst) (Tool).

3.5. Pressures on the System: Shocks

Shocks are unpredictable and dangerous events that threaten the system occasionally and with high impact for the environment, settlements, and populations. Shocks are intended as the major catastrophic events that the system has to absorb in case of adverse conditions. Shocks are unpredictable since their occurrence is viewed in a long-time period and, moreover, their effect is unpredictable too. To provide a spatial distribution of shocks, auxiliary maps of the public administration were consulted (flooded areas of 2016 and the map of fire risk taken by the civil protection plan) in order to obtain updated information (Figure 5).
Figure 5. Spatial per-pixel representation of each indicator of shocks.

Shocks are composed by three indicators:

- An indicator refers to the risk of fire IBO;
Two indicators ALU and ALA refer to meteo-hydrological related risks. ALU represent the spatial distribution of flooded areas in case of a catastrophic event while ALA represents the areas that are threatened by high run-off processes and therefore are affected by debris flows.

IBO—The spatial distribution of fires risk has been obtained by an autonomous elaboration that has been conducted using the methodological requirements of the Italian Civil Protection that is the selection of areas where buildings are less than 10 m from a forested area. This condition is evaluated as potentially dangerous in case of fire since these buildings are highly exposed to flames. The indicator has been created by ArcGIS Kernel Density (Spatial Analyst Tool) with a degree of risk that increases as much as there is a concentration of exposed buildings.

ALU—This indicator has been calculated using the ancillary map of the flooded areas of the event that occurred in 2016 that has been considered ‘catastrophic’ since the flooding overcomes for large parts the maximum exposed areas that the hydrological plan was originally considering. This event showed that the traditional single risk maps underestimate the potential effect of a natural hazard where the accumulation of causes generates a highly dangerous condition. Flooded areas were mapped by ranking the catastrophic effect of the flooding, thus the indicator maintains the scoring from 0 to 1 of the potential dangerousness in each pixel.

ALA—This indicator differs from the previous since the phenomena of intense rainfall can generate in the medium period a flood peak in the existent streams, but at the same time in the short period, the run-off along sloping areas often causes debris flows where the soil reaches the point of saturation. This is the case of hilly areas, but also the plain areas in low drainage soils that reach the saturation in case of heavy rain. This indicator has been created using the InVEST Nutrient Retention model that generates a preliminary intermediate output where each pixel of the landscape is affected by a run-off index. The upstream areas where selected and evaluated by a 0–1 indicator alongside the run-off streams.

3.6. Mapping the Vulnerability of the System

Once the sensitivities, disturbances, and shocks were mapped with the same parcel units the spatial overlay of each component has been employed to generate a final index of the overall evaluation of variables, where the vulnerability here is intended as the unweighted sum of sensitivities with the disturbances and shocks.

The map is the product of the per-pixel formula that follows

\[ Vul = Sen + D + S \]  

where

- \( Vul \) = vulnerability of the system
- \( Sen \) = sensitivity composed by a composite unweighted sum of IMP + IFI + HQ + CS + WY + SH
- \( D \) = disturbances composed by a composite unweighted sum of NDR + SDR + CDS
- \( S \) = shocks composed by a composite unweighted sum of IBO + ALU + ALA

The dark violet areas are the ones where the highly sensible pixels interact (are exposed to) linear pressures and unpredictable shocks (see Figure 4). Therefore, it is highly probable that from an environmental and ecosystem perspective, the system is subjected to disruptive effects in that parts, both in case of unpredictable natural hazards or long-time exposures to linear pressures that modify the state of the system. The probability that the environment will be threatened by climate-change-driven consequences in the violet areas is a piece of valuable information since it gives the possibility to comprehend the extent to which this system is vulnerable spatially and to which degree. This represents the first step into the experimental spatial measurement of the resilience of the system whereas the system is considered more resilient when is less vulnerable in a first attempt. In this view, resilience is the product of a combined reduction of vulnerability with and augment of adapting and coping capacity.
It is relevant to state that the Vulnerability is here produced by an unweighted overlay of indicators, meaning that there is no priority between the variables that are summed up to define the vulnerable parts of the system. We acknowledge that this is an essential limitation of this first empirical exercise, but we are opening the debate around this issue that is relevant to the final utilization of this pioneer and partial approach.

4. Discussion and Conclusions

4.1. Designing Adaptation: Where?

As demonstrated in the boxplot distribution of the composite sum of sensitivity, disturbances, and shocks (see Figure 6), values ranging from 0 to 1 (some outliers in shocks and disturbances are present due to unaccounted decimal values during normalization) displays how the average value of sensitivity is a decimal value above the disturbances and more than three decimal values above the shocks. This depends on the fact that disturbances and shock are concentrated in some parts of the municipality while sensitivities are spread in all the system, with lower clustering zones. The system, in that case, is generally sensible by itself without external factors that affect its condition. The dark violet vulnerable areas are the ones where the Vul value overcomes the 1.40 value and therefore a composure of Sens values over 0.7 overlays D over 0.65 and S over 0.4.

![Figure 6. Boxplot of sensitivities, disturbances, and shocks.](image_url)

The production of a composite overlaid map of vulnerabilities, as a product of the spatial interpolation of different indicators grouped as sensitivities, disturbances, and shocks, turned out to be significant for the following considerations and their relevance to better design the adaptation/transformation measures increasing the resilience of the system.

The distribution of dark violet areas is mainly concentrated in four priority areas (Figure 7):
The hilly development of Revigliasco (area 1) which comprises the landscape of natural and seminatural forested areas with the disperse and fragmented settlement system that is developed along the historical track, namely “Strada della Maddalena”. Here, a high vulnerability is particularly due to the probability that an event (fire) occurs destroying the rural and natural environment characterized by the presence of human settlements that are composed by detached and semi-detached houses with a high landscape and scenic quality.
The upper town development (area 2) along the panoramic routes that provides accessibility to the hilly semi-detached development that forms a continuum with the dense and highly developed ancient town center. This part of the system is characterized by high promiscuity between the natural landscape and the built-up system made up by villas and big private gardens and parks. In these areas, the development of the real-estate market for upper-class development of the city has been historically polarized and the vulnerability is characterized by the predominance of the land take disturbance over these areas;

The rural Po riverbed (areas 3 and 4) that is constrained between the A6 Highway Torino-Savona, the national ancient street that connects Torino (Nichelino) and Carignano, the railway, and the national road to Carmagnola. This part of the landscape preserves the character of a humid ecosystem only along the stripped riverbanks because it has historically subjected to a high process of urbanization and hydraulic regulation. The landscape comprises intensive seminative fields with dispersed settlements on the west side with orchards and some formerly productive sites. Here, the vulnerability is mainly due to shocks (flooding) that compromises the environmental and ecosystem integrity of the system and to highly sensitive parts of these areas that are sensitive to hydrological regimes.

The clustering analysis is a first attempt to define where specific actions to develop mitigation and compensation measure to pursue the adaptation of the system should be planned.

4.2. Designing Adaptation: What?

Resilient approaches rose to attention and became pivotal to introduce the vulnerable dimension of the system during the land use planning process. Nonetheless, they remain a weak approach if there is not an operational integration of the vast quantity of information that frames the assessment to support effective land use planning [57–59].

The above-presented spatial measurement of vulnerability of the system in a selected case-of-study area represents a first tentative to prioritize area of intervention to implement the transformation and the adaptation of the system.

The spatial measure of the vulnerability wants to overcome the analytical approaches that aim to define lists of city-performance indicators, thus becoming a tool that indicates where the system is vulnerable to potential hazards. The implication of this finding is that this measure should be implemented in the local analysis as a step towards the implementation of resilience, whereas resilience is further characterized by an additional capacity to cope with hazards by innovative governance solutions, adaptive and learning capacity, and adaptation.

The utilization of the map is crucial to define the kind (what) of interventions in urban areas that are necessary to lower the vulnerability of the system. Intervention ranges from the most commonly used ‘green’ nature-based solutions [60] to infrastructural ‘grey’ interventions. The bullet point that follows results from a first recognition of interventions categories that spans across a multitude of potential possible measures.

To what concern Moncalieri, some actions should be developed in vulnerable areas. In areas 3 and 4, preferable actions range from different measures to achieve flow regulation:

- planting green roofs or green walls to intercept rainfall;
- creating rain gardens/plaza reducing run-off;
- create underground water storage that increase the absorption capacity of urban areas;
- urban catchment forestry to retrofit sustainable urban tree cover to reduce flood risk;
- floodable parks to absorb flood peaks.

While the hill (areas 1 and 2) should pursue a de-sealing process with a rational regulation of the interconnection between natural areas and the built-up system.

- creating landscape connections with urban green space—trees, alleys, hedges, riparian vegetation;
- increase biodiversity within green areas, paying particular attention to the distance between forested areas and settlements to cope with fire risk;
• urban catchment forestry to retrofit sustainable urban tree cover to improve water supply;
• natural wastewater treatment to reduce drinking water consumption for irrigation.

These measures are just some of the solutions provided by the national guidelines to define the Adaptation to Climate Change—according to the Italian National Plan of Adaptation to Climate Change (PNCC, 2016)—that we purpose here as an operational methodology that links the assessment of vulnerability to the definition of a selected target of transformational measures. The selection mainly depends on two factors: the location of the vulnerability respect to the system and the kind of vulnerability that affects the system (see Section 4.1). Grey interventions, suggested in the plan, should be developed where technological, civil, and architectural projects are designed to retrofit, refresh, substitute, or re-develop the built-up system achieving a more efficient, sustainable, and resilient anthropic environment. Here, the National Adaptation Plan suggests implementing structural solutions in highly sealed contexts referring to the capacity of using the available technology to increase the ability of the built-up system to be more efficient in terms of energy consumption also absorbing the potential effects of common natural hazards such as flooding, heat islands, or earthquakes. Grey measures also include public interventions concerning sewage, electrical, and telecommunication systems, in order to augment the capacity of absorbing shocks providing an adequate communication system even in case of profound damages on buildings. On the other side, nature-based solutions are recommendable in peri-urban, rural, and hilly parts of the system where the greening and de-sealing are necessary actions to provide a higher regulative capacity of ecosystems to regenerate the environmental functions. Both green and grey interventions range from mitigative to long term adaptive solutions that transform the system to reach a measurable resilient condition.

5. Conclusions

The first step to achieve resilience is to reduce the vulnerability. In this study, a parcel-based analysis of the vulnerability has been spatially mapped in GIS environment using ArcGis ver.10.6 as the output of a spatial overlay interaction between many variables.

The design of a parcel-level composite index [61] introduces a significant step forward to developing urban policies aimed at incorporating the measure of vulnerability increasing the resilience of the system [62–64]. Composite indexes support the spatial development of sustainable policies, achieving a long-term benefit for people by connecting environmental values with socio-cultural and economic values [63,65,66]. Nonetheless, communicability of technical maps during the decision-making process remains a critical issue and if planners are not able to represent their information in a spatial and simplistic way [59,67–69] the utilization of the scientific assessment is weak.

This empirical study demonstrated that measuring the vulnerability of the system helped in the preliminary definition of a normative list of priorities in the urban agenda of the Public Administration of Moncalieri. The acknowledgment of the vulnerable dimension in the system provides a keen awareness that citizens are exposed to potential damages in the next years if some adaptations and transformation measures are not considered. Within the study, a first attempt to provide a scientific background in the definition of public interventions to increase the resilience of the system has been obtained. We are aware that this is a preliminary study and that the adaptation of the system includes measures of preparedness and response capacity that are not included in the list of actions here proposed. Nonetheless, we aim at integrating this study including the ‘soft’ measures that are the ones which are not referred to the physical transformation of the territory but depends on the innovation, governance, and self-adaptation of society to the vulnerable dimensions. Regarding this point, the first draft of action was considered to augment the resilience of the environment and ecosystem services:

• as regards the governance system, introducing local prescriptions that lead to propose natural parks and environmental protection zones in high habitat quality areas should be considered. Moreover, the re-design of the ecological network should consider much more the connections between primary ecological zones and the built-up environment. Strategic environmental assessment
for plans and projects should include the evaluation of ecosystem services and the efficiency of buildings and infrastructures introducing a monitoring system that provide an ongoing adaptation of policies and environmental strategies;

- regarding associations, fire vulnerability sheds light on the need to consider the activation of an inter-municipal consortium of forested areas that also includes active associations and citizens to promote conservation, monitoring, and emergency coordination in case of dangerous events;

- regarding the population, awareness, learning capacity, and innovation, the need to increase the perception of natural capital is an asset to develop and promote a diffuse preparation and the spread of initiatives aimed at improving the value of the territory and the needs to understand the vulnerability of the system. Teaching classes in primary schools while providing evening courses for workers and seniors are, among others, channels to promote knowledge of the territory that is fundamental to increasing the social resilience and the capacity of adaptability to dangerous events.

The experience here presented shows how to provide a first attempt to achieve the resilience of the system by increasing the knowledge of the spatial distribution of vulnerabilities. Such an approach includes the visualization of a final multilayered indicator \[70–73\] that is the product of a geostatistical procedure made by GIS analysis. Maps of sensitivities, disturbances, and shocks were used to overlay every single value and generate a spatial representation of vulnerabilities at parcel-level scale. The methodology has been conceived to be replicated in another context in the future since it has been structured by grouping different indicators in different components of the system. This means that, independently from the utilization of the same indicators (which depends on availability of data and the practicability of measures), the relation between sensitivities, pressures, and shocks measured in a GIS-spatial-gridded environment with an unweighted overlay procedure can produce a spatial representation of the vulnerable dimension of the system, aiding decision-making for applying resilience measures.

**Author Contributions:** Conceptualization, methodology, writing—review and editing, G.B. and S.S.

**Funding:** This research received no external funding.

**Acknowledgments:** This manuscript is a product of the project “Measuring Resilience” of the Responsible Risk Resilience Centre (R3C) of Politecnico di Torino (see \[http://www.r3c.polito.it\]). R3C is the first Italian research centre with specific goals of promoting adaptive and resilient strategies to address natural- and human-related risks, ensuring the safety of territorial and cultural heritage.

**Conflicts of Interest:** The authors declare no conflict of interest.

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The Multi-Risk Assessment Approach as a Basis for the Territorial Resilience

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Received: 18 March 2019; Accepted: 26 April 2019; Published: 7 May 2019

Abstract: The deep modifications to climate are currently provoking risks of increasing impact, that can cause unexpected consequences, interacting with other risks. However, the available planning regulations and instruments appear inadequate to face this challenge, most of all at a local scale. This paper presents a semi-quantitative methodology for the assessment of multiple risks, developed for the direct use of the municipality technicians, in order to increase their awareness towards multiple risks and unexpected events that could hit their territory. The methodology is based on the assignation of rates to the risks, and on a simple calculation of the binary interactions. It was tested on two Italian case studies, revealing a good feasibility in the results obtained for the interactions, and highlighting some problems neglected in the sectorial risk plans. The methodology is a background knowledge of the ‘Responsible Risk Resilience Center’ (R3C) of Politecnico di Torino, and it was furtherly developed through an in-depth analysis of the territorial vulnerabilities. This paper introduces two new indicators of sensitivity towards external risks, related to fire and flood risks, proposed for the application at a local scale. The indicators belong to a wider R3C framework in the phase of development to operationalize resilience.

Keywords: multi-risk; vulnerability; flood; fire; indicators

1. Introduction

The methodology for the semi-quantitative assessment of multiple risks at a local scale constitutes the background employed for the development of the framework and theories of the multidisciplinary research center of Politecnico di Torino ‘R3C’—Responsible Risk Resilience Center. The R3C Project aims at designing and operationalizing an interdisciplinary research methodology to implement resilience in regional and urban systems. Within the project, an in-depth discussion around the epistemological meaning of resilience in different fields of application has been set up, comparing the theoretical approaches and their practical applications derived from the operational research carried out by urban and regional planners, social scientists, anthropologists, engineers, historicists, and ecologists [1].

The R3C group adheres to the definition of resilience as “the capacity of the system—and of all its socio-ecological, technical, and infrastructural components—to preserve or rapidly return to basic functionalities, responding to turbulence and/or shocks, of adaptation to climate change, and to transform the subset of components which limit the present and/or the future evolution capacity” [2]. In particular, the emerging idea of “territorial resilience” is introduced, as a concept capable of supporting the decision-making process, together with the tool needed for identifying vulnerabilities and guiding the transformation of socio-geographical areas [3]. In order to operationalize the “territorial resilience”, it is essential to develop a framework for the measurement of the resilience itself. Measurement is
strictly related to the management of the risks impinging on an area, integrating the approaches of multi-risk assessment with climate modelling and the qualitative study of governance models [1].

The methodology described in this paper aimed at overcoming the common approach to risk analysis for single hazard factors [1], through the proposition of a multi-risk approach able to represent the mutual interaction of natural and anthropic stressors for the territory in a more useful view, for the development of an “operational resilience approach”. The methodology was expressly developed and tested for the application at a local scale, because local authorities are on the front-line in facing the consequences of shocks and territorial changes, and often they do not have adequate instruments to cope with them. In fact, in Italy, as an example, the land use planning is delegated to municipalities, that are responsible both for the emergency planning and land use strategies. The operative tools available to the municipalities are the City Plan and the Municipal Emergency Plan. The first one aims at regulating urban and land functions, adapting the needs of urban development to the natural specificities of the territory (geomorphological, hydrological, etc.). The second one sets up the operational activities, the materials, capacities, and means to deal with possible emergencies, on the basis of the existing sectorial risk analysis. Both the plans implement and apply planning measures derived from the superordinate sectorial plans (seismic, flood, etc.), but, even if they share the same basic indications, they are not mutually linked in terms of long-term risk management, adaptation, and increase of resilience [4].

As a consequence of this planning structure, municipalities currently deal with multiple risks, but they merely implement contents from superior plans, without analyzing or correlating them in a systemic way. Additionally, the management of risks in a separate way, with different procedures, timings, and methodologies, makes it difficult for the municipalities to have a clear and updated concept of the actual hazards that threaten their territories, most of all for those deriving from the mutual influence and interaction between risks.

Till now, no mandatory rules require municipalities to evaluate the combined effects of risks; but the increasing effects of the climate change, together with the lack of resources for preventive and protective interventions, highlights the need of advanced approaches and tools for the identification of the areas more exposed to risks and risk interactions, to optimize and better address the use of resources, and to improve the actions related to adaptation and mitigation strategies.

However, the available methodologies for multi-risk assessment could present some problems for the application at a local scale (see [5] for a complete literature review). On one side, they still suffer some criticalities that need to be settled out, for example, as highlighted by Garcia-Aristizabal and Marzocchi [6], there are huge difficulties on the definition of a common metric for loss assessment, and the weighting of the different categories of exposed elements. On the other side, sometimes “specialists in various fields studying risks have failed to produce results in a form that could be useful to planners” [7]. Many methodologies for multiple risks are based on quantitative techniques for risk analysis; even if this mathematically rigorous approach can seem the most reliable one, the application to real cases usually require great simplifications, mainly related to the difficulties in obtaining the detailed information needed. Additionally, the high specialization level of this type of methodologies makes them hardly manageable for local administrations, that can have a limited technical preparation, and in many cases cannot afford the expenses for detailed risk investigations.

In order to address the problems above-mentioned, multi-risk projects like MATRIX [8] adopted a multi-level strategy, introducing the most technical phase of the methodology only after a first simpler phase. Analogously, the objective of the authors was the implementation of an easy-to-use risk screening instrument, based on a simplified methodology like an index approach, to allow the municipalities to directly evaluate the risks and possible risk interactions that affect their territory. After this, the Municipalities could define possible further actions, including the adoption of more specific risk-assessment procedures, in accordance with superior local authorities (provinces, regions).

The following paragraph presents the methodology proposed for this screening path. This approach was adopted as a baseline for the identification of the vulnerabilities of the territorial system
and the measure of its resilience. As discussed in Section 3, a set of indicators of resilience are under development, able to estimate territorial vulnerabilities, and some of them are introduced in this paper.

2. Materials and Methods

2.1. A Semi-Quantitative Methodology at a Local Scale

The proposed methodology considers, in an integrated framework, the main risks on the territory and their possible interactions, in order to better orient further in-depth studies and interventions related to land use planning and emergency. Since the methodology was intended for a direct use from the municipalities’ technicians, it recovered the simplified scheme adopted for the Italian plans related to the industrial risk, called E.R.I.R.—Elaborato Tecnico per il Rischio di Incidente Rilevante (Technical Plan for Major Risk accidents), composed by:

1. Characterization of risks;
2. Characterization of the territorial and environmental vulnerable elements;
3. Assessment of the compatibility;
4. Planning phase (development of further studies and adaptation strategies).

The risks to be taken into account were chosen following the concept of the “spatial relevance” stated in the ESPON project [9]: only risks that regularly or irregularly interest the same territorial area should be taken into account, disregarding those that could take place everywhere. The methodology was developed for the risks more used in Italy: industrial, flood, and seismic risk, and, given the recent increase in extreme climatic events—violent rains, windstorms etc.—a climate related factor was also included. Each municipality should clearly consider also its main territorial criticalities, other than those included in the main model (i.e., volcanic risk, avalanches, wildfires, etc.).

A semi-quantitative approach was adopted, introducing a rating system common for all the main risks present on the territory. This type of approach, already employed in European projects [7] or regional methodologies [10], was chosen for its simplicity, which could allow its use also with low economical resources and technical skills. The adopted rating scale assumes different scores related to the possible impact of the risk/risks analyzed:

- $0 < I \leq 0.99$: Negligible;
- $1 < I \leq 1.99$: From low to moderate;
- $2 < I \leq 2.99$: From moderate to high;
- $I \geq 3$ onwards: From high to very high.

2.2. Characterization of the Risks

The first step of the proposed methodology consists of an in-depth analysis of the main territorial risks that insist on the territory of the municipality. An in-depth data collection has to be developed on the basis of existing sectorial plans, emergency plans, and through a direct investigation of the territory. In order to better understand and address the description of each risk, the risk characterization was based on three macro-categories, aimed at highlighting the characteristics of the analyzed risk which could mostly influence its dangerousness and its possible interaction with other events. The categories are:

1. SE—strengthening effects: Local characteristics able to increase the dangerousness (i.e., in case of seismic risk, the type of soil);
2. HE—historical and recent events: All the events related to the specific risk should be taken into account, to evaluate if the return times expressed by the overall plans are reliable;
3. PM—protection measures: The presence of protection and preventive measures could reduce the impact of the risk analyzed.

The ratings defined in Section 2.1 were assigned to each risk based on these three macro-categories; a guideline for the assignation of the scores was defined. Climate related events were introduced
and rated, but they were evaluated through a simplified approach, related to the global tendencies, because an analysis of the local trends could present difficulties related to the data collection and interpretation. Table 1 below shows the guide for flood risk; it analyzes the functioning of individual regulatory subsystems or elements, such as water intakes, pumping stations, the water distribution network [11,12], and the events that occurred on the territory, both those reported in the flood plans through probabilistic approach, and the recent occurred ones.

Table 1. Guiding table for the assignation of the ratings to the flood risk.

| Macro-Category          | Rating          |
|-------------------------|-----------------|
|                         | 1 < I ≤ 1.99    | 2 < I ≤ 2.99   | I ≥ 3 Onwards |
| SE: Strengthening effects | Interaction with other rivers/creeks with low or reduced criticalities; hydraulic devices in good state; no or few critical points (crossing and bridges with insufficient flow section; eroding or sliding banks/leveses; sudden section variations, etc.). | Interaction with other rivers/creeks and hydraulic control devices with moderate criticalities; identified critical points (see precedent column); the river/creek/etc. analyzed contains key element for the safeguarding of the general safety of the system. | Problematic interaction points with other rivers/creeks, recognized high critical areas, reported in flood plans (i.e., throttling points, areas interested by erosion etc.). Hydraulic devices in bad conditions, with recognized criticalities. |
| HE: Historical events   | Rare main flood events return time of flood management plans is confirmed (zones classified as C, Em, or Cn if recent events do not evidence different distributions/timing of the floods). | Floods of moderate impact, and/or in areas not included in plans, with a short return time (≥50 years) (zones classified as B, Eb, or Cp if recent events do not evidence different distributions/timing of the floods). | Events with return time > than that of the flood management plan worst zone (zones classified as A, Ec, or Ca if recent events do not evidence different distributions/timing of the floods). |
| PM: Protection measures | No water regulation artefacts/systems or insufficient number/way. Criticalities and inadequate safety level. | Water network/river/creek is properly controlled, the artefacts do not show relevant criticalities. | The management of the water network/river/creek is well coordinated, evidencing no criticalities. |

2.3. Risks Interactions

The macro-categories SE, HE, and PM are the basis to assess the possible impact of risk interaction, because they determine the risk role in a possible risk interaction and provide useful indications on the possible plausible effects. However, the macro-categories have different levels of influence on the interaction, and different reliability in terms of data; therefore, different weights were attributed to express this variability. The weights (HE = 2, SE = 1, and PM = 0.5) were designed to obtain results in line with the general scale employed in the methodology (see Section 2.1.) and were validated through experts’ judgement.

The binary risk interaction, intended as the impact a hazard factor could have on another one, should be assessed in the area of risk overlaying, where vulnerable environmental or territorial elements are present. The binary risk interaction is calculated through a weighted average of the values assigned to each category of the different risks, shown in Equation (1).

\[ I = \frac{[\text{HE}_{\text{risk1}} + \text{HE}_{\text{risk2}}] \times 2 + (\text{SE}_{\text{risk1}} + \text{SE}_{\text{risk2}}) \times 1 + (\text{PM}_{\text{risk1}} + \text{PM}_{\text{risk2}}) \times 0.5]{6} \quad (1) \]

A dedicated binary interaction table was developed in order to simplify the assessment of the possible interactions: the values assumed by each risk macro-categories in the analyzed point of the territory are reported in the table; when a possible risk correlation was encountered, the formula of Equation (1) was applied.
The values of interaction obtained through the Table can be also assessed directly through a GIS (Geographic Information System): each risk factor can be represented on a single layer; then, it is possible to directly obtain the georeferenced value of the integrated risk intersecting the risk layers and making use of the “calculator” field.

Table 2 shows an example of an interaction table: in this case, on the territory under study, a major risk chemical plant (I) was present and flood (F), earthquake (E), and extreme climate events (C) could occur. The table shows the values assigned to each macro-category and it returns the results of the mutual interaction between the risks, where relevant. In the specific case, interactions with moderate effects could occur; in fact, despite the high dangerousness of the Seveso plant (due to the huge quantity of substances stored, presence of vulnerable items, etc. (SE = 3)), the natural risks had quite low values. The seismic risk was unlikely in the area (HE = 1), even if the poor quality of soil could enhance the SEISMIC EFFECTS (SE = 2), while the flood risk had been dramatically reduced through an effective system of protection (PM = –3); as a consequence, the possible binary interactions obtained a low value, tending towards moderate.

Table 2. Example of binary interaction table.

| Impact | E | F | I | C |
|--------|---|---|---|---|
|        | SE | HE | PM | SE | HE | PM | SE | HE | PM | SE | HE | PM |
| E      | 2  | 1  | 0  | 1.5| 1  | –3 | 3  | 2  | –1 | 2  | 1  | 0  |
| HE     | 1  | 1  | 0  | 0.92| 1.75| No interaction |
| PM     | 0  | 1  | –3 | No interaction | No interaction | 1.42 | No interaction |
| F      | SE | 1.5| 1  | No interaction | No interaction | No interaction | No interaction |
| HE     | 1  | 1  | –3 | No interaction | No interaction | No interaction | No interaction |
| PM     | 0  | 1  | –3 | No interaction | No interaction | No interaction | No interaction |
| I      | SE | 3  | 2  | No interaction | No interaction | No interaction | No interaction |
| HE     | 2  | 1  | –1 | No interaction | No interaction | 0.92 | 1.75 | No interaction |
| PM     | 0  | 1  | –1 | No interaction | No interaction | No interaction | No interaction |

2.4. Vulnerability and Compatibility Assessment

The assessment of territorial and environmental vulnerabilities was based on the legislative indications of Ministerial Decree 09/05/2001 [13] and of D.G.R. 17/377 [14] for E.R.I.R. plan—plan for the safe planning of the areas around major risk plants. According to [13,14], the vulnerability is mainly identified as “exposure to the risks in terms of population”; the possible factors of sensitivity and coping capacity of the analyzed elements are not taken into account.

The proposed methodology recovered the classification of urban functions and strategic buildings in six different categories (see Table 3), assigned on the basis of the people density and mobility.
Table 3. DM 09/05/2001 territorial vulnerabilities.

| Category | Vulnerable Elements |
|----------|---------------------|
| A        | 1. Residential areas, with building ratio index > 4.5 m³/m²  
           2. Buildings hosting people with limited mobility (more than 100 people or 25 hospital beds); 
           hospitals, hospices, nursery schools  
           3. Outdoor places interested by a high presence of people, like markets or other commercial functions (more than 500 people) |
| B        | 1. Residential areas, with building ratio index from 1.5 to 4.5 m³/m²  
           2. Buildings hosting people with limited mobility (up to 100 people or 25 hospital beds); 
           hospitals, hospices, nursery schools  
           3. Outdoor places interested by a high presence of people, like markets or other commercial functions (up to 500 people)  
           4. Indoor places interested by a high presence of people, like shopping centers, business districts, hotels, universities, high schools, etc. (more than 500 people)  
           5. Places interested in limited periods by a high presence of people, for example, places for public entertainment and for cultural, sporting, and religious activities (more than 100 people for outdoor places, more than 1000 people for indoor places)  
           6. Railway stations (more than 1000 passengers by day). |
| C        | 1. Residential areas, with building ratio index from 1 to 1.5 m³/m²  
           2. Indoor places interested by a high presence of people, like shopping centers, business districts, hotels, universities, high schools, etc. (up to 500 people)  
           3. Places interested in limited periods by a high presence of people, for example, places for public entertainment and for cultural, sporting, and religious activities (up to 100 people for outdoor places, up to 1000 people for indoor places)  
           4. Railway stations (up to 1000 passengers by day). |
| D        | 1. Residential areas, with building ratio index from 0.5 to 1.5 m³/m²  
           2. Places interested by high presence of people once a month (e.g., local fairs, flea markets, events, cemeteries, etc.) |
| E        | 1. Residential areas, with building ratio index < 0.5 m³/m²  
           2. Industrial, artisan, agricultural, and livestock activities |
| F        | 1. Area inside the plant boundaries |

However, the assessment of the compatibility differed from that indicated by [13,14], because multiple risks had to be considered. Therefore, the assessment was based on a threshold of 2.5, corresponding to a medium impact tending towards high: If the ratings of risk interactions and of macro-categories SE and HE overcome the threshold in areas where A and B elements are included, a potential incompatibility is detected. This is a signal for the municipality that a further investigation on the area is needed, to prove the incompatibility and verify possible preventive and protective measures.

2.5. Planning

The last step of the methodology is dedicated to the studies and actions to be carried out to face possible incompatibilities. Two levels of actions are foreseen: The first step is an analysis in detail of the potential incompatible situations, both as far as it concerns the hazards and the vulnerabilities. If the incompatibility is confirmed, the second step, based on possible prevention and protection measures and interventions, could be prepared; in this last phase, the municipality will have to involve and cooperate with experts of several fields.

Some existing manuals and guidelines, diffused by the government or other public authorities [15–23] or settled by research groups [24–26], already provide useful indications for in-depth analysis and actions, but in many cases, they do not have binding value, and; therefore, are little known and applied. These indications were collected in dedicated tables, that can guide the municipalities in the choice of a correct approach to face problems related to multiple risks. Table 4 below reports an example of
further investigations that can be carried on related to flood and seismic risk, here referred to as Italian regulations and guidelines.

| RISK              | Measures                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Earthquake        | Draft of data sheets related to the constructive and seismic characteristics of the building [15], starting from the public buildings and infrastructures classified as A. For the archaeological and historical monuments, and protected landscapes: development of an in-depth analysis of structural and non-structural elements in compliance with [16]. |
| Flood             | For the buildings classified A and B, the characteristics of the pavement, walls etc. should be analyzed on the basis of the indication of [17]: i.e., ground level should be higher than that of the reference flood or levee height. For the bridges (linear element), it is recommended the compilation of the vulnerability sheet proposed by [18], an Operative manual on the hydraulic vulnerability of bridges. Case by case assessment of the specific vulnerabilities for the elements subjected to high influence. |
| Interactions      | The interactions between risks could cause an increase of the effects; in case the threshold of interaction is higher than 2.5, it could be useful to proceed with an in-depth analysis related to the probability of occurrence and the assessment of the spatial distributions of the possible effects. Involvement of experts with skills in matters of Seismic/flood and other hazards. |

2.6. A Step towards a Measure for the Resilience: The Definition of Vulnerabilities

As remarked in Section 2.4, the characterization of the vulnerabilities for the proposed methodology followed the simplified approach proposed by the Ministerial Decree 09/05/2001 [13]. This classification does not explore in-depth the intrinsic characteristics of the vulnerable element that contribute to its sensitivity or capacity to react and recover towards an external event, therefore the further investigation on the vulnerable elements were transferred to the last step of the methodology, the Planning.

The awareness of the need to develop a more detailed investigation on vulnerability was considered and developed in the wider context of the framework for the ‘Operationalization of resilience’ by R3C research Centre. In fact, one of the ongoing projects within the Centre refers to measuring the resilience of a territory, and its first step is the identification of indicators able to spatially describe the vulnerability of the territorial and urban system.

Indicators were defined for three main components of the system (Environment, Urban system, Population). With reference to the indicators related to Urban systems and building, general indicators able to express the sensitivity towards external pressure and events were settled, i.e., in relation to quality, function and age of the buildings.

In this context, the authors proposed specific risk-oriented indicators, developed to test the peculiar sensitivity towards the risks more recurrent in a determined territory. One of the guiding principles for the selection of these indicators was the availability and reliability of the data, in order to be able to provide quick elaborations and quick responses. In fact, the survey of specific vulnerability towards risks is often based on a deep level of investigation on site, that requires the compilation of data-sheets, the involvement of owners etc.; these long procedures sometimes can obstacle or even stop the correct application of plans and legislation. In example in Italy, the compilation of the basic level of the seismic vulnerability data-sheets required by [15] for the strategic public buildings required ten years more than those foreseen.

As far as it concerns Flood, a valid help to identify the factors of increment of the sensitivity was found in [17, 27, 28], that provide detailed lists of technical indications on the best characteristics that buildings should have to resist to a flood. However, these indications were rarely translatable
into helpful indicators at a local scale; firstly, they usually referred to new buildings, and not existing ones; secondly, they required a level of information too punctual (i.e., material composing pavements, presence of interspaces, specific use of the underground spaces, etc.), very difficult to be acquired in a reasonable period and without the cooperation of the building owners.

For this reason, only one possible parameter was selected from these literature resources and converted into an indicator: the height of the ground floor compared to the flood height. The expected flood height is usually known from the existing flood plans and the surveys of the events occurred, while the ground floor height is easily verifiable through Google street-view. Exposure being equal, this indicator of sensitivity can provide an essential information on the vulnerability of built landscape, because a ground floor used for residential purposes located under the max flood height is deeply more vulnerable with respect to other types of buildings and functions.

The second indicator here presented is related to Fire risks; in this case, the vulnerability towards a fire strictly depends on the characteristics of the building and of the vegetation cover in its close surrounds. An index considering 4 different factors of vulnerability towards risks is defined by [29], like i.e., type of materials employed for the roof and coating of the building, and some of these factors can be found also in [27,28].

The parameters most suitable to be applied at a local scale, because of the availability of information and spatial data, were the so-called ‘defensive space’ around the buildings and the slope. The defensive space is an area of 10 m around the building in which only grass should be present; if trees or bushes are included in it, they can increase the sensitivity of the building towards fire. The slope should be minor of 40%. Spatial data related to vegetation cover and slopes are available in regional archives.

3. Results

The proposed semiquantitative methodology, as described from Sections 2.1–2.5 was tested and applied to two Italian case studies that returned positive results in terms of soundness of the interactions detected, highlighting possible problems that were not clearly signaled or neglected by the risk sectorial plans.

I.e., one of the case studies considered was Mantua: on the Mincio river, in front of the ancient city that is an Unesco site, an important industrial hub rose in 1950. Two plants are still active and relevant for their dimensions and quantities of stored hazardous substances: a petrochemical plant and a warehouse of gasoline and diesel fuels. During the years, both the plants produced a serious situation of pollution, but despite of the proximity to the river, and the unexpected earthquake of 2012, the possible effects of the interactions between the industries and natural events were not taken into account in the official planning instruments of the city. The methodology was applied to find out if the risk-interactions could produce damages not analyzed in Mantua E.R.I.R. The values of interaction obtained through the interaction tables resulted between low and moderate (see Table 2, referred to the petrochemical plant), because of the initial low levels of the natural risk. These values were therefore employed to settle simulations of industrial damages with ALOHA® and HSSM®, that revealed possible criticalities both for the environment and the population. On one side, due to the quality of the soil, even a very small damage to the tanks caused by an external event could cause the penetration of pollutants in the underground aquifer, confirming why the pollution under Mantua plants is still ongoing today. On the other side, despite of the several protections adopted by the petrochemical plant and the warehouse, unexpected consequences could come from minor damages to the rail-tankers that bring the products to the plants; as shown by Figure 1 below, possible toxic releases could interest residential areas located alongside the railway.
Figure 1. Possible toxic releases of acrylonitrile or benzene due to a hole of 3 cm in the rail tanker, following a seismic event. The release can interest residential areas along the railway.

The second case study was related to a small city in Piedmont; it was repeatedly interested by floods due to a minor hydrographic network, not reported and analyzed in the regional Flood plan. Some Seveso plants were located in the town (see Figure 2), so that it was important to verify possible risk interactions.

Figure 2. Position of the plants and areas interested by floods (blue and light blue).

The following two tables (Tables 5 and 6) report the analysis developed for Plant B, a plant detaining an amount of hazardous substances that overcame the Seveso thresholds, but that was not compliant with the Seveso regulations. Plant B was hit by Flood in 1994, 2000 and 2008; the flood events however had a moderate impact, reaching the maximum height of 1 m. This initial moderate
value of the flood risk, combined with low value adopted for the Industrial macro-category H.E. in absence of certain information, produced a low interaction risk tending to medium (1.98).

**Table 5.** Plant B binary Interaction table.

| Impact → | Flood | Industry | Climate |
|----------|-------|----------|---------|
|          | SE    | HE       | PM      | SE    | HE       | PM      | SE    | HE       | PM      |
| F        | 3     | 2        | 0       | 2.8   | 1.5      | 1.8     | No interaction | 1.98 | No interaction |
| I        | SE    | 2.8      | HE      | 1.5   | PM 0     | No interaction | -     | No interaction |
| C        | SE    | 2        | HE      | 1.5   | PM -1.8  | 1.83    | 1.48   | No interaction |

Even if the Interaction values were moderate, the ratings assigned to some risk macro-categories overcame the threshold of 2.5, therefore the Compatibility analysis was carried out:

**Table 6.** Plant 'B' Compatibility and planning actions.

| RATINGS | Territorial Vulnerabilities Inside 500 m. | Environmental Vulnerabilities Inside 500 m. |
|---------|------------------------------------------|--------------------------------------------|
| Interaction | (1) C residential areas. 2 productive areas (E) destined for reconversion to commercial function, whose transformation should be monitored. | RV—water table depth < 3 m. Presence of a canal for irrigation adjacent to the northern of the plant |
| Industrial risk | SE 2.8, HE 1.5 | |
| Flood risk | (2) 2 punctual elements in B (commercial centre/bowling; church) | |
| SE 3, HE 2 | (3) Energetic lines | |

**Judgement of compatibility & possible further steps**

Potential incompatibility in case of toxic release with the two punctual elements classified as B (threshold for S.E. > 2.5). An in-depth analysis is recommended for: (1) the specific activities of the 2 vulnerable elements classified as B; (2) the storage methods and protection and preventive measures of the substances classified as TOXIC (H2)

The plant, detaining toxic substances and substances dangerous for the environment, is not compatible. S.E. = 2.8 overcomes the compatibility threshold; the interaction with flood events, even if connoted by a low-medium value (1.98), could enhance the threat. Further analysis on the possible pollution scenarios and prevention and protective measures against flood should be carried out.

Even starting from low level impact risks, some problematics related to the environment were identified (as shown by Table 6). The Municipality in this case should develop some further in-depth investigations.

The proposed approach provides the Municipalities with a quick and easy to use tool that can be developed almost completely with internal resources; the application of the methodology can be done by a work team composed by Municipal technicians and members of superior authorities or institutes (like Regions, Agencies for the Protection of the Environment, etc.). The work team proceed with the assignation of ratings, exploiting the major direct knowledge of the territory that usually the Municipality has, and then assess the risk interactions and the possible incompatibilities. The methodology aims at filling a gap in the existing planning and risk instruments, helping local planners
in find out the unexpected effects of multiple risks and providing an important indication on the priority areas to which address technical studies and financial resources.

The methodology constituted an important background for the development of the “R3C” framework, whose development is at an initial stage: The R3C research group is focusing on the development of spatial indicators able to describe the vulnerability of a territory, in order then to test and develop effective solutions to increase resilience and adaptation. In particular, the research group is currently working on the definition of indicators of vulnerability that are spatially meaningful and able to usefully describe the local vulnerability. The experience with the above-mentioned multi-risk methodology guided the authors in the definition of indicators of sensitivity strictly related to risks.

The indicators proposed in the context of R3C were identified and tested for the experimental case-study of Moncalieri, a town of medium dimensions nearby Turin, that constitutes an interesting case-study for its peculiarities. In fact, it presents both hilly and flat areas, crossed by the Po river and its tributaries, it owns an important historical heritage together with extensive industrial areas, and it is crossed by important transport and energy infrastructures.

The indicator “Height of the ground floor compared to the flood height”, mentioned in Section 2.6., was investigated and identified for the experimental case study of Moncalieri, that in 2016 was interested by a huge flood event that overcame the limits reported in the flood plan for catastrophic events. Following the rupture of a levee, the flood hit some quarters of Moncalieri never reached by floods, connoted by residential cottages of maximum of two floors. These areas were accurately investigated to identify all the buildings more sensitive to the flood because of the height of their ground floor. Figure 3 below shows the superimposition between the flooded areas and the residential building whose ground floor was below the flood height (1 m).

As far as it concerns the indicator related to fire risk, the area of Moncalieri more exposed is the hilly one: the defensive space of the buildings here located was investigated to identify the presence of trees or bushes. This data was spatially obtained though GIS, using the thematic regional map of the vegetable cover and verifying, for each building, a buffer zone of 10 m. The result of the investigation is shown in Figure 4.
pre-screening produced interesting results for the analyzed case-studies, evidencing possible negative vulnerability of buildings towards flood and fire. They identify important aspects of sensitivity towards external risks, and, at the same time, are quite reliable in terms of available information and spatial data. The insertion of specific indicators of vulnerability of residential buildings, but they could be applicable also to industrial buildings. However, in this case, a further investigation on the type of substances detained should be indispensable to verify possible effects and unexpected consequences of the impact of flood or fire.

A process of weighting will be soon carried out for all the R3C spatial indicators of vulnerability, in order to properly use them to give priorities to the most vulnerable areas.

4. Discussion and Conclusions

R3C adopted the concept of territorial resilience as the focus and objective of its research work: It expresses a novel concept of resilience, aimed at reconnecting the theoretical knowledge to a factual translation into spatial plans and projects. The implementation of resilience in a territorial system means reduction of vulnerability, the pursuit of social and institutional learning capacity, and the achievement of better territorial governance that increase the adaptation ability and reduce vulnerabilities [1]. The R3C research group is composed of several contributors, coming from different disciplines, both related to risks and land use planning; it promotes a multi-disciplinary approach that should generate feedback between assessment and territorial government, indicating and selecting sites where specific actions of mitigation, adaptation, risk reduction, or transformations should be implemented to reduce the vulnerability of the system.

This paper presents, on one side, a background contribution to the research carried out by R3C, and, on the other side, one of the outputs of R3C’s first stage—the research of feasible indicators of vulnerability for urban systems. The proposed semi-quantitative methodology for multi-risk pre-screening produced interesting results for the analyzed case-studies, evidencing possible negative events deriving from risk interactions; however, since the methodology requires a phase of in-depth studies to confirm and prove the consistency of the results, wider investigations on the vulnerabilities of the territorial system should be carried out. As mentioned in Section 2.4, at the moment the vulnerabilities are evaluated according to the Ministerial decree 09/05/2001 [13], but further analyses on the risk-specific sensitivity were needed: two indicators were proposed to quickly evaluate the vulnerability of buildings towards flood and fire. They identify important aspects of sensitivity towards external risks, and, at the same time, are quite reliable in terms of available information and spatial

Figure 4. Indicator of vulnerability towards fire: Red points signal buildings whose defensive space include trees or bushes. These buildings are more sensitive in the case of fires.

The indicators for sensitivity here presented could be valid not only to highlight the vulnerability of residential buildings, but they could be applicable also to industrial buildings. However, in this case, a further investigation on the type of substances detained should be indispensable to verify possible effects and unexpected consequences of the impact of flood or fire.
data. The insertion of specific indicators of sensitivity related to risks in a wider approach aimed at influencing the current practices of land use planning could represent an important advancement to obtain major preparedness and awareness at a local scale, obviously keeping in mind the final objective of increasing “territorial resilience”.

Beside the indicators here presented, the authors are currently working to develop indicators of sensitivity more strictly related to industrial areas and strategic infrastructures on the territory. Both these elements are connoted by a dual nature: On one side they are vulnerable towards external natural events, but at the same time, they can provoke damages to the population and urban functioning in case of failure and damage. For this reason, the authors are in the development phase of specific indicators related to: (1) the type of production and items correlated for industries; and (2) accessibility and redundancy for strategic infrastructures.

As far as it concerns the methodology for rapid risk pre-screening, some further refinements are in progress; in particular, a sensitivity test was carried out to verify the impact of subjectivity in the phase of the rating attributions, and possible corrective actions were proposed. The sensitivity test made clear that the interaction values that are more susceptible to variations consequent to the assignation of the rating are those closer to the limits between the intervals of the scale adopted (“low”, “medium”, “high”). In fact, in these cases, the variation of only one parameter of the risk macro-categories can determine an interval change; therefore, it can be said that these interaction values are those more exposed to discretion risks. In order to compensate for this result, a variation was proposed for the application of the methodology: In the case of interaction values near to the limit of the intervals, an attention threshold of ±0.25 could be adopted. This means that, for example, if the interaction value is 1.75, or 2.25, the user should know that this value could be particularly sensitive to uncertainties and thus discretion occurred during the rating phase; therefore, the results of the interaction tables could need some in-depth analyses [30].

Author Contributions: Conceptualization and writing, E.P.; Software, G.B.; Supervision and revision, M.D.

Funding: This research received no external funding.

Acknowledgments: We desire to acknowledge the scientific mutual enrichment in progress within the R3C—Responsible Risk Resilience Centre of Politecnico di Torino.

Conflicts of Interest: The authors declare no conflict of interest.

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Resilience and Sectoral Composition Change of Italian Inner Areas in Response to the Great Recession

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Received: 30 March 2019; Accepted: 5 May 2019; Published: 10 May 2019

Abstract: This paper focuses on the response of Italian inner areas to the Great Recession. Inner areas represent the majority of the Italian territory and are very heterogeneous in terms of (unstable) growth trajectories and industrial composition. One key issue that has partially hindered a thorough empirical analysis of the development paths of these areas so far, is defining these inner areas. To this aim, we adopt the recent classification proposed by the National Strategy for Inner Areas (2014), which identified six categories based on the travel distance from service provision centers. Our purpose is to analyze the potential structural change of inner vs non-inner areas in the face of the 2007–2008 economic crisis, assessing their adaptive capacity to the recessionary disturbance and the factors underlying their industrial composition change. We found that urban poles and inner areas had different abilities to re-adapt their local industrial compositions in response to the economic crisis with obvious effects on their future resilience.

Keywords: regional resilience; adaptive capacity; sectoral industry composition; urban vs. inner areas

1. Introduction

The body of academic contributions dealing with local and regional development has recently broadened to study the concept of regional resilience (i.e., how different regions respond and adapt to a wide array of external shocks). Seeking to understand the factors affecting the ability of a place to react to a more or less unexpected change inevitably begs the question of what influences its endogenous development, as well as what policy and governance structures are best in enabling and facilitating a positive change. One of the most intriguing facts is that while some areas manage to renew themselves, others start, or remain locked in, a path of decline.

Although many different notions of resilience have been proposed in recent years, resilience, broadly speaking, is simply meant as the ability of a socio-economic system to recover from a shock or disruption [1–8]. However, this concept has been fine-tuned, and three main interpretations of this ability to recover are now found in the literature [1,9,10]. The first one—also known as engineering resilience [11]—focuses on the resistance of a region to disturbances, and on the speed and extent of its recovery, where recovery is simply the return to the pre-shock equilibrium state or path. The second one—known as ecological resilience [11]—emphasizes the magnitude/size of the disturbance that a system can tolerate before it moves to a new state or equilibrium (i.e., it changes form, function or position). The third one—known as adaptive resilience—refers to the capacity of a system to maintain core performances, despite a shock, by adapting its structure, functions and organization to change, and hence bouncing forward. This view is quintessentially an evolutionary one. Following
Boschma [4], resilience, meant as the capacity of a region to sustain long-run development, is regarded as important as the capacity of a region to respond positively to short-term shocks. Therefore, this interpretation focuses on the long-term evolution of regions and their abilities to adapt and reconfigure their industrial and institutional structures. Our paper is an initial attempt to study both dimensions of resilience. Within the evolutionary perspective, we also extensively draw on the theoretical framework built by Martin and Sunley [9], who focus on the capacity of regions to change the evolution of their structural, organizational and behavioral characteristics as an answer to any kind of shock. Therefore, recovery is just one of the aspects of a multifaceted concept such as resilience. It simply considers the return to the pre-shock equilibrium state or path, without saying anything about the capacity of an economic system to adapt or move to a better development path than before the shock [9]. We partially disagree with the limitation of excluding regional reactions to adverse processes that cumulate slowly and incrementally over long periods of time from the theoretical framework on resilience. Indeed, shocks “are often closely intertwined with the unfolding of broader, longer run and slow-burn processes of change” [12] (p. 5).

The question of how resilience to a major shock interacts with long-term patterns of economic growth is intriguing, and is the main focus of our study. This interaction is at the core of why, for instance, the same major economic shock (at the national or international scale) can have highly spatially uneven local impacts, as in the great recessions of the early 1930s, early 1980s and early 1990s. Capello et al. [13] point out that even the last crisis was characterized by a high degree of spatial heterogeneity in terms of regional and local effects [14,15]. Many studies have dealt with the evaluation of regional resilience in different countries [1,4,9,13,16–29] in response to the Great Recession. Nonetheless, there is a paucity of studies that focus specifically on the role of changes to local industrial structures as a result of regional adaptation in coping with economic crises (see [30–33]). Furthermore, to the best of our knowledge, our paper is the first that aims to discuss the relationship between the Great Recession, sectoral composition change and peripheral areas.

In fact, what is interesting in focusing on peripheral areas with long-run negative growth trajectories is that this allows us to see if a sudden, unexpected shock, such as the 2008–2009 global financial–economic crisis, makes them reach a critical tipping point that makes incremental slow-burn economic changes all at once disruptive. The underexplored issue here is whether such slow-burn processes are accelerated by shocks, or whether they could be positively reversed by them. Martin et al. [31] suggest that the resistance of a national economy as a whole is counterfactual. Regions experiencing a larger fall in employment than the national economy would be deemed as being less resistant to the shock, while regions in which the fall is lessened would be regarded as being relatively resistant. Thus, the direction of industrial change (e.g., in line with the growth of the “national champions” or not) would be intended as a proxy of the capacity of peripheral areas to better respond to shocks.

With reference to the four-part question that the concept of resilience entails, in order to more accurately define the field and scope of investigation—following Martin and Sunley [9]—the “to what” dimension is particularly relevant. We examined resilience to an acute shock (the Great Recession) in areas affected by chronic slow-moving challenges [34], such as depopulation and ageing, economic decline, contraction of the provision of essential services, which tend to be corrosive to the adaptability capacity of places [12,35]. Economic shocks can be different in their nature, and hence, in their effects and implications for resilience.

If the “to what” is an economic crisis, as in our case, to build our analytical framework we can fruitfully rely on the four interrelated dimensions identified by Martin [1] to conceptualize the notion of resilience precisely in relation to recessionary or other such shocks, which we found very salient to our purpose. These are: resistance (the capacity of a regional economy to face disruptions, such as recessions), recovery (the speed and degree of bouncing back from such a disturbance), re-orientation (the extent to which the regional economy undergoes structural realignment or adaptation) and renewal (the degree of resumption of the growth path that characterized the regional economy prior to the shock). It is worth noting that these different aspects of regional economic resilience interact in different ways with each other, but also with the various factors and characteristics that shape a
region’s economic landscape. The economic structure of regions is commonly thought to play a pivotal role in shaping the resistance of places to recessionary shocks in particular [1], despite also affecting the speed and extent of the recovery. More specifically, a diverse and heterogeneous economic structure might provide greater regional resilience by allowing a greater resistance to the crisis, with resistance being assumed in this sense as the capacity to absorb potential sectoral unemployment through the re-distribution of the local workforce in other sectors. Investigating industrial local composition in terms of pro- and anti-trend sectors, with reference to national trajectories, could thus help in building knowledge on this specific aspect. As a potential outcome of future, follow-up research, this would help answer the fourth question inherent to the concept of resilience, which focuses on the “nature” of the recovery, exploring the direction of sectoral employment changes, the scale of shifts and whether they brought about a structural re-orientation of local economies over the long run (and if so, along which paths compared to national growing trajectories—see [31]).

Empirically, our analysis starts from the first dimension of resilience (resistance) [9] in order to gain some insight into whether a disturbance leads to rapid changes in a region’s economic structure. After the initial assessment of the degree of resistance, this paper moves onto: (i) other phases that are part and parcel of the very notion of resilience to economic crises, and (ii) the urban hierarchy exploiting the classification developed within the National Strategy for Inner Areas launched in Italy in 2014 (six categories from core to ultra-peripheral areas). The assumption is that the areas so defined could be functionally meaningful socio-economic entities, providing new pieces of knowledge on the topic, and ultimately unveiling the very determinants of the capacities of different places (in terms of their prior economic growth performances and structures) to react to a nationwide disruption. This answers the crucial “of what” question, since resilience clearly depends on the consistency and relevance of the geographical units used to delimit the local economies, which we will scrutinize through the lens of this analytical framework.

Inner areas are in fact economically weak areas, because of the long-term dynamics characterized jointly by population decline, aging, reduction in employment and scarcity of local public and private services, to a degradation of cultural and landscape heritage. Therefore, these areas are potentially very exposed to decline processes accelerated by the Great Recession. Nonetheless, in comparison with urban areas, inner areas show a temporal lag in response to the crisis [36,37].

Hence, this paper explores the short-medium term shock-induced change in the sectoral composition of Italian poles and peripheral areas following the Great Recession. In particular, we look at the trend of structural change across space in comparison with the national average. To this end, we are interested—following the methodological approach by Dauth and Suedekum [38]—in the relationship between local industrial composition along the urban hierarchy. We have classified Italian municipalities according to “pro-trend” (i.e., a direction of industrial change similar to that of the nation as a whole), “anti-trend” (i.e., a direction of industrial change opposite to that of the nation as a whole) or “not-significant” growth (i.e., no clear pattern of the direction of industrial change), and we will provide a detailed comparison of these groups. Our main results show that one of the impacts of the Great Recession on inner areas was to promote a change in the local industry composition even though their local industry composition was not in line with the nationally booming sectors. This could be an intriguing research avenues will lead to the identification of a possible re-
orientation or renewal of the inner areas of Italy in the face of a recessionary disturbance under scrutiny, possibly providing more general conclusions on the degree and nature of the resilience abilities of these areas, as well as on areas showing similar characteristics in other countries. In this sense, we look at the factors influencing a change in the economic base from one state (pro-trend/anti-trend) to another, if this were the case.

Ultimately, a follow-up of our work could contribute to filling the gap identified within the theoretical and analytical framework underpinning our study; namely, the impact that major shocks might have on long-run regional growth patterns, and thus whether disturbances could set in motion (positive) structural changes in a local economy.

Our results clearly point at a heterogenous response to the recessionary shock of urban poles and peripheral areas. Besides the relevance as a research question, from a policy perspective (especially for strategies intended to cope with uneven regional development which could be in part due to differential in resilience capacity, see [39]), this is extremely relevant to unveil the factors fostering a region’s recovery trajectory with a more favorable outcome, thus with a higher growth potential than its pre-shock trend and inform policy-making in the direction of more context-tailored strategies for preparedness to and recovery from economic disruptions.

This paper is structured as follows: Sections 2 outlines the data and methodology of the analysis; Section 3 describes the main results, which are further discussed in Section 4; and Section 5 concludes.

2. Data and Methodology

As discussed above, the impact of shocks on long-term growth is more deserving of study than has traditionally been recognized, a shortage acknowledged by various scholars [9,12,40]. Accounting for the evolutionary development path of places over time and disentangling the changes following a major shock brings about analytical and methodological challenges. This is due to the blurring between a single event and process-based change [12], as well as the recursive nature of the relationship between the features and structures of a region’s economic growth and resilience [9].

Being aware of this, our aim is to provide some insights on the effect of a discrete recessionary disturbance on areas that have been challenged by slow-burn pressures over a time span of almost seven decades (since the 1950s). Concerning the spatial units of our analysis, we relied on the classification produced by the National Strategy for Inner Areas (SNAI), which was launched by the Italian Minister for Economic Development in 2014. This allows us to focus on clearly identified areas that are very likely to have undergone negative path-dependence processes, locking them into a socio-economic decline. As stated in the official document of the strategy [41], many inner areas have faced a reduction in the man-made environments because of aging, depopulation [28,42–46], dwindling employment and use of territorial capital, coupled with a progressive decline in offers of local public and private services. Inner areas are interpreted as areas located at a considerable distance from centers providing essential services (namely education, health and transport). Methodologically, “service provision centers” were identified as those municipalities (A: urban poles of attraction) or groups of neighboring municipalities (B: intermunicipal poles of attraction) able to simultaneously provide a full range of secondary education, at least one emergency care hospital and at least one railway station providing metropolitan/regional journeys. The identification of these centers was followed by the classification of the remaining municipalities into four bands: (C) outlying areas; (D) intermediate areas; (E) peripheral areas and (F) ultra-peripheral areas. This was carried out using an accessibility indicator in terms of the number of minutes taken to get to the nearest hub. The bands were defined based on distribution of the distance in minutes: <20 min for outlying areas (C); 20–40 min for intermediate areas (D); 40–75 for peripheral areas (E) and >75 for ultra-peripheral areas (F). The last three classes (D, E and F) are labeled “inner areas” (see Figure 1).
Having defined the units of our empirical analysis, and the rationale for choosing them, we used one variable to proxy resilience: employment (no complex index) disaggregated by industry, according to the statistical classification of economic activities of the European Community, Nace (rev 2), which is provided by ISTAT (Italian National Institute of Statistics). We excluded from the analysis public and agriculture sectors as no reliable information was available for them.

The dataset provides information on employment at the municipal level (NUTS3 equivalent). In order to avoid excessive zeros and small number issues (such as high volatility over time), we focused on industrial activities at the two-digit level. Data cover a decade, from 2004 to 2014, which can be almost symmetrically split into a pre-recession (2004–2008) and post-recession (2009–2014) period.

The sectoral mix in the two sub-periods gives us a clear idea of the local level trends in industrial composition compared to the national trend. To this end, we drew on the methodology proposed by Dauth and Suedekum [38], which we found particularly useful for our purpose. We also built on a previous work of ours ([46]; see Step 1 and 2, see below).

Our empirical strategy can be classified into four steps:

1. **Descriptive statistics**—We started with a descriptive analysis of trends over time to identify possible differences along the urban hierarchy between areas with a different degree of peripherality, according to SNAI’s terminology [41] (p. 25);

2. **Defining the Excess of change**—The second step, following Dauth and Suedekum (2016) [38], was to look at the changes in sectoral composition before and after the Great Recession, defining a sort of excess of change ($EC_o$) at the municipality ($i$) level—as compared with the national level—for each industrial sector ($s$):

   \[
   EC_i = \sum_s \left| \frac{empl_{i,s,t} - empl_{i,s,t-1}}{empl_{i,t-1}} - \frac{empl_{i,s,t} - empl_{i,s,t-1}}{empl_{i,t-1}} \right|
   \]

   where $\frac{empl_{i,s,t} - empl_{i,s,t-1}}{empl_{i,t-1}}$ is the percentage change of employment in sector $s$ in municipality $i$, and $\frac{empl_{i,s,t} - empl_{i,s,t-1}}{empl_{i,t-1}}$ is the change of employment in sector $s$ in the country (Please note that we adopt weighted sectoral growth rates for both class of inner areas (A, B … F) and at national level (see [16] for details).

   If we divide the excess of change according to sectoral national growth, we take the null sector, $s_0$, as the benchmark (see Figure 2) to obtain four different areas:
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• $EC^+_i = \sum_{t=1}^{\Delta g} \frac{\text{empl}_{t+i} - \text{empl}_{t+i-1}}{\text{empl}_{t+i-1}} - \frac{\text{empl}_{t} - \text{empl}_{t-1}}{\text{empl}_{t-1}}$ if $EC_{t,i} > 0$
• $EC^-_{i} = \sum_{t=1}^{\Delta g} \frac{\text{empl}_{t+i} - \text{empl}_{t+i-1}}{\text{empl}_{t+i-1}} - \frac{\text{empl}_{t} - \text{empl}_{t-1}}{\text{empl}_{t-1}}$ if $EC_{t,i} < 0$
• $EC^+_{i} = \sum_{t=1}^{\Delta g} \frac{\text{empl}_{t+i} - \text{empl}_{t+i-1}}{\text{empl}_{t+i-1}} - \frac{\text{empl}_{t} - \text{empl}_{t-1}}{\text{empl}_{t-1}}$ if $EC_{t,i} > 0$
• $EC^-_{i} = \sum_{t=1}^{\Delta g} \frac{\text{empl}_{t+i} - \text{empl}_{t+i-1}}{\text{empl}_{t+i-1}} - \frac{\text{empl}_{t} - \text{empl}_{t-1}}{\text{empl}_{t-1}}$ if $EC_{t,i} < 0$

Figure 2. Visual representation of direction of local industrial change (based on [38]).

All amplitudes for area $EC^+_i$ imply excess growth in sectors that at the national level have expressed positive growth in municipality $i$, whereas amplitudes in area $EC^-_i$ imply excess growth in nationally declining sectors. On the contrary, it is possible to see above-average decline in increasing and declining industries for area $EC^+_{i}$ and $EC^-_{i}$, respectively.

In order to take into consideration the peculiarities of different inner areas, with particular reference to the distinction between urban and rural areas and in line with Dauth and Suedekum (2016) [38], we applied this idea to the different municipalities classified by SNAl categories (six from A (center) to F (ultra-peripheral)). Therefore, for each group $a = \{A, B, C, D, E, F\}$ with above- and below-average growth, $g = \{+, -\}$, we computed the average excess change according to their reference group and average growth ($EC^\beta_a$).

We then calculated the following shares for every municipality:

$\alpha_{(a,g)} = \frac{EC^+_i}{EC^\beta_a}$, $\alpha^*_m = \frac{EC^+_i}{EC^\beta_a}$

$\beta_{(a,g)} = \frac{EC^-_{i}}{EC^\beta_a}$, $\beta^*_m = \frac{EC^-_{i}}{EC^\beta_a}$

Finally, we calculated the average of these shares $\bar{\alpha}_{(a,g)}$, $\bar{\beta}_{(a,g)}$, $\bar{\alpha}^*_m$, $\bar{\beta}^*_m$. The optimal rules of thumb in order to assess if the municipalities were pro-trend or anti-trend are as follows (see [16]):

**Pro-trend:**
- if $g = +$: $\alpha_{(a,g)} > \beta_{(a,g)}$ and $\alpha^*_m > \beta^*_m$
- if $g = -$: $\beta_{(a,g)} > \alpha_{(a,g)}$ and $\beta^*_m > \alpha^*_m$

**Anti-trend:**
- if $g = +$: $\beta_{(a,g)} > \alpha_{(a,g)}$ and $\beta^*_m > \alpha^*_m$
- if $g = -$: $\alpha_{(a,g)} > \beta_{(a,g)}$ and $\alpha^*_m > \beta^*_m$

Figure 2, presented above, can help us distinguish areas as pro-trend vs anti-trend in this way:

1. If a municipality grows more than the nation in growing sectors at the national level (Area $EC^+_i$), and declines in declining sectors at the national level (Area $EC^-_{i}$) then it is "pro-trend".
2. Oppositely, if most of the excess of change lines are in the Areas $EC^+_{i}$ and $EC^-_{i}$, municipalities are defined as "anti-trend".
3. Detecting the Switch—We applied Step 2 to the pre-crisis (2004–2008) and post-crisis (2009–2014) periods, identifying whether or not the industrial composition of each Italian municipality followed the national trend. We then compared the pre- and post-shock periods to define municipalities that switched in terms of their direction of trend.

4. Finding its Determinants—Finally, we inferred which characteristics affected the pro-trend and anti-trend municipalities, and which “switched” between the two through a logit model.

3. Results

Drawing on previous empirical evidence [46] resulting from an examination of employment trends (Step 1), we found that peripheral areas had a two-year delay and a deeper recession. This double dip could be a testament of two crises of different natures: a first, financial one, more strongly affecting urban areas; and a second, economic one (namely concerning the proper real economy), more severely impacting peripheral areas. Among the poles, it was actually the areas surrounding the big cities (Outlying areas in the SNAl’s nomenclature) that performed the best. This is compatible with Faggian et al. [37], but also Dijkstra et al. [47], who found that, in fact, the intermediate regions in Europe responded to the economic crisis the best. Some other studies, however, point to the underperformance of peri-urban hinterland areas compared with city cores as contrary to what could be expected from a favorable combination of urbanization economic (available in proximity to metropolitan cores) and lower prices [48,49]. Even more interesting, metropolitan cores proved to be resilient partly by pushing the recessionary shock to the outlying areas [48]. It must be acknowledged thus that, at the European level, there was no clear, uncontroversial pattern of economic growth or decline in response to the Great Recession, in regards to urban vs outlying regions.

Looking at inner areas, intermediate (D) and peripheral (E) areas showed a similar behavior, with two specular drops in growth rate in 2011 and 2013. More interesting is the trend of ultra-peripheral areas (F), which deviated from the other inner areas. In fact, the Great Recession seems to have affected them with a one-year delay, and the decline in employment growth, once started (in 2009), lasted longer (two years) and had a greater magnitude. However, recovery occurred at the same pace as the remaining inner areas, although in contrast with them (and with urban areas as well) the positive trajectory remained unaltered by the subsequent recession of 2013.

Looking at the difference in employment growth before and after the Great Recession (Step 2) of the six SNAI classes as compared with the national one, the poles clearly showed very similar trends to the national ones. This is not surprising, given that urban areas represented about 44% of the entire national employment. Moving along the urban hierarchy, from outlying and peripheral areas to ultra-peripheral areas, the differences appear to have been larger and larger. Comparing the pre- and post-shock periods, poles and peripheral areas showed a similar sectoral composition overall, with positive and significant Spearman correlation coefficients (0.24 and 0.22, respectively) between the rankings of the sectors pre- and post-recession. The recessionary disturbance did not change the economic base of urban areas, or of close belt/intermediate areas in the immediate post-shock phase. In contrast, all remaining areas showed a change in their sectoral mix due to the financial-economic crisis.

Was this change to re-align with the national trend, or to move farther away? Answering this question might pose interesting insights into policy, and hence it is the focus of the next section.

3.1. The Geography of Pro-Trend and Anti-Trend Municipalities

Table 1 shows the distribution of “pro-trend”, “not-significant” and “anti-trend” municipalities before and after the Great Recession.
Table 1. Distribution of pro-trend, not-significant and anti-trend municipalities before and after the Great Recession.

|               | Trend 2004–2008 | Trend 2009–2014 |
|---------------|-----------------|-----------------|
|               | # Obs. | %      | # Obs. | %      |
| Pro-trend     | 1550   | 19.83  | 524    | 6.7    |
| Not-significant | 5657   | 72.38  | 6531   | 83.56  |
| Anti-trend    | 609    | 7.79   | 761    | 9.74   |
| Total         | 7816   | 100    | 7816   | 100    |

| 2004–2008          | 2009–2014          | Total          |
|--------------------|--------------------|----------------|
| Anti-Trend         | Not significant    | Pro-Trend      |
| 69                 | 494                | 46             |
| 529                | 4780               | 163            |
| 163                | 1257               | 130            |
| Total              | 761                | 6531           | 524     |
| 7816               | 7816               | 7816           |

The recessionary shock caused a reshuffling of the Italian municipalities within the 3 classes we are considering, with a reduction (−13.1%) of Pro-trend areas almost completely in favor of Not Significant ones.

Figure 3 illustrates the geographical distribution of pro-trend, not-significant and anti-trend municipalities in the two sub-periods we identified: (a) pre-shock (2004–2008), and (b) post-shock (2009–2014).

More specifically, Figure 3a shows how in the pre-shock period, pro-trend municipalities were mainly located along the two mountain ranges in Italy (i.e., the Alps and the Apennines), where many inner areas are located (see Figure 1). Many of the not-significant municipalities were located in regions leading the Italian economic system (namely Veneto, Lombardy, Emilia Romagna and Tuscany). Anti-trend areas were slightly more heterogeneously distributed across the country, but with similar patterns as in the pro-trend areas.

Following the Great Recession, the geography of pro-trend and anti-trend municipalities changed dramatically in favor of anti-trend areas and, to a lesser extent, to not-significant ones. In other words, the number of municipalities that grew more than the country in nationally growing sectors, and that declined in nationally declining sectors, dropped considerably after the shock.
especially in inner areas. What is worth noting is that municipalities that showed opposite trajectories with respect to the national ones grew most significantly in the Northern–Central part of the country, which was the one closest to the national sectoral composition before the global financial–economic crisis.

These results call for a deeper investigation to understand whether—and where—the recessionary shock produced a shift in terms of local industrial profile trends.

3.2. A Geography of the “Switch”

Figure 4 shows the geography of “switching” municipalities; that is, those municipalities that moved from their initial state towards another one after the Great Recession as compared with “not-switching” municipalities, which remained stable following the shock. 36.3% of the municipalities (Table 2) changed the direction of their trend (pro- vs. anti- the national trajectory) after the crisis.

Most of the switching municipalities were located in inner areas, as shown in Figure 4.

Table 2. Distribution of switching and not-switching municipalities.

|                | Urban | Inter-Municipal | Outlying | Intermediate | Peripheral | Ultra-Peripheral | Total |
|----------------|-------|-----------------|----------|--------------|------------|-----------------|-------|
| 0—No switch    | 4979  | 204             | 104      | 2394         | 1348       | 791             | 138   | 4979 |
| 1—Switch       | 2837  | 7               | 11       | 1053         | 935        | 679             | 152   | 2837 |
| % Switch       | 36.3  | 3.32            | 9.57     | 30.55        | 40.96      | 46.19           | 52.41 | 36.3 |
| Total          | 7816  | 211             | 115      | 3447         | 2283       | 1470            | 290   | 7816 |

4. Discussion

Having mapped the spatial distribution of the switching vs not-switching areas, the next step of analysis is to try and uncover what were the factors underlying the “geography of the switch”.

In the previous section, we showed the industrial composition changes of Italian municipalities by differentiating the peripheral gradient of the areas. We found that inner areas seemed to be more prone to reconfiguring their sectoral mix due to the Great Recession. However, we have not yet provided any explanation of this switch. The aim of this section is therefore to shed light on the determinants of this switch between the two periods. Thus, our dependent variable is the switch, which might be seen as a proxy of the restructuring of economic sectoral composition following to the shock.
We start by looking at the switch with a logit model whose dependent variable was simply 1 if the area switched, or 0 otherwise.

Our control variables included geographical, economic, social and political factors. In particular:

1. Dummies for different degrees of peripherality (SNAI categories);
2. Population and population density: number of inhabitants and inhabitants per km² (Census 2011);
3. Share of employment in public services: composite indicator (Atlante Prin-Postmetropoli 2011) including employees in the public administration over total population, employees in state education over total population, employees in public health;
4. Education: percentage of people aged 15–24 who did not attend a regular course of study (Census 2011);
5. Poverty: households with potential economic discomfort (Census 2011);
6. Income (log): average income per household (Ministry of Economy and Finance 2011);
7. Female condition: male employment rate over female employment rate (Census 2011);
8. Social capital (Composite indicator from Nannicini et al., 2012);
9. Density of business: number of local units per km² (Atlante Prin-Postmetropoli 2011);
10. Dependency ratio: age–population ratio between population in, and population not in, the labor force (Census 2011);
11. Affordability index: percentage of average annual income needed to pay an average mortgage annual payment (own calculations on Ministry of Economy and Finance 2011);
12. Inequality index: Gini index (Atlante Prin-Postmetropoli 2011);
13. Political rights: turnover of 2014 EU Parliament election (Ministry of Interior 2014);
14. Dependency on agriculture: number of cattle per person (Agricultural Census 2010).

Summary statistics are provided in Table 3 (correlation matrix available upon request).

| Variable                  | Observations | Mean  | Std. Dev. | Min.   | Max.   |
|---------------------------|--------------|-------|-----------|--------|--------|
| Population (log)          | 7816         | 7.84  | 1.34      | 3.40   | 14.78  |
| Institutional capacity    | 8080         | 0.00  | 0.61      | -0.35  | 17.03  |
| Education                 | 8089         | 16.51 | 9.93      | 0.00   | 200.00 |
| Unemployment              | 8092         | 10.14 | 6.31      | 0.00   | 42.20  |
| Poverty                   | 8092         | 2.02  | 1.87      | 0.00   | 17.90  |
| Income (log)              | 8055         | 10.12 | 0.23      | 9.23   | 49.20  |
| Female condition          | 8092         | 1.61  | 0.31      | 0.00   | 11.19  |
| Social Capital            | 7946         | 0.45  | 0.16      | 0.00   | 1.00   |
| Business density          | 8092         | 0.07  | 0.06      | 0.00   | 1.00   |
| Population density        | 8092         | 277.34| 606.79    | 1.4    | 11346.3|
| Affordability index       | 7981         | 1.26  | 12.56     | -154.76| 22.00  |
| Inequality                | 8055         | 0.19  | 0.02      | 0.11   | 0.33   |
| Political rights          | 7869         | 0.31  | 0.08      | 0.07   | 0.63   |
| Agriculture dependency    | 7581         | 6.99  | 29.97     | 0.00004| 922.52 |
| Peripherality class       | 7816         | 3.71  | 1.00      | 1.00   | 6.00   |
We estimated the following logit model:

\[ \text{Switch} = \beta_0 + \beta \text{peripherality} + \gamma \text{CONTRROLS} + \epsilon. \]

Results are provided in Table 4. It is interesting to note that the probability of switching, namely the probability for a greater magnitude of change in local industry composition over time, compared with the average national pattern of structural change, increases with the degree of peripherality of the municipality (i.e., 0.9 for outlying areas and 1.4 for ultra-peripheral areas). In other words, the more peripheral the area, the more likely it is to switch. This probability is clearly higher when looking at the basic model (model 1) in Table 4, as including more controls attenuates the effect.

Our results show that places are more likely to switch if they are smaller (in terms of population size), if they have a lower share of employment in public services, if they have a lower level of education and if they have a lower level of social capital. It is worth noting that the main determinants for switching are also the main features of Italian Inner areas, where poor institutions, prolonged high-skilled out-migration of young people and a scarce endowment, or dissipation over time, of relational capital are part and parcel of—or co-evolve with (to use an expression proper to the Evolutionary Economic Geography approach)—their long-term often precarious development trajectories.

These results show an inherent potential weakness of peripheral areas: they suffer the most from the depopulation process and youth migration, as they are not poles of attraction for the people who are more likely to confront economic shocks.

According to what we underlined above, we know that inner areas show a local industry composition that is not in line with the nationally booming sectors (i.e., manufacturing sectors are quite relevant in peripheral areas, while other key sectors at the national level are not). However, so far, we only know that one of the impacts of the Great Recession on inner areas was to promote a change in local industry composition, with no clue as to the direction of change. This could be an intriguing research path to follow in the future, given the straightforward policy implications of such an analysis.

**Table 4.** Results of the logit model. Dependent variable is the switch of industrial composition trend in comparison to the national one.

| Dependent Variable: Switch (0, 1) | Model (1) | Model (2) |
|----------------------------------|-----------|-----------|
| Intermunicipal poles (dummy)     | 1.126 **  | 0.563     |
|                                  | (0.498)   | (0.508)   |
| Outlying areas (dummy)          | 2.551 *** | 0.922 **  |
|                                  | (0.386)   | (0.398)   |
| Intermediate areas (dummy)      | 3.006 *** | 1.026 **  |
|                                  | (0.387)   | (0.401)   |
| Peripheral areas (dummy)        | 3.220 *** | 1.176 *** |
|                                  | (0.388)   | (0.405)   |
| Ultra-peripheral areas (dummy)   | 3.469 *** | 1.380 *** |
|                                  | (0.402)   | (0.423)   |
| Population (log)                | −0.542 ***|           |
|                                  | (0.0352)  |           |
| Share of employment in public services | −0.105 * |           |
|                                  | (0.0544)  |           |
| Education                        | −0.00779 **|          |
|                                  | (0.00326) |           |
| Unemployment                     | −0.00917 |           |
|                                  | (0.00831) |           |
| Poverty                          | 0.0665 ** |           |
|                                  | (0.0298)  |           |
5. Conclusions

The search for new paths to resilience of peripheral regions is a fascinating research topic from a transdisciplinary and also a policy-oriented perspective. The ultimate objective of our study is to provide insights into the diversity, variety and also unevenness of the multifaceted processes underpinning the capacity of places to restructure their sectoral composition following a recessionary shock.

Our results encourage further analysis by addressing questions into what kind of resilience these areas can cultivate, and by investigating the role played by prolonged slow-burn challenges that are often corrosive to the ability of regions to adapt or (more desirably) anticipate change.

We found that inner areas showed a higher probability to switch from the pre-shock structure of their industrial profile to another. This is very interesting, in that it indicates a higher capacity to adapt to, or a lower propensity to resist, the disturbance produced by the Great Recession. The relevant weight of manufacturing on the overall economic base of Italian inner areas, however, may underline a low propensity to innovate and transition quickly into another sectoral composition under the new conditions—in other words, it may result in a scarce ability to answer to a recessionary shock.

This calls for special academic and policy attention. If we acknowledge the idea that shocks, and the magnitude of their impact, are often closely intertwined with the unfolding of broader, long-run slow-burn processes of change [7]—which have a high spatial differentiation—then proper, tailored policies are needed to improve regions’ abilities to rapidly react to unforeseen disruptions. Focusing on the notion of resilience could enhance our understanding of the factors influencing the development of regions and the scope for appropriate policy responses, not only in the emergency post-crisis phase, but rather in helping regions find and strengthen what could be the drivers of their context-specific abilities to react. In a word, a place-based resilience strategy is needed.

Building on this work, several extensions and research avenues open up. Aside from refining the model, some future steps may include: studying the direction of the switch and all the possible
combinations (we do not know a priori since we should look at the direction of change); progressing further in the investigation of the characteristics of the different areas and, in particular, of the differences by sub-groups classified according the degree of peripherality. Moreover, the post-crisis period is not so “post” in reality. It could therefore be useful to expand our dataset so as to account for longer post-shock times. We could divide these further in two sub-periods, to test and better explore the effects of the double dip on peripheries, and to better disentangle the impact of a first disturbance, more financial in nature, and a second one, more economic in its character. This might explain the lag in the decline of inner areas after the first financial crisis.

Knowing how the sectoral composition of these areas changes following this kind of shock could give us a clue on the untapped potential of the resistance of industrial sectors that have so far been ignored for not performing better at the national level and, within inner areas themselves, on how and to what extent the geography of a switch overlaps or interacts with the geography of resilience.

**Author Contributions:** Conceptualization: A.F., M.M. and G.U.; methodology: A.F. and M.M.; validation: G.U.; formal analysis: M.M.; investigation: A.F., M.M. and G.U.; resources: G.U.; data curation: M.M. and G.U.; writing—original draft preparation: G.U. and M.M.; writing—review and editing: A.F.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflict of interest.

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Evaluating and Planning Green Infrastructure: A Strategic Perspective for Sustainability and Resilience

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Received: 28 March 2019; Accepted: 10 May 2019; Published: 14 May 2019

Abstract: In the light of the current changing global scenarios, green infrastructure is obtaining increasing relevance in planning policies, especially due to its ecological, environmental and social components which contribute to pursuing sustainable and resilient planning and designing of cities and territories. The issue of green infrastructure is framed within the conceptual contexts of sustainability and resilience, which are described through the analysis of their common aspects and differences with a particular focus on planning elements. In particular, the paper uses two distinct case studies of green infrastructure as representative: the green infrastructure of the Region Languedoc-Roussillon in France and the one of the Province of Turin in Italy. The analysis of two case studies focuses on the evaluation process carried on about the social-ecological system and describes the methodologies and the social-ecological indicators used to define the green infrastructure network. We related these indicators to their possible contribution to the measurement of sustainability and resilience. The analysis of this relationship led us to outline some conclusive considerations on the complex role of the design of green infrastructure with reference to sustainability and resilience.

Keywords: green infrastructure; resilience; sustainability; social-ecological indicators

1. Introduction

In the context of the current changing global scenarios and overwhelming urbanization, the concepts of sustainability and resilience can help us to understand and adequately shape all the global transformations (environmental, social, energetic, climatic). These two concepts can be both read as major potential shifts in the understanding of the global territorial system and as key drivers of a more desirable future. Starting from the assumption that the two concepts have to be distinguished, we reflect on their implications in planning, design, and evaluation, with a particular focus on social, ecological and environmental issues. Since the literature on sustainability and resilience is quite extensive, we decided to select the most suitable references which attempt to conceptualize similarities and differences between sustainability and resilience. Such a focus on sustainability and resilience is necessary because there is often a common belief that “the resilience approach is a subset of sustainability science” [1] (p. 5) or is just a renewed system approach for sustainability science [2].

In particular, the focus of our research is twofold: on the one hand, we want to highlight the main similarities and differences in sustainability and resilience discourses, and on the other hand, we attempt to fill the gap between evaluation methods, measurements, and planning tools. In order to achieve these objectives, the paper analyzes some specific methodologies in the French and Italian planning frameworks which use indicators and/or multicriteria analysis as tools for designing green infrastructure (GI). We have chosen the GI strategy because it is a nature-based solution capable of enhancing the social-ecological quality of a specific territory, both in a sustainable and resilient way [3].
The methodologies and approaches will be compared in order to identify which elements of each case study fit better in the framework of the two concepts of sustainability and resilience.

The concepts of sustainability and resilience have been discussed and used in different disciplines, such as ecology, engineering, and sociology, and have been subject to multiple interpretations which cannot be interchangeable, but they can both be used to understand system dynamics and to promote strategic capabilities [4,5]. In literature, these multiple interpretations have resulted in a general fuzziness, unclarity, and malleability on the meaning of the two concepts. For instance, the malleable meaning of resilience has led to the interpretation of resilience as a “boundary object” [6] which allows a common background for different disciplines and stakeholders. This common background can enable the production of visions or consensus in decision-making and in implementation processes [7] and the creation of a common and shared communication across disciplinary borders.

In a nutshell, for our purposes, on the one hand, we can identify how the concept of sustainability is mainly referred to as a perspective issue which cities and societies attempt to reach in the face of a relevant societal transaction. In this sense, sustainability is an objective and a principle of spatial and temporal equity and “an overarching goal that includes assumptions or preferences about which system states are desirable” [2] (p. 128). On the other hand, differently from sustainability, resilience describes the system, its functionality and its behavior after a shock [8].

2. Materials and Methods

As mentioned in the previous section, the paper has a double objective: on the one hand, the analysis of sustainability and resilience, and on the other hand, the compared evaluation of GI’s indicators.

Given this as a general statement, the first step of the investigation process is a literature review on sustainability and resilience. Literature was identified by focused searches in major scientific databases (such as Scopus and Google Scholar). This analysis has its main focus in the identification of the key characteristics which compose a social-ecological system, where “social and ecological systems are deeply interconnected and co-evolving across spatial and temporal scales” [9] (p. 14). Social-ecological systems are particularly relevant nowadays in the understanding of resilience [10] and have inspired advances in sustainability science and practice [11]. In the social-ecological systems approach, where the “delineation between social and natural systems is artificial and arbitrary” [12] (p. 4), it is emphasized that “people, communities, economies, societies, cultures are embedded parts of the biosphere and shape it, from local to global scales” [13] (p. 1).

In the social-ecological context, an important strategy is the one of GI which, if provided with high multifunctionality and connectivity quality, can help to reach the objective of sustainable and resilient regions [14]. The multifunctionality of GI is intended as a necessity to “combine ecological, social and economic/abiotic, biotic and cultural functions of green spaces” [15] (p. 517) while the connectivity is represented by “the physical and functional connections between green spaces at different scales and from different perspectives” [15] (p. 517). GI is developed using different methods: for example, land-use analysis, visual interpretation, permeability studies, and multicriteria analysis. Despite the importance of considering stakeholder preferences [15] and different functionalities, there are still few studies that apply a spatial multicriteria evaluation to GI [3,16]. The majority of these methods use available territorial and environmental data (for example, Corine Land Cover data or regional database) in order to develop suitable indicators.

In the vast range of GI experimentations, we have selected two case studies: the first one is the GI developed by the French former Region of Languedoc-Roussillon (since 2015, it is part of the Occitanie Region) and the second one is the GI developed by the Italian former Province of Turin (since 2014, it has been converted into a Metropolitan City) with the contribution of the research group of Politecnico di Torino. We chose these two case studies because they are representative of two distinct European planning systems which share a long tradition in planning but have a different approach toward GI. Indeed, the two case studies represent two evaluation models based on a range of diverse
social-ecological indicators. On the one hand, the Region of Languedoc-Roussillon developed its GI using a multicriteria analysis which applies indicators based on available data (homogeneous and spatially linked on the regional scale). Since the diverse resolution of available data, the regional territory has been divided into hexagonal patterns which correspond to the best compromise. The database input OCSOL (soil occupation) of the regional agency SIG-LR is available online for free and it is specifically related to the regional territory of Languedoc-Roussillon.

On the other hand, the former Province of Turin proposed a specific methodology for the identification of the ecological character of the territory and defined a set of criteria for the evaluation of different land use typologies. In this case study the data used were the ones of Corine Land Cover. Both of the two case studies have spatialized the indicators through GIS; this spatialization is useful to interpret and analyze the two methodologies in a cross-comparative perspective.

In order to fill the gap between planning and measurement in the framework of sustainability and resilience, the comparative analysis of the two methodologies is useful for the construction of a strategic GI framework through the selection of the advantages of each case study.

3. Sustainability and Resilience in Planning Debates

Many scholars have long argued on the differences which can inhabit the two concepts [4,5,17–19] but there is also a branch of research which highlights the possible links between the two concepts (Table 1), while considering resilience as a possible way to conceptualize sustainability by describing its typical features [20]. In other cases, resilience is described with reference to its implications on sustainability [21], for the fact that, if cities are understood as dynamic and self-organizing, the concept of sustainability has a different connotation than the original one; in this case “sustainability is challenged to build the resilience capacity of cities” [21] (p. 1203).

Table 1. Features of sustainability science approach and resilience approach.

|                      | Sustainability Science Approach                                      | Resilience Approach                                      |
|----------------------|--------------------------------------------------------------------|-----------------------------------------------------------|
| **Peculiarities**    | Overarching goal for social justice, environmental protection and economic efficiency | Capacity to change, adapt and transform over time with or without disturbances |
|                      | Radical reorganization of the social-ecological system              | Overcome social-ecological limits                         |
| **Common elements**  | Integrate environmental and planning management                     |                                                            |
|                      | Need of a reflective capacity                                      |                                                            |
|                      | Need of flexibility of the process                                  |                                                            |
|                      | Inclusion of stakeholders                                           |                                                            |
|                      | Robustness                                                         |                                                            |
|                      | Biological diversity                                               |                                                            |

On the one hand, the wide literature shows how there are many definitions of resilience related to risks, climate, socio-economic, environmental and landscape changes which are taking place in the current global scenario, determining actions and transformations in the territorial system, conceived as “complex, non-linear and self-organized, permitting by uncertainty and discontinuities” [12] (p. 12). Within this framework, resilience refers to the capacity of the territorial systems and of their components to change, adapt and transform over time with or without external disturbance [22]. In particular, for our aims, we assume that one of the most prominent resilience theories has its focus on social-ecological system dynamics and interactions [10], which originates from ecological studies [23]. In this theoretical perspective, the human component must be seen as a part of nature, not separated from it. The main aspect of resilience is the ability to adapt or transform in unexpected cases of environmental and climate changes, and to transform the systems in the attempt of overcoming social-ecological limits [24]. This approach to resilience is connected to a “strong sustainability” understanding [25].
On the other hand, sustainability has become a mainstream topic since its first recognized definition of the Brundtland report “Our Common Future” [26], which focused on three pillars of sustainable development: economic, social, and environmental. This model is usually interpreted with reference to the simultaneous consideration of three main issues: economic efficiency, environmental protection, and social justice [27–30]. This model also stresses the need for integration of environmental and territorial policies for improved quality of life by relating humans to the environment. Recently, in 2015 this concept was resumed by the United Nations in setting the Sustainable Development Goals (SDGs); such a decision shows how sustainability aims at reaching certain goals which are specified in advance and can be achieved through the transformation of a system [31]. In such a perspective, sustainability can be a transformation, intended as a “radical reorganization of the social-ecological system” [17], measurable through policies and projects, while the adaptive character of a system is not always evident. In addition, it is argued that “the difference between adaptation and transformation can also be seen through time and space cross-scale interactions” [17] (p. 6). So, in some specific cases, adaptation can also include transformation, but they are not always directly linked at each scale.

With the aim of framing these concepts within the planning debate, it is essential to integrate environmental planning and management, and integration between environmental policy and spatial planning [30] and to identify the importance of a multi-level governance in order to recognize “the ubiquity of changes, the inherent uncertainties, and the potential of novelty and surprise” [32] (p. 304). In planning and design for sustainability and resilience [33], there is an evident need for a reflective capacity, linked to the recognition and management of territorial resources in order to adapt and maintain ecological and cultural diversity, maximizing environmental benefits; the flexibility of the process, that allows adaptation of decisions to the territorial needs and implementation of strategies over time [34]; the creativity that gives space to individual initiatives and to the integration with institutional practices; the inclusion of stakeholders, local actors and self-organized protagonists in the decision-making process empowering local self-reliance; the integration of different action scales and multiple policies, focus on river, rural areas, city, nature and agriculture; the robustness, the ability to converge the society toward a common evolutionary perspective, widely shared, through the guarantee of quality and effectiveness of results.

Considering the concepts of sustainability and resilience, it is possible to interpret them with reference to some of the abovementioned characteristics, which can fit both. In particular, the two concepts gather robustness [35] as an important factor for addressing social-ecological problems at different scales and levels of organization. In sustainability, robustness is related to the need to measure the persistence of a territorial system and the performance in the transformation of complex social-ecological structures. In fact, robustness is the capacity of a system to preserve its stocks and identity after a shock [35] through its reorganization and innovation abilities [36].

On the one side, robustness is a key concept while considering the preservation of a specific component of a social-ecological system (i.e., the system capital stocks including natural, human, and human-made) in the face of innovation, stress or transformation processes. On the other side, sustainability is a framework to legitimate the performance of the transformation of a system, recognizing that the functionality of the system is the precondition for economic and social development [37]. The functionality of the system depends on the quality and the persistence of the system capital stocks over time embracing inter and intra-generational equity [38].

Another common aspect is related to the specific role of biological diversity for resilience and sustainability, as a way for enhancing, for example, ecosystem quality. In biological systems, diversity must respond to the necessities of different species, which have diverse reactions towards disturbances and shocks. In this context, biological diversity (biodiversity) is furthermore essential for the self-organizing ability of complex adaptive systems [39] in terms of absorbing the disturbance and regenerating itself, but the social, the economic and the physical diversity are also effective strategies for the support of resilience. The adaptive cycle [40] is often considered to be a central metaphor in the conceptualization of the dynamics of change in social-ecological resilience. Adaptability is indeed a
key aspect of resilience of social-ecological systems as it considers the interrelation between concepts of “diversity (biodiversity), redundancy (ecological variability), cycles of adaptation (multiple equilibrium states), and interaction between spatial scales (hierarchy) and temporal (activation of different times responses)” [41] (p. 780).

In social-ecological systems approach and in planning discourses, in order to enhance both sustainability and resilience, the role played by GI is highly relevant. Addressing this statement, we assume that GI can reinforce the characteristics of robustness and biological diversity of the territorial system besides fostering sustainability and resilience by increasing flexibility, redundancy, modularization and decentralization [40,42]. With reference to GI, evidence on these resilience characteristics has been mainly applied to stormwater management [21,43]; for example, a modular approach, characterized by a functional redundancy and decentralized elements, in planning and design helps to be prepared and to preplan in the event of a system’s failure [21]. GI can also contribute to perform connectivity besides functionality; connectivity is indeed a trigger of sustainable and resilient urban forms [44,45] by providing cities, from macro to micro-scale elements, with an enhanced biodiversity, improved hydrological processes and a healthier life.

4. Green (and Blue) Infrastructure in Sustainability and Resilience Discourses

GI, originally inspired by the principles of landscape ecology [46,47], has been widely recognized and promoted as the “ecological framework needed for environmental, social and economic sustainability” [48] (p. 5), thus connecting and supplying ecological, economic and social benefits which are at the basis of sustainable development; this definition of GI can indeed be considered as the first one that explicitly links GI to sustainable development. By reviewing international literature on GI, we can identify different definitions but, generally, there is a consistent presence of both natural and human-made components as essential elements. GI has firstly developed in response to different needs and, in recent years, has also influenced and entered into planning theories and policies [49] and design practices; for example, its strategic role is underlined by the European Commission, which recognized GI as a “strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services” [50]. In this context, GI can be considered as a producer of multiple benefits [15,42,51] for health and life quality. Furthermore, the concept of GI “differs from conventional approaches to open space planning because it looks at conservation values and actions in concert with land development, growth management and built infrastructure planning.” [48] (p. 5) Thus including also a sustainable development perspective in addition to a preservative one. There is also increasing evidence in literature, even though not always unambiguous, that GI contributes to climate change mitigation and adaptation by supplying several benefits and services to urban environments [52,53]. With this in mind, the multifunctionality of GI can mitigate the urban heat island effect, flood risk management and ecosystem resilience [53].

The growing popularity of GI is also detectable in pioneering climate change adaptation policies of some cities, such as London, New York, Copenhagen and Paris [54,55]; these policies have indeed introduced green infrastructures in their planning and design tools for climate change adaptation and biodiversity preservation.

Since our focus is on social-ecological systems, sustainability, and resilience, we can notice (Table 2) how literature applies GI mainly to stormwater management and design even though they can contribute to provide other several benefits, such as improved air quality, urban heat island mitigation, improved communities and reduced social vulnerability, greater access to green space and increased landscape connectivity [3].
Table 2. Sustainable and resilient solutions of GI.

| Resilience | Sustainability | References |
|------------|----------------|------------|
| Governing climate change | Managing and regulating stormwater hazards | x | [21,42,52,55] |
| Improving soil, air and water quality | x | [52] |
| Regulating urban heat island effect | x | [53,56] |
| Limiting land take and soil sealing | x | [57,58] |
| Enhancing landscape quality | Supporting landscape connectivity and fruition (slow mobility) | x | [3,59] |
| Supporting ecological functionality and accessibility to green space | x | [3] |
| Promoting well-being | Recovery of degraded and vacant land | x | [59–61] |
| Reducing social and ecological vulnerability | x | [3] |
| Developing healthy communities | x | [52,56] |

The literature review (Table 2) shows how GI can help trigger some sustainable and resilient solutions. In particular, GI can:

1. be a flexible and adaptable answer to climate change through actions of stormwater management [21,42,52,55], improvement of soil, water and air quality [52], regulation of the urban heat island effect [53,56], and limiting of land take [57,58];

2. enhance landscape quality by favoring landscape connectivity and fruition [3,59], supporting ecological functionality and accessibility to green space [3], and recovering degraded and vacant land [59–61];

3. promote well-being in favor of a reduced social and ecological vulnerability [3] and the development of healthy communities [52,56].

In our view, GI is a strategy which combines both natural and social elements and can be conceived as a landscape network [62,63] that can enhance ecological quality through an integrated and socially inclusive approach to territories as requested by the European Landscape Convention. At the same time, it can help to overcome habitat fragmentation and promote healthy communities and, in order to be equally recognized and accessible, it must have extensive public support in policy decision-making and realization.

The project of GI needs to be based on a social-ecological evaluation of the territorial system based on index and indicators essential for the identification of quality aspects of ecosystem diversity and for the interpretation of possible pressures of human activities.

The index and indicators are used to interpret the social-ecological system with respect to the capacity of the system to preserve the ecological functionality but also to consider the impacts of human activities and the possible adaptation strategies capable of enhancing resilience and sustainability. In fact, they can measure the robustness and the persistence of a system, relating it to the capacity of maintaining their functions acting in buffer areas around the naturality core areas and in the case of withstanding shocks. They can act as interpreters of the interplay disturbance between nature and
human activities, favoring a reorganization or a development of the system. By using these indicators in promoting GI, it is possible to develop an integrated social-ecological system capable of acting in a cross-scale dynamic interaction.

The spatialization of the integrated measurement of potential ecological functionality is used to evaluate the vulnerability of a territory and the loss of biodiversity, to define possible design scenarios able to contrast potential irreversible transformations and unexpected shocks. It can also be used to envision possible future directions.

5. Two Case Studies in Comparison

Towards this perspective, as mentioned in paragraph 2, we analyzed the methodologies used for the identification of two case studies of GI in France, the Region of Languedoc-Roussillon, and Italy, the Province of Turin. The two case studies, and their referring planning system, differ in some elements but the interpretation of their methodologies for GI help to demonstrate the link between the measurement of ecological functionality in terms of sustainability and resilience and the GI design.

On the one hand, the French case study is representative of a multiscale design from the national scale to the local one and it is based on a participatory multicriteria analysis of the ecological value of the territory and of the human impacts on naturality. The methodology of the Region of Languedoc-Roussillon provides a wide range of indicators for the evaluation of both ecological and social aspects of the territory. This analysis can be used to define design scenarios of the GI at a vast scale and can be redefined at the local scale, contributing to adaptation and sustainable use of territories.

On the other hand, Italy is characterized by a jeopardized approach in the different regional landscape plans and has no national disposition towards GI. Despite this national situation, some Regions and Provinces have attempted to define their own methodology for developing ecological networks, such as the Province of Turin. In this particular case the active participation of stakeholders was fundamental for the definition of connectivity scenarios. Despite the active participatory process, no social indicators were included in the process, thus leading us to state that this methodology is less comprehensive and overarching.

5.1. French ‘Trames Vertes et Bleues’

France in its planning system has always given great relevance to environmental and ecological elements; since 2009 this relevance has even been more strongly emphasized with the promulgation of two specific laws: the Grenelle laws I and II (the second is an extension of the first one and has been promulgated the year after, in 2010). These laws, implementing and modifying both the Code of Urbanism and the Code of Environment in line with the principles of sustainable development, can be considered as a turning point in the French planning system as they introduce new issues connected to ecological preservation.

Grenelle laws introduce a new planning tool, the *Trame Verte et Bleue* (TVB). It resumes the principles of landscape ecology [46,47] and shapes its characteristics in order to properly fit it into planning tools. TVB are indeed applied to different scales of planning, from the national to the local one (Figure 1). The French National State in 2014 defined and approved the “*Orientations nationales pour la préservation et la remise en bon état des continuités écologiques*” (National orientations for the preservation and maintenance of ecological continuities) which must be taken into account at lower scales: the regional and the local one. Regions are indeed in charge of developing a *Schéma régional de cohérence écologique* (SRCE), a new planning tool introduced by the Grenelle laws which must define the stakes of TVB at a regional scale.
The SRCE can appear to be juridically fragile as it has no prescriptive value (such as in the sense of granting building permits); in this sense it is neither a brake or an obstacle to land use planning but rather a functional framework for the ecological coherence of a territory and its planning tools. In this context, it gives some recommendations for raising awareness on ecological issues, for managing and protecting ecological continuities and for allowing a sustainable development and management of territories. The only legal and regulatory obligation is the necessity to be taken into account (prise en compte) by subordinate urban plans (principally Schéma de Cohérence Territoriale - SCoT).

The most operational scale for a more precise specification of TVB elements is the local one, SCoT and Plan Local d’Urbanisme (PLU) or Plan Local d’Urbanisme Intercommunal (PLUi). In this context, indeed, these territories (they are often an ensemble, big or small, of municipalities) became strategic in the operational implementation of TVB for their competences in urbanism and territorial planning and projects.

TVB are composed of two main elements: biodiversity reserves and ecological corridors. In order to define and map these two elements, the National orientations document provided a methodological guide which identifies the areas that are automatically integrated in the network as biodiversity reserves or ecological corridors (for example: the core of national parks, national and regional natural reserves and spaces assigned to the conservation of specific biotopes, etc.). In order to define “extra” biodiversity reserves and ecological corridors, in addition to the ones identified by the national orientations, some Regions have identified specific methodologies, such as multicriteria analysis. The multicriteria analyses developed by some Regions (such as Aquitaine, Auvergne, Languedoc-Roussillon, etc.) have interpreted some elements of landscape ecology in the form of indicators and indices. These analyses are indeed based upon specific ecological notes, values and criteria which are applied to the single land pattern or to a network; this modeling allows us to reach a global value of functional or ecological quality of a specific territory.

Some Regions (such as Languedoc-Roussillon) have combined different indicators, not only the ones strictly connected to ecological importance but also sociological ones, linked to the presence (or absence) of human activities and their related impacts.

The Region of Languedoc-Roussillon, an Example of Ecological Functionality

The Region of Languedoc-Roussillon, situated in the south of France, has a high percentage, almost half of its total surface (48%), characterized as natural protected areas [64]. Despite this positive outcome, the Region is facing the process of land take and artificialization at a rate of almost 830 ha
per year [64]; the most affected lands are the agricultural ones, with a loss of 51% of lands with high agronomic value between 1997 and 2009 [64].

The SRCE identifies 23 grands ensembles paysagers on the basis of their characteristics which in turn have been further detailed in 175 landscape units, thus dividing the territory into different geographical categories (such as littoral, plain areas, mountain areas, etc.).

In order to define a regional TVB, the methodological choice made by the SRCE of Languedoc-Roussillon was to qualify the ecological value of the territory by a global approach, through the identification and implementation of some indicators.

The Region of Languedoc-Roussillon in its SRCE proposed a spatialized multicriteria analysis based on the identification of a global index of potential ecological functionality of the territory, which is the result of a combination of ecological indicators (index of ecological importance) and social-ecological ones (index of human footprint).

The index of ecological importance (indice d’importance écologique) corresponds to the importance that an area is likely to have for biodiversity and ecological continuities preservation. This index is based on a spatialized multicriteria analysis which attempts to qualify the landscape mosaic. It is made up of 5 different indicators (Figure 2): ecological functionality of natural milieu, density of remarkable landscapes, patrimonial responsibility, ecological functionality connected to agricultural practices and ecological functionality of continental water milieu. These indicators show how they embrace different land uses and landscapes typologies, which are strategic for the social-ecological effectiveness of GI.

![Figure 2. The index of ecological importance and its indicators.](image-url)

The first indicator, ecological functionality of natural milieu, gives an approximation of the ecological functionality of natural terrestrial milieu; it takes into account the surface of natural habitats and their potential inclusion in a specific protected zone, called ZNIEFF of type 2 (Zone naturelle d’intérét écologique, faunistique et floristique). Due to the presence of different contexts (degree of naturality, differences in habitats, alteration of natural milieu by human activities and fragmentation), the indicator relies on different indicators. In a situation of a network characterized by a different natural milieu that is not so fragmented or altered by human activities, the ecological functionality is considered to be high; as a first input, since the area of natural milieu is the most relevant factor in terms of ecological functionality, it is assigned the highest weighting. In addition, the indicators concerning the diversity of the milieu (with a diverse resolution and based on categorical values) have a lower weighting in
order to limit bias induced by different geometries and themes of data. The weight of naturality is furthermore reduced so as not to overestimate its importance; in identifying stakes there finally is a crossover with the global index of the human footprint.

As shown in Figure 2, the first indicator is made up by:

- the density of the natural milieu and its ecological cohesion with ZNIEFF of type 2 (considered to be a milieu of high ecological integrity);
- the naturality of the milieu, translating the level of human interventions or artificialization of a determined milieu. A low weighting is given to this indicator in the calculus of the indicator of the “integrity of natural milieu” in order to avoid an overestimation of the socio-economic factors related to the human footprint (it is strictly connected to factors used in the evaluation of the indicator of human footprint);
- fragmentation of a natural milieu;
- diversity of the milieu measures the spatial subdivision (including elevation) of different milieus which are present in a single pattern.

The second indicator expresses the density of remarkable landscapes within a parcel; different types of zoning have been included (such as cores of UNESCO sites, protection zones previously defined by law). The third indicator, the patrimonial responsibility, reports on the presence of species and/or habitats of regional, national or European interest.

The fourth indicator, the ecological functionality of agricultural practices, is based on data on land use, agricultural practices and according to experts, gives an estimation of the state of preservation and intra-network connectivity of agricultural milieu. The last indicator is connected to ecological functionality supplied by water milieu (rivers, lakes and damp zones).

The index of human footprint (indice d’empreinte humaine), aims to translate the intensity of human activities on biodiversity and, likewise the index of ecological importance, is estimated by a combination of different indicators which are weighted on the basis of supposed impacts on biodiversity preservation and ecological continuities. In this context, the index takes into account potential risks on biodiversity and ecological functionality of each single pattern. The indicators which concur with the definition of this index are: an indicator of soil artificialization, an indicator of transport networks, an indicator of demography, density of energetic network, and planning and transport projects (Figure 3).

![Figure 3](image-url)
The first indicator is a composed one which quantifies the density of urbanization and soil artificialization. The second indicator quantifies on the one hand on the density of transport network on the basis of the type of road and railway and, on the other hand, impassable obstacles (such as highways and high-speed railways) and fauna passages.

The third indicator quantifies demographic presence at a municipal level; it combines three different indicators:

- population density, based on number of inhabitants in each municipality;
- population growth in each municipality;
- accommodation capacity of each pattern.

The fourth indicator reports the presence of energy production and energy transport zones which affect ecological functionality. The last indicator takes into account the perimeters of planning and transport projects, which may impact on ecological functionality.

The two global indexes of global importance and of human footprint have been distributed in four classes using the quantile method. Their intersection allows for estimating the ecological importance of each pattern of the territory in relation to human footprint. Starting from this intersection, some relevant stakes of biodiversity preservation and ecological continuities for the development of the regional TVB can be identified. The successive intersection between indicators and the ecological structure makes the overall approach more evident, also allowing a spatialization of stakes (Figure 4).

![Figure 4. Map of intersection of ecological and social indicators (source: adapted from SRCE Languedoc-Roussillon).](image)

The spatialization of indicators (Figure 4) is a combined map with different gradients. On the one hand, a gradient from pale green (low ecological importance and low human footprint) to dark green
(high ecological importance and low human footprint), and on the other hand, a gradient from pale green to yellow and grey (low ecological importance and strong human footprint). A third gradient goes instead from pale green to orange and brown, thus representing a gradual increase of the spatial ecological importance but also the human footprint.

This map allows us to focus the attention on the importance of avoiding two types of transitions: the transformation of green areas into brown ones can signify an increase of vulnerability of spaces relevant for biodiversity, while the transformation from brown to yellow or grey contributes to the loss of ecological importance connected to a high human footprint.

Starting from this first work, it will be possible to identify the ecological continuities useful for the full development of the regional TVB. The intersection of these ecological continuities with protected areas allows us to identify the minimum biodiversity reserves; in the sectors of high human footprint, the map enables the visualization of existing ecological continuities and the identification of areas potentially important for their maintenance and restoration. This approach aims at identifying large areas finalized to support the functioning of biodiversity at the regional scale; these areas represent the matrix which embraces biodiversity reserves, within which it is possible to identify ecological corridors, thus emphasizing the importance of the matrix in its entirety (reserves + corridors).

5.2. The Italian Framework of Landscape and Ecological Networks

In Italy, since the National Strategy of sustainability and biodiversity preservation in 2010 [65], the realization of ecological and landscape networks has become central in the current planning debate. Nevertheless, despite this initial boost, a national organic and shared project of landscape and ecological network in Italy is still lacking. The first attempts of designing landscape and ecological networks in the Italian planning framework come from the regional level, within the context of regional landscape plans.

Italian regional landscape plans have mainly taken on a structural interpretation of landscape following a design approach; this approach assumes as the main object of preservation the ecological value and the ecosystem service value of the entire regional landscape. Within the framework of such an approach, ecological networks help to efficiently interpret this vision. In the latest years, many regions have, indeed, drafted and/or approved their landscape plan: the Regions of Piedmont (2017), Lombardy (2017), Friuli-Venezia-Giulia (2018), Tuscany (2015), Puglia (2015) and partly Sardinia (2006). Within this context, Regions have included their reasonings on landscape and ecological networks, mostly connecting them to the topic of design.

The first approved regional landscape plan which promoted this approach is the one of the Region of Puglia with the identification of an ecological network of biodiversity, in charge of identifying all the naturality elements, and a general director scheme for the multi-purpose ecological network characterized by a design approach and a strategic significance. Also, the regional landscape plan of Tuscany entrusts a leading role to the ecological network by including it as one of the four pillars on which the plan is built.

The regional landscape plan of Piedmont, the Region in which our case study is located, identifies a network of landscape connection, a multi-purpose and multifunctional system which combines ecological elements (nodes, ecological connections, and restoration areas) with historical and cultural ones. The regional landscape plan of Friuli-Venezia-Giulia considers the regional ecological network one of the networks of strategic importance, together with those of cultural heritage and slow mobility.

The Region of Lombardy has approved a regional territorial plan with a landscape value which recognize the ecological network as a priority infrastructure of this plan, and it constitutes an indicative tool for provincial and local plans.

The developed regional ecological networks are intended for delivering a territorial project [66] in its entirety; they can help to reach an economic development and a vision of long-lasting development, which is bound to landscape preservation and valorization through the development of a landscape network that can increase the benefits and services they offer. The ecological networks of these plans.
identify and protect the environmental value of territories in their entirety, also in urbanized areas, overcoming the confined vision of considering them only relegated to protected areas.

Ecological Networks in the Metropolitan City of Turin

The Metropolitan City of Turin (formerly the Province of Turin), selected as the Italian case study, is representative of a large and multifaceted conurbation, made up of more than 300 municipalities of different landscapes. Since the first Provincial Territorial Coordination Plan (PTCP) of 1999, the former Province of Turin has always carried out extensive territorial planning, with particular regard for the safeguarding of soils and the limitation of land take, by including their protection as a major objective together with the preservation of biodiversity.

With the aim of preserving biodiversity and controlling the increasing process of land take, the new PTCP, approved in 2011, has reinforced the abovementioned objectives. Later, between 2014 and 2016, the ENEA (the Italian national agency for new technologies, energy and economic sustainable development) and Politecnico di Torino [67,68], have defined the guidelines for the green system (LGSV) within which a specific methodology for the definition of the provincial ecological network (LGRE) was identified. The objective of this research is the definition of a proposal for the implementation of the provincial ecological network at the local level.

The proposed methodology promotes a bioecological approach [69,70] which identifies landscape as an interconnected system of habitats by linking areas of the Natura 2000 network (core areas, corridors and buffer zones), essential for the development of ecological functionality, and sustainable use areas and potential restoration areas. In order to define an efficient process of evaluation of both ecological functionality and environmental critical issues, it has been necessary to evaluate the different land use typologies in relation to some ecological-environmental criteria: Naturality, Relevance for preservation, Fragility, Extroversion, Irreversibility (Figure 5). They do not refer to a single land use and landscape typology, as in the French case study, but they do refer to habitats and their functionality as complex and interrelated systems.

![Figure 5. Indicators of the provincial ecological network of Turin.](image)

Each ecological-environmental criterion has been attributed to each of the 97 land use typologies; the ensemble of attributed values to each land use typology characterizes them from the ecological-environmental point of view. These indicators have been further divided into different levels of specificity, varying from 5 levels (naturality and extroversion) to 3 (irreversibility).

The value of naturality, subdivided into 5 levels, is attributed to each land use typology on the basis of its proximity to the one which should be present in the absence of an anthropic disturbance (climax).

The second value, relevance for conservation, defines the level (in a scale of 4) of relevance or suitability of land uses for biodiversity preservation and considers the importance for habitat and species. It includes not only habitats of communitarian interest but also the ones whose preservation is necessary for the protection of plant and animal species of Natura 2000 network.
The classification of land uses with reference to fragility, specified on 4 levels, is carried out evaluating how much the different land use typologies are intrinsically unable of resisting to the ensemble of pressures generated by the anthropic use of the territory (such as pollution and anthropic disturbances). This indicator can be used to measure the vulnerability of a system, with reference to disaster risk, poverty, food security and climate change, within the key concepts of exposure and adaptive capacity [71]. The value of fragility principally refers to the intrinsic characteristics of a territory but, in particular for some land use typologies it is essential to evaluate the fragility which derives from the limited extension of this land use typology (for example a specific vegetal formation which characterizes a land use typology).

The level of extroversion of a land use typology depends on the intensity, probability or possibility with which that land use typology can generate pressures on neighboring areas. The value considers pressures (such as pollution, industrial production, possible diffusion of exotic species) in an integrated perspective. It is subdivided into 5 levels, ranging from the first which includes land use typologies that coincide with areas mostly occupied by human settlements to the fifth which refers to areas containing more natural typologies of land use.

The last criterion is irreversibility, which defines the level (in a scale of 3) of improbability of irreversibility in land use change which could lead to a higher degree of naturality. The first level corresponds to the most irreversible areas, as it includes sealed land use typologies (urban settlements, commercial and industrial areas).

The integrated combination of the first two indicators, naturality and relevance for conservation, has allowed us to define a territorial zoning process based upon its reticular value and its ecological functionality (Figure 6). Based on their ecological functionality, areas have been divided into four different classes: (1) areas with a high ecological functionality, (2) moderate functionality, (3) residual functionality and (4) null functionality. The first class, areas with a high ecological functionality, is optimal for the development of habitats and species; the second class, despite a lower functionality, gathers areas which are very important for reticularity. Areas with a residual functionality can be partially used for the expansion of the network. Areas included in the last class are considered as obstacles for the development of the network.

The application of this methodology to specific territories has allowed us to define a diffused reticularity for the territories involved and it contributed to making it more evident which parts of these territories are more sensitive to sudden changes caused by human activities. In fact, the methodology can be used to identify the natural areas of significant importance for the conservation of biodiversity. In addition, it also allows us to define possible areas for priority expansion of the ecological network.

Starting from their peculiar territorial context, this methodology has been further adopted and adapted to some local experimentations [67]: municipalities of Bruino, Ivrea with Bollengo, and Chieri. These experimentations were developed starting from analysis of the supra-municipal ecological system and with an active participatory process and public consultation to select the most suitable local connectivity paths. Indeed, the approach previously presented was reconsidered in each experimentation in order to guide and provide local bodies with specific measures to limit urbanization and enhance the ecological state of each territory. Each experimentation has therefore defined specific methodological and operative orientations which could be further implemented in urban plans. This implementation is eased through a simplified analysis of land use typologies which allow also to non-experts to create specific local ecological functionality maps.

The experimentation of the bioecological approach has led to the definition of a processual methodology which defines two types of action: the conservation of the structural elements of the network, which could consider implementing interventions of environmental improvement, and the design.
Figure 6. Ecological functionality of the city of Turin (source: adapted from PTC2 Torino).

6. Discussion

Thus far, we have shown how the concept of GI has entered both sustainability and resilience discourses; in particular, we explored some representative case studies of GI with the objective of interpreting the role of evaluation tools for the definition of territorial sustainable and resilient scenarios. This exploration has attempted to clarify and explain how some planning elements of design, implementation and management, such as GI, can help to enhance sustainability and resilience (Table 3) at different scales (from the national to the local one).

The analyzed methods for biodiversity evaluation surely contribute to improving the ecological quality of a system, its resilience, and its adaptivity, but they also necessitate further development of specific indicators for a more precise analysis of vulnerability and of the equilibrium states of the system. We emphasize how these methods measure ecological functionality on the basis of the capacity of each habitat and buffer zones to resist and react to pressures or shocks maintaining their functions within a long period perspective.

In both cases (Table 3), indicators of ecological functionality appear to be highly relevant for reading the quality of the system. All the indicators can be associated with sustainability while not all of them can be considered as suitable indicators for measuring resilience. In order to qualitatively measure resilience, in particular social-ecological resilience, it is indeed necessary to consider more specific aspects which allow for reading the persistence of social-ecological elements of the system and its biological diversity.
Table 3. French and Italian indicators and their relationships with sustainability and resilience.

| Indicator                                                                 | Resilience | Sustainability |
|--------------------------------------------------------------------------|------------|----------------|
| French indicators                                                        |            |                |
| Index of ecological importance                                           |            |                |
| ecological functionality of natural milieu                               | x          | x              |
| density of remarkable landscapes                                         | x          | x              |
| patrimonial responsibility                                               |            |                |
| ecological functionality of agricultural practices                       | x          | x              |
| ecological functionality supplied by water milieu                        | x          | x              |
| composed indicator of soil artificialization                             | x          | x              |
| composed indicator of transport network                                   | x          |                |
| composed indicator of demographic presence                               | partially  | x              |
| density of energy network                                                | x          |                |
| development projects                                                     | x          |                |
| Index of human footprint                                                 |            |                |
| composed indicator of soil artificialization                             | x          | x              |
| composed indicator of transport network                                   | x          |                |
| composed indicator of demographic presence                               | partially  | x              |
| density of energy network                                                | x          |                |
| development projects                                                     | x          |                |
| Italian indicators                                                       |            |                |
| naturality                                                               | x          | x              |
| relevance for preservation                                               | x          | x              |
| fragility                                                                | x          | x              |
| extroversion                                                             | x          |                |
| irreversibility                                                          | x          |                |

Framing our analysis within the social-ecological perspective of resilience, which is about “people and nature as interdependent systems” [72], we can delineate some main differences between the two approaches led by the French case study and the Italian one. Under the GI definition, the Italian methodology has opted to develop a strictly ecological approach, with few indicators. They do not explicitly refer to a specific milieu, as occurs in the French case study, but they tend to analyze habitat functionality in a more aggregate and integrated way, as a complex system. On the other hand, the French methodology appears to be more complex as it operates in a wider spectrum, combining ecological indicators with social ones and showing itself to be capable of evaluating the impacts of human activities on the environment. Despite the apparent complexity of these indices, the French methodology allows us not only to assess the sustainability of a social-ecological system but also its resilience. Instead, the Italian methodology, since its apparent simplification in indicators and operationalization, seems to mainly address sustainability, as if it is an aggregated component of the habitat quality.

The two cases analyze two uneven territorial systems: on the one hand, the French case study considers a regional scale which must refer to a national framework of biodiversity valorization; on the other hand, the Italian case study refers to a provincial network. Despite the differences of territorial scale, an element common to the two approaches is the necessity of reaching the network project after a debate between the spatialization of the evaluation of biodiversity gradients and territorial stakeholders. In both cases, the selection of the most relevant connectivity paths for the construction of the ecological network is the result of an inclusive process in which stakeholders identify the most relevant landscape for integrity, quality and identity of each social-ecological system. Participation, in the Italian case study, is actively proposed in order to develop a sustainable approach for GI quality; in fact, GI design is the result of shared visions for the future and for the management of the territory (building consensus, promoting participation and trying to integrate self-organization initiatives for environment management and top-down approaches). Another difference lies in the fact that, as is demonstrated by the recently approved regional landscape plans, Italian networks act as
multifunctional networks in support of ecological and recreational landscapes. In contrast, in France there is a relationship with the fruition and the social use of these spaces but the projects of TVB aim mainly at improving habitat quality.

7. Conclusions

Each experience has shown how a GI approach can contribute towards implementing the social-ecological quality of a territory and delivering value to sustainability and resilience. In particular, starting from the measurement of social-ecological quality of territories they are significant as they allow us to identify territorial and local stakes and delineate strategic and transversal design actions. It is difficult to decide which experience provides greater assistance towards achieving the objectives of sustainability and resilience; indeed, the choice of a proper method depends on different factors, such as data availability and precision, territorial features, and scale of analysis.

The activity of measuring ecological quality and the resilience of a system is a requirement for the construction and the selection of territories on which to attribute a transformative scenario in an integrated, reticular green system, that is a GI. GI is indeed a system which can guarantee multiple equilibria and the stability of a social-ecological system by increasing and maintaining ecosystem services. GI is also a fundamental tool for orienting towards an adaptive transformation through the selection of those territories which better fit as places of connectivity; this selection is made upon participatory processes, in both case studies, which give priority to the creation of biodiversity scenarios for the construction of a shared and desirable future. In this context, a GI project first has to be evaluative but as a second step it must be designed together with different territorial stakeholders; this approach could strongly contribute to the construction of a new, adaptive and less vulnerable cycle for territories.

With this in mind, it is important to underline how cities are increasingly giving higher importance to the role that society has to play; in particular, they are engaging on people empowerment and on the improvement of decision-making processes through the active participation of citizens in developing GI [73]. In resilience discussion, GI appears to be not just a design of systems or structures, but it is also a co-created and integrated process within complex social-ecological systems. With regard to sustainability, GI surely conveys an idea of the future based on a different ecological quality of a territory to which a dynamic fruition of the landscape has to be associated; the combined outputs can result in a weighted multi-scalar territorial choice highly anchored to the desiderata of territorial actors. Despite literature on the resilience of GI agrees that, if poorly planned, it can lead to decrease social inclusiveness [74], in our view it is fundamental to expand GI in planning mainly for their multifunctionality, for promoting diversity and for managing connectivity. It is furthermore essential to guarantee that the localization of connectivity systems is chosen through the measurement of ecological quality and functionality but also through social awareness of all possible networks, including the ones supporting the fruition of GI.

In conclusion, a sustainability and resilience strategy based on GI appears to be more adaptable not only to new and evolving territorial and societal challenges, but, as it can also be tailored to each local context, it can also provide multidimensional solutions to multidimensional challenges in cities. Additionally, we have noticed how literature on resilience is rapidly growing while there are still few studies on the linkages between urban project, urban form and resilience. In this context, a further step of the research is the shift from the measurement to the proposal of proper design and technological nature-based solutions at different scales, from the vast-scale to the lot one. These design and technological solutions can help to overcome different territorial vulnerabilities and shocks in the face of adaptation to climate change and quality of life.

Author Contributions: The article has been conceptualized, written, read and approved jointly by the two authors—A.V. and B.G.

Funding: This research received no external funding.
Conflicts of Interest: The authors declare no conflict of interest.

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Article

Indicators for Monitoring Urban Climate Change Resilience and Adaptation

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Received: 30 April 2019; Accepted: 21 May 2019; Published: 23 May 2019

Abstract: In the face of accelerating climate change, urbanization and the need to adapt to these changes, the concept of resilience as an interdisciplinary and positive approach has gained increasing attention over the last decade. However, measuring resilience and monitoring adaptation efforts have received only limited attention from science and practice so far. Thus, this paper aims to provide an indicator set to measure urban climate resilience and monitor adaptation activities. In order to develop this indicator set, a four-step mixed method approach was implemented: (1) based on a literature review, relevant resilience indicators were selected, (2) researchers, consultants and city representatives were then invited to evaluate those indicators in an online survey before the remaining indicator candidates were validated in a workshop (3) and finally reviewed by sector experts (4). This thorough process resulted in 24 indicators distributed over 24 action fields based on secondary data. The participatory approach allowed the research team to take into account the complexity and interdisciplinarity nature of the topic, as well as place- and context-specific parameters. However, it also showed that in order to conduct a holistic assessment of urban climate resilience, a purely quantitative, indicator-based approach is not sufficient, and additional qualitative information is needed.

Keywords: resilience; indicator; monitoring; climate change; climate adaptation

1. Introduction

Our society is facing multitudinous different challenges—in this paper we are focusing on two main challenges: climate change and urbanization. In 2015, 3.9 billion people were living in cities. By 2050, the population in cities is projected to reach up to 6.7 billion people [1]. Urban agglomerations will continue to grow and are increasingly threatened by the high uncertainty of climate change impacts [2]. In response to these impacts, cities are already implementing climate change adaptation measures in order to prepare for uncertain future changes. Adaptation to climate change and climate variability is not a new phenomenon [3]. However, steadily rising temperatures, increasing magnitude and frequencies of climate-induced extreme events, such as droughts, floods, storms or intense rainfall, as well as the growth of the global human population pose new adaptation challenges to humankind [3]. In our research, we use the term adaptation as defined by the United Nations Climate Change [4]: “Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and
structures to moderate potential damages or to benefit from opportunities associated with climate change”. Furthermore, the ability of adaptation is understood as part of resilience, as described by Folke et al. [5]. The concept of resilience can be attributed to Holling [6] and originates from ecology. He described resilience as the “measure of persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationship between population or state variables” [6]. The original concept of resilience gained increased importance in other disciplines, whereby the definitions of resilience were steadily differentiated, broadened and deepened. There are three main understandings of the character of resilience: “bounce back” which refers to the fast return to an equilibrium state of a system after a shock event, “bounce forward” which focuses on a system which should have capacities to be adapted to uncertainty and “both” which addresses the co-occurrence of the capacities for “bounce back” and “bounce forward” [7]. Meerow et al. [2] analysed 57 academic definitions of urban resilience, with particular regard to these fundamental understandings of urban resilience. The analysis showed that 35 definitions focus on “bouncing back”, 15 on “bouncing forward” and only seven see both capacities as elementary for resilience. Figueiredo et al. [8] pointed out that the definitions shifted from an equilibrium-centred understanding of resilience towards an evolutionary/transformational understanding of resilience. Four main approaches to resilience can be identified: disaster risk reduction [9], socio-ecological [10], sustainable livelihoods [11] and the community-oriented approach [12]. Resilience can also be discussed on different scales (county, region, urban area, city, community and household) [8]. Even though it is important to take action on all scales, in this work we are focusing on cities—particularly in Germany—and are using the socio-ecological approach. Besides the definitions and understandings of resilience in academia, it is very important to also consider how practitioners interpret resilience. Practitioners and policy makers are a central part of the resilience-transformation process. Therefore, it is remarkable that the term resilience is interpreted in a much wider range of ways by practitioners than by academia [13].

Adaptation measures are implemented in different sectors of the city system. Since cities are complex and multifaceted systems, which in turn contain other systems, measuring the success of resilience-increasing activities poses a particular challenge. However, measurement is of great importance in order to be able to govern and steer the adaptation and transformation process. Every city has its specific context and needs, and its exposure to risk and vulnerability is dynamic and changes over time [8]. However, it is important to develop measurable indicators for different reasons. Indicators enable monitoring of the resilience-building process, as they provide regular and impartial feedback. They build an evidence base and make resilience more tangible for decision and policy makers as well as society at large. Furthermore, indicators can help to govern and steer the transformation process because they help to structure the new field of urban climate resilience. Clear indicators are not only important for the general measurement of resilience, but also for the analysis of whether adaptation measures were effective and whether the expected results were achieved [14]. Indicators also contribute to the credibility, transparency and accountability of the measures implemented. This in turn is very important for local policy makers to support further adaptation measures.

However, the development of indicators in this context poses particular challenges. In addition to the conceptual challenges of urban climate resilience, context specificity represents another challenge for the development of resilience indicators. Consequently, it is very important to consider how to include context specificity in the indicator set. Another fundamental consideration is in regard to the context-specific, dynamic and ever-changing nature of risk and vulnerability [8].

MONARES (monitoring of adaptation measures and climate resilience in cities), a project funded by the German Federal Ministry of Education and Research (BMBF), was initiated in order to address the main challenges of (1) developing a consistent understanding of resilience for both practitioners and academia, (2) shaping the adaptation and transformation process into a transparent process of governing and steering and (3) the use of resilience and adaptation measurements. The aim of MONARES is to create application-oriented methodologies for monitoring and evaluating local
adaptation measures. As we are focusing on the special needs for cities in Germany, we are working together with 14 other projects of the funding initiative “Climate resilience through action in cities and regions” of the BMBF, who are focusing on climate change adaptation measures and urban resilience, as well as doing on-the-ground research in municipalities across Germany. These projects and cities differ considerably concerning scale (street, district, city, suburbs and region), inhabitants and type of adaptation measure (e.g., planning, physical infrastructure, capacity building or greening). Important commonalities of the projects are their interdisciplinary approach, the aim to enhance urban climate resilience and that they conduct on-the-ground research. However, the projects test many different pathways to improve resilience, and MONARES is focusing on how to measure the success and impact of these different projects and activities with a common set of indicators. In order to ensure applicability, we began to involve the projects at an early stage of our research. The first key step (Figure 1 Phase 1) before developing the indicators was to develop a framework [15] to describe urban resilience. Based on 19 frameworks described in the literature [16–34], our first draft was developed, which then was modified together with the projects. This process was indispensable as it resulted in a definition of urban resilience that is suitable for all projects so that there was agreement on common basic principles.

The climate resilience of a city depends on the ability of its sub-systems to anticipate the consequences of extreme weather and climate change, to resist the negative consequences of these events and to recover essential functions after disturbance quickly, as well as to learn from these events and to adapt to the consequences of climate change in the short and medium term, and transform in the long term. The more pronounced these abilities are, the more resilient a city is to the consequences of climate change. All abilities are important.

Based on this preliminary work, a four-step mixed-method approach (Figure 1 Phases 4–7) was designed to develop the indicators for urban climate resilience on which this paper focuses.

**Figure 1.** MONARES—research process.
2. Materials and Methods

The exponential growth of literature concerning urban resilience contains a multitude of approaches, indicators and methods stressing the resistance of an urban system. The development of the method of this paper was guided by the questions: resilience for whom, for what and where [35]. A reflexive approach of input and feedback loops was developed in order to adapt and validate international indicators. A main challenge was to adapt the indicators to the specific context of German communities in the face of climate change.

2.1. Literature Review: “Resilience Indicators”

The selected frameworks (see Figure 1 Phase 1) were identified through an extensive literature review using the key search terms “resilience”, “urban resilience”, “climate resilience”, “adaptive capacity + urban/city”, “resistibility + urban” and “learning capacity + urban/city” (in German and English). Based on these frameworks and their operationalisation of resilience, an extensive list of indicators was deduced. These indicators were matched with the MONARES framework, developed in steps 1–3, which consists of dimensions and action fields (see Table 1).

| Dimension   | Action Field                        |
|-------------|-------------------------------------|
| Environment | Soil and green spaces               |
|             | Water bodies                        |
|             | Biodiversity                         |
|             | Air                                 |
| Infrastructure | Settlement structure              |
|             | Energy                              |
|             | Telecommunication                    |
|             | Traffic                             |
|             | Drinking and wastewater             |
| Economy     | Innovation                          |
|             | Business                            |
|             | Economic structure                   |
| Society     | Research                            |
|             | Knowledge and risk competence       |
|             | Healthcare                          |
|             | Socio-demographic structure          |
|             | Civil society                       |
|             | Civil protection                    |
| Governance  | Participation                       |
|             | Municipal budget                    |
|             | Strategy, plans and environment     |
|             | Administration                      |

As we have the aim to develop a user-friendly, applicable and transparent indicator set, we firstly reduced the indicators to two indicators per action-field. The two most important selection criteria were (1) context specificity of industrial nations, especially Germany, and (2) data availability. Context specificity is important because many of the indicators in the literature are suitable for the context of the Global South but not for the Global North, and even indicators that might be suitable for the Global North might not be suitable in the German context. The second criteria—data availability—is therefore important because municipalities have, on the one hand, good access to a lot of data but have,
on the other hand, resource problems regarding time, finances and human resources. Action fields without literature-based indicators required the development of new ideas within the project. Given the available data, some action fields were difficult to measure without significantly neglecting the complexity of the action field.

2.2. Survey to Assimilate the Indicators for Context Specificity

Based on the literature review (see Figure 1 Phase 4) and the described selection process, an online-survey was developed (see Figure 1 Phase 5). The survey was used because, given that the indicators should be transparent and user-friendly, not only the scientific background is important, but a clear understanding of the indicators in the broad community is important also. The survey was sent to all persons who are working in one of the 14 projects mentioned above. 39 people answered the survey.

The main aim of the survey was to measure how participants assess the different indicators. They were requested to rate the importance of every indicator regarding urban climate resilience on a scale from one (low importance) to five (high importance). Each action field was represented by at least one indicator (Table 1). Besides the rating of indicators, the survey consisted of four chapters: First, some general background; Second, the context of urban climate resilience; Thirdly, the indicators; Fourthly, the possibility of extending the set of indicators by indicators without existing data sources, and some final remarks.

2.3. Workshop Following the Survey

As mentioned previously, the explanatory power of an indicator set of urban climate resilience is hugely dependent on the context, and therefore we discussed the results of the survey again with the 14 projects (see. Figure 1 Phase 6). Moreover, this feedback loop increases the transparency of the process and the robustness of the results. The workshop started with presenting the survey results and then the participants were split into two groups in order to create two independent feedback loops and cross-validation of the indicator set. For each group, a poster was prepared, listing all indicators included in the survey. The indicators that were ranked lower in the survey were written on the poster in light grey (compared to black), for an improved visualization of the survey results. Hence, both groups had the visual results to discuss and were asked to compare each pair in detail and find explanations for the survey results. In addition, the overall set remained visible, which allowed participants to keep the important question of the overall themes in mind. Therefore, indicators could be moved across the set or could become more important if they were deemed a missing piece in the mosaic. The guiding questions for this phase of the workshop were: (1) Are there enough indicators? (2) How many indicators are needed and sufficient? (3) Are the selected indicators the right ones or should they be changed? And (4) are there important gaps in the set that are yet to be filled?

2.4. Finalizing the Indicators Set

In Step 7 (see Figure 1) we analyzed the results of the workshop. Furthermore, expert interviews with practitioners were conducted with the aim to develop indicators in action fields where neither the literature review nor survey and workshop produced results. On this basis, we finalized the urban resilience indicator set.

3. Results

In our review of the academic literature, 19 indicator-based resilience frameworks were analyzed. Based on the indicators of these frameworks a list of 498 indicators (including duplicates) was generated. The indicator list was used as an important starting point for developing the MONARES Indicator Set (MIS). After screening the indicators through the lens of the MONARES-framework, some action fields remained empty and were filled by proposed indicators of the MONARES project-team. One to four
Indicators were selected per action field in order to cover all topics and include sufficient redundancy. Table 2 shows the selected and proposed indicators.

### Table 2. Delineated indicators and action fields.

| Dimension          | Action Field               | Indicator                                                                 | Code   | Literature |
|--------------------|----------------------------|----------------------------------------------------------------------------|--------|------------|
| **Environment**    | Soil and green spaces      | Degree of soil sealing                                                     | A_a_1  | [31]       |
|                    |                            | Land consumption                                                          | A_a_2  | [21]       |
|                    |                            | Recreational area                                                         | A_a_3  | [21]       |
|                    | Water bodies               | Share of water bodies                                                     | A_b_1  | [36]       |
|                    |                            | State of water bodies                                                     | A_b_2  | [23]       |
|                    | Biodiversity               | Share of nature conservation and protection areas                         | A_c_1  | [23]       |
|                    |                            | Wetlands and retention areas                                              | A_c_2  | [36]       |
|                    | Air                        | Cold air parcels                                                          | A_d_1  | [23]       |
| **Infrastructure** | Settlement structure       | Density of buildings                                                      | B_a_1  | [37]       |
|                    |                            | Accessibility of green spaces                                             | B_a_2  | [38]       |
|                    | Energy                     | Share renewable energy                                                    | B_b_1  | [18]       |
|                    |                            | Diversity renewable energy                                                | B_b_2  | [18]       |
|                    | Telecommunication           | Broadband access                                                          | B_c_1  | [37]       |
|                    | Traffic                    | Concept for sustainable traffic                                           | B_d_1  | [21]       |
|                    | Drinking and wastewater    | Number of springs                                                         | B_e_1  | [8]        |
| **Economy**        | Innovation                 | Innovation index                                                          | C_a_1  | [37]       |
|                    | Business                   | Ratio of insolvencies to start-ups                                        | C_b_1  | [22]       |
|                    | Economic structure         | Share of employees in largest sector                                      | C_c_1  | [39]       |
|                    |                            | Employees in research intensive companies                                 | C_c_2  | [40]       |
|                    | Research                   | Number of research projects                                               | D_a_1  | [18]       |
|                    | Knowledge and risk competence | Citizen information about heat, heavy rain and flooding                  | D_b_1  | [37]       |
|                    |                            | Experience with extreme events in last five years                         | D_b_2  | [37]       |
|                    | Health care                | Accessibility of hospitals                                                | D_c_1  | [41]       |
|                    |                            | Doctors per 10,000 citizens                                               | D_c_2  | [40]       |
|                    | Socio-demographic structure | Share of citizens ABVs/L65                                                | D_d_1  | [42]       |
|                    |                            | Share of employees                                                        | D_d_2  | [30]       |
|                    | Civil society              | Voter turnout                                                             | D_e_1  | [42]       |
|                    |                            | Number of associations                                                    | D_e_2  | [42]       |
|                    | Civil protection           | Fire brigade                                                               | D_f_1  | [37]       |
|                    |                            | Citizens in honorary positions                                            | D_f_2  | [31]       |
|                    | Participation              | Number of participation processes                                          | E_a_1  | [37]       |
|                    |                            | Contact point for participation                                          | E_a_2  | [37]       |
|                    | Municipal budget           | Depth per citizen                                                         | E_b_1  | [21]       |
|                    |                            | Tax income                                                                 | E_b_2  | [21]       |
|                    | Strategy, plans and environment | Risk and vulnerability analysis                                          | E_c_1  | [26]       |
|                    |                            | Strategies against heavy rain and heat in plans                           | E_c_2  | [26]       |
|                    |                            | Landscape plan legally binding                                            | E_c_3  | [37]       |
|                    |                            | Climate change adaptation part of urban development plan                   | E_c_4  | [30]       |
|                    | Administration             | Inter-office working group regarding risk, climate change and resilience   | E_d_1  | [37]       |
|                    |                            | Climate manager                                                           | E_d_2  | [37]       |
3.1. Survey about Resilience Indicators

The survey was structured based on the results of Phase 4. The survey (Figure 1 Phase 5) was filled out by 39 respondents within the funding initiative “Climate resilience through action in cities and regions” of the BMBF. The overall mean perceived importance of the indicators was 3.63 within the complete range from one to five. Considering the complexity of the urban system and the interdisciplinary character of the indicator set, this rating was regarded as high. The median of four was also high. The standard deviation of 1.17 together with the entire evaluation range reflected the diversity of interpretations. Nevertheless, despite this diversity, these core numbers show that the indicators were overall judged as important. Splitting the indicators into the five main dimensions (Figure 2), the median shows that only the indicators within the dimension of economy were rated less important, they are rated in the middle of the range, which might indicate a slight indecisiveness. Several reasons could explain this, such as that the indicators selected were not covering the dimension in a satisfactory manner or that the dimension is perceived as unrelated to urban climate resilience. Those questions were discussed in the workshop (Figure 1 Phase 6) in detail.

![Figure 2. Median importance of indicators grouped into five dimensions.](image)

All top five ranked indicators had a median rating of 5. The mean values ranged from 4.4 to 4.6. Only two respectively three respondents did not rate the indicators, showing the general agreement regarding the importance. Nevertheless, regarding the minimum values, all had a large range from 2 to 5.

The set of five indicators in Table 3 shows that the three dimensions environment, governance and society were seen as particular important. The indicator rated as the most important was the environment indicator cold air parcels. Second and fourth ranked were governance indicators, namely inter-offices working groups regarding risk, climate change and resilience and strategies against heavy rain and heat in plans. Third and fifth ranked were two indicators from the dimension society. The respondents saw the importance of experience with extreme events in the last five years and citizen information about heat, heavy rain and flooding as particularly crucial for building urban resilience.

| Dimension | Action field | Indicators                                                                 | Min. | 1st | Median | Mean | 3rd | Max |
|-----------|--------------|-----------------------------------------------------------------------------|------|-----|--------|------|-----|-----|
| Environment | Air          | Cold air parcels                                                            | 2    | 4   | 5      | 4.6  | 3   | 5   |
| Governance | Administration | Inter-offices working groups regarding risk, climate change and resilience | 2    | 4   | 5      | 4.4  | 3   | 5   |
| Governance | Strategies    | Against heavy rain and heat in plans                                       | 3    | 4   | 5      | 4.4  | 3   | 5   |
| Society   | Knowledge and competence | Experience with extreme events in last five years | 3    | 4   | 5      | 4.6  | 3   | 5   |
| Society   | Knowledge and competence | Citizen information about heat, heavy rain and flooding | 3    | 4   | 5      | 4.5  | 3   | 5   |
Table 3. The five indicators rated as most important in the survey.

| Dimension      | Action field                   | Indicator                                                                 | Min. | 1st Quartile | Median | Mean | 3rd Quartile | Max | N/A |
|----------------|--------------------------------|---------------------------------------------------------------------------|------|--------------|--------|------|--------------|-----|-----|
| Environment    | Air                            | Cold air parcels                                                          | 2    | 4            | 5      | 4.6  | 5            | 5   | 3   |
| Governance     | Administration                 | Inter-offices working group regarding risk, climate change and resilience | 2    | 4            | 5      | 4.5  | 5            | 5   | 2   |
| Society        | Knowledge and competence       | Experience with extreme events in last five years                          | 3    | 4            | 5      | 4.5  | 5            | 5   | 3   |
| Governance     | Strategy, planned and environment | Strategies against heavy rain and heat in plans                           | 2    | 4            | 5      | 4.5  | 5            | 5   | 3   |
| Society        | Knowledge and competence       | Citizen information about heat, heavy rain and flooding                   | 2    | 4            | 5      | 4.4  | 5            | 5   | 2   |

Table 4 displays the five lowest ranked indicators in context of their relevance related to urban climate resilience. The overall lowest rated indicators were both from the society dimension, namely voter turnout and number of associations. The respondents did not think that they were relevant for measuring and monitoring urban resilience. The third lowest indicator was the infrastructure indicator broadband access. Fourth and fifth were two economic indicators measuring ratio insolvencies to start-ups and share employees in largest sector.

Table 4. Five lowest rated indicators.

| Dimension      | Action field                   | Indicator                           | Min. | 1st Quartile | Median | Mean | 3rd Quartile | Max | N/A |
|----------------|--------------------------------|-------------------------------------|------|--------------|--------|------|--------------|-----|-----|
| Society        | Civil society                  | Voter turnout                       | 1    | 2            | 3      | 2.4  | 3            | 4   | 1   |
| Society        | Civil society                  | Number of associations              | 1    | 2            | 3      | 2.6  | 3            | 4   | 2   |
| Infrastructure | Telecommunication              | Broadband access                    | 1    | 2            | 3      | 2.8  | 4            | 5   | 3   |
| Economy        | Business                        | Ratio insolvencies to start-ups     | 1    | 2            | 3      | 2.8  | 3.5          | 5   | 4   |
| Economy        | Economic structure              | Share Employees in largest sector   | 1    | 2            | 3      | 2.8  | 3            | 4   | 6   |

Figure 3 displays boxplots of all indicators. The main tendency has already been shown in a more condensed form previously in Figure 2. Share of nature conservation and protection areas (A_c_1) was the lowest ranking in the dimension environment. The second indicator of the action field biodiversity, however, received high approval, which emphasised the perceived importance of biodiversity considerations for climate resilience in the urban context. Settlement structure (B_a_1&2) was seen as vital for structural climate change adaptation, similar to the first action fields of soil and green spaces (A_a_1-3).

Energy (B_b_1&2) indicators, in contrast, not only ranged from a rating of one to five, but the quartiles of the boxplot also show a comparably high range around the middle of the scale.
3.2. General Workshop Results Regarding the MIS

The discussion of the indicators during two discussion groups yielded important feedback on the overarching attributes and requirements of the MIS. They were mentioned several times from different persons and related to different indicators. Firstly, one important aspect was the size of the municipality and hence the scaling of the indicator. No universal scaling was found appropriate, since the different units and scales required indicator-specific scaling. Nevertheless, the scaling was seen as an important factor in order to reach the goal of acquiring indicators for municipalities and therefore an interpretable result on this level of administrative organization.

The overall discussion about applicability and feasibility was touched on in many ways from different angles, most prominently regarding data availability, numbers of indicators and total effort needed. The balancing of the loss of information related to simpler indicators or vice versa with more complex indicators with higher explanatory power but with an infeasibility to be handled by the target group was seen as a key challenge. Therefore, the participants agreed that the indicators should be based solely on existing data, thereby reducing the overall effort and simplifying the calculations and data management.

The idea of detailed factsheets describing the data source and calculation of the indicator and helping with the interpretation of the result was raised by participants and received wide support. Factsheets also help to communicate the meaning of an indicator to uninitiated persons, which was also mentioned as a crucial aspect.

The total number of indicators to be feasible was seen at around 25. Certain gaps were identified during the workshop due to the fact that specific expertise related to certain action fields was missing.
in the room, specifically regarding the action fields energy, wastewater and civil protection. Here, single expert interviews were carried out after the workshop to fill in the gaps.

3.3. Indicator Specific Workshop Results

Table 5 summarizes the process of indicator development during the three phases of the survey, the workshop and ending in the final set of indicators. The indicators highlighted in grey are those of the initial indicator set that were seen as important by survey respondents and therefore stayed on the list. The indicators highlighted in orange were updated or modified as a result of the survey and/or workshop. The yellow indicators were moved from one action field to another. The indicator degree of soil sealing was inverted to degree of unsealed ground, as sealing is not per se negative, even may even be desirable or unavoidable in urban areas. The cold air parcels was seen as an important factor of resilience but should be updated, adding cold air streams to the indicators. Biodiversity was discussed in contradictory ways, as it was not clear to the participants how it is related to climate hazards. Hence, the workshop resulted in representing urban biodiversity with the indicator wetland and retention areas in order to include flood protection arguments into the indicator of biodiversity.

Infrastructure was seen undoubtedly as a key area for achieving urban climate resilience, but also related to secondary data and its inherent complexity most difficult to quantify currently. Accessibility of green spaces was rather seen as an indicator of social justice and less as a settlement structural indicator and hence the second indicator building density, slightly lower ranked in the survey, was included instead. The share of renewable energy indicator focused strongly on climate protection and less on resilience factors, such as robustness and redundancy. These factors were seen to be better covered by the diversity of renewable energy sources. However, it was also argued that even conventional energy should be included in the indicator. This observation was followed by the consideration that no climate resilience can be achieved without climate protection in the long term. Therefore conventional energy sources cannot be regarded as a positive contribution to climate resilience in the long term. The action field of telecommunication was deleted in accordance with the participants’ perception of this as being less important than the other action fields, lacking data and having low to no influence of the municipality. Instead, the action field wastewater treatment was included, as there was agreement on its importance additionally to the supply side. No specific indicator was defined in the workshop due to missing competence in this regard. Transportation was discussed as an important action field for municipalities, but participants agreed that its complexity cannot be covered by one indicator. Therefore, the action field remained as an action field of the framework, reminding of the importance of the topic and urging municipalities to consider and discuss it qualitatively.

The discussion around the economic dimension reflected the lower ranking of its indicators in the survey. The dimensions environment and infrastructure were seen to be more naturally linked to resilience than the economic dimension. Nevertheless, discussing the importance of a resilient economy for an urban system generated acceptance for the dimension and its components. This example illustrates one very important lesson of the workshop: the need for explanation and building a common understanding. Innovation was seen to be covered best by the number of employees in research intensive companies not by the innovation index. The tax income from companies was considered an important resource for the financial ability of the municipality to adapt. This indicator was part of the action field municipal budget in the survey and has since been moved to business. Similar to energy, a diverse economy was considered more robust, flexible and redundant when facing uncertainty of climate impacts. It was also discussed whether there might be sectors with crucial or higher relevance than others, but the group agreed that no single sector could be selected.

There was a general agreement on the importance and contribution of society to urban climate resilience, but less agreement on how to measure it quantitatively. Literature shows that the experience with extreme events contributes positively to citizens’ resilience. In addition, citizen information about heat, heavy rain and flooding (Table 3) was amongst the top five rated indicators. However, regarding the spatial scale of municipalities, it was argued that information is not only provided by the local authority
and therefore the indicator was not further considered. Civil society started an intense discussion on how to measure it and if the proposed indicators were adequate. In contrast to the survey, where the indicator voter turnout ranked higher, the workshop participants disliked this indicator, arguing that voter turnout nowadays cannot be seen as a proxy indicator for solidarity and community in Germany. The indicator associations was also critically reflected upon as being unable to capture civil society entirely. Still, the participants were in favour of the imperfect indicator associations instead of deleting the action field. In the survey, the dimension governance and its indicators were ranked high, and this result was confirmed in the workshop. Only one change was decided: replacing the contact point for participation processes with the number of conducted participation processes. Both were ranked very close in the survey with a mean of 3.3 and 3.4, respectively.

Table 5. Indicator set after the survey, workshop and final set.

| Dimension          | Action Field                  | Survey Result                      | Workshop Result                        | MIS                  |
|--------------------|--------------------------------|------------------------------------|----------------------------------------|----------------------|
| Environment        | Soil and green spaces         | Degree of unsealed ground          | Degree of unsealed ground              | Degree of unsealed ground |
|                    | Water bodies                  | State of water bodies              | State of water bodies                  | State of water bodies |
|                    | Biodiversity                  | Wetlands and retention areas       | Wetlands and retention areas           | Nature conservation and protection areas |
|                    | Air                            | Cold air parcels                   | Cold air parcels and flows             | Ventilation status   |
| Infrastructure     | Settlement structure          | Accessibility of green spaces      | Building density                       | Building density     |
|                    | Energy                        | Share renewable energy             | Diversity of renewable energy          | Diversity of renewable energy |
|                    | Water supply and wastewater treatment | Number of springs                  | Number of springs                      | Number of springs    |
|                    | (Including wastewater indicator) |                                | (Including wastewater indicator)       | Adapted sewer system |
| Economy            | Innovation                    | Innovation index                   | Employees in research intensive companies | Employees in research intensive companies |
|                    | Business                      | Ration insolencies to start-ups    | Commercial tax per capita              | Commercial tax per capita |
|                    | Economic structure            | Employees in research intensive companies | Diversity of business                  | Diversity of business |
| Society            | Research                      | Number of research projects        | Number of research projects            | Number of research projects |
|                    | Knowledge and risk competence | History with extreme events        | History with extreme events            | History with extreme events |
|                    | Health care                   | Accessibility of hospitals          | Accessibility of hospitals              | Number of doctors    |
|                    | Sociodemographic structure    | Share of citizens ABV6/U65         | Share of citizens ABV6/U65             | Share of citizens ABV6/U65 |
|                    | Civil society                 | Voter turnout                      | Associations per 10000 capita           | Associations per 10000 capita |
|                    | Civil protection              | Fire brigade                        | Fire brigade                            | Fire brigade volunteers |
| Governance         | Participation                 | Contact point for participation    | Number of participation processes      | Number of participation processes |
|                    | Municipal budget              | Depth per citizen                  | Depth per citizen                       | Depth per citizen    |
|                    | Strategy, plans and environment | Risk and vulnerability analysis    | Risk and vulnerability analysis        | Risk and vulnerability analysis |
|                    | Administration                | Inter-offices working group regarding risk, climate change and resilience | Inter-offices working group regarding risk, climate change and resilience | Inter-offices working group regarding risk, climate change and resilience |

3.4. Urban Climate Resilience Indicator Set

Since even the diverse group of participants of the workshop did not cover all topics of the indicator set, experts were interviewed. Furthermore, the results of the survey and the results of the workshop were summarized and merged.
The final set of indicators is shown in Table 5 in the column MIS. Compared with the workshop set, the action field of biodiversity was seen crucial in its own right and better approximated by the indicator nature conservation and protection areas. Moreover, wetlands and retention areas were already covered by the state of the water bodies in line with the European Water Framework Directive regarding good ecological and chemical status. Hence, in order to create a balanced set of indicators, it was seen that the latter indicator added thematically more information and another aspect to the overall set. Secondly, the air action field was further developed, as cold air parcels and flows was difficult to interpret. The simple number or share of cold air parcels and streams were not clearly related to resulting air status. The ventilation status including the effects of air streams and cold air production parcels was therefore selected. For the wastewater action field introduced by the workshop, an expert interview recommended the indicator share of adopted sewer system. Another interview was conducted with the lower civil protection agency. The interviewee stressed the importance of volunteers across organizations, but as no data were gathered assessing the total numbers of volunteers, the most important one of the fire brigade was considered. Moreover, the municipality may have to consider this important topic even more in the future, as the principle of volunteers may be endangered due to demographic development. Finally, yet importantly, the accessibility of hospitals was interchanged with the density of doctors.

4. Discussion

The results from the work on indicators for monitoring urban climate resilience presented above yields a number of important insights and implications—with respect to previous studies but also for future research and for practitioners in this field.

Existing indicator sets are a good starting point, but adapting and extending them for the context at hand is crucial. There are numerous indicator sets for urban resilience; these provided a good basis from which the MONARES indicator set could be developed. However, many of the indicators analysed in the literature review were aimed at the context of developing countries. To adapt indicators identified in the review for the German context, four steps were important: (A) Disregarding indicators that do not allow sufficient distinction between cities, e.g., literacy rate is favoured as an indicator in many sources, but in Germany the literacy rate is rather high and differences between cities are marginal. (B) Disregarding indicators for which the data availability was rather limited in Germany. (C) Adding new indicators for action fields that are deemed important in the context of MONARES but which were not touched upon in the literature. (D) Focusing on municipalities as the key player for climate change adaptation. These level of municipalities require the set to be manageable in terms of data availability as well as size and complexity of the calculations.

Step A did not pose any major difficulties. Further, step B based on research concerning data availability did not cause problems. However, step C and D need to be examined in more detail.

First, the workshop clearly stated here the conflicting goals when discussing single action fields. It was felt that one indicator does not reflect the entirety of the topic, but at the same time all action fields were considered important and the total number of indicators should not exceed around 20, in order to stay manageable, which is far less than the proposed 52 indicators by the City Resilience Index (CRI) [22] and comparable to the core of 14 by the project Building Resilience Amongst Communities in Europe (embrace) [37] or Cutter’s [43] core of 22. Since researchers, as well as practitioners, participated in our workshop, we had the impression that researchers tended to prefer larger, encompassing indicator sets. Compared with the scientists, practitioners were more in favour of concise and compact sets. The discussions in the workshop showed that persons with a research background had numerous ideas for new indicators for all dimensions, and advocated for their inclusion. During the workshop and its aftermath, practitioners working in municipalities displayed a different tendency—their perspective tended to focus more on how to handle the indicators in practice. Hence, what some researchers considered a concise indicator set was perceived by practitioners as overwhelming and too extensive. In order to find an adequate balance between a broad coverage and good usability in practice, it
is important to involve both researchers and practitioners in the development of an indicator set. This finding is consistent with the literature and is one strength of the current study. Meerow and Stults [13], for example, stress the need for including practitioners in the process. Consequently, the trade-off between practicability and completeness had to be balanced, leading to the fact that some indicators that were considered important were still sorted out in order to cover all action fields and still achieve a manageable amount of indicators.

Second, it was mentioned that the indicators just by title were not clear in terms of their effect on and relation to urban climate resilience, and were consequently rated around the middle. This fact was considered while developing the survey, but an in-depth explanation of indicators was removed from the survey in favour of including more indicators covering all action fields and in consideration of the time needed to fill out the survey. However, this lack of explanations meant that the disciplinary background of respondents affected the ratings.

Third, indicators from the dimension environment were met with relatively high consensus while indicators from the dimension economy were faced with more diverging opinions. The indicator selection was dependent on the conceptualization of urban resilience and the urban context. The results contribute to the gap between the understanding of urban resilience by scholars and practitioners [13]. This became apparent both in the survey and the workshop and shows that more research is warranted on what characterizes a climate resilience urban economy. Supporting evidence for this can be taken from the fact that much more has been published on climate resilience and environmental issues than on climate resilience and economic issues. Moreover, this discussion displayed the importance of a negotiation-focused approach for defining place-specific attributes of urban resilience and its measures [44].

Fourth, secondary data was seen as crucial for monitoring purposes in order to reduce resource expenditure by the administration. In other words, “The best indicator is inoperable if there is no feasible way to obtain the required data.” [37]. Moreover, there was a strong request from the local administrations for more provision of data from the higher administrations. They argued that data handling, data collection and finances for these activities are lacking. They stressed the need for data provision to be handled at the higher level of administration to avoid scaling and data comparability issues. Hence, data availability for indicators on a municipal level is a strong limiting factor, especially when it comes to indicators concerning infrastructure and social aspects [45]. Parts of the infrastructure related to energy, transport and communication are owned or organized by entities on a higher administrative level, such as the national government or by private entities. This tends to lead to limited data availability when it comes to data with a sufficient resolution on a municipal level. Here it would be favourable if entities in charge of the respective infrastructure made access to data easier and provided data with a resolution that is suitable for analyses on a municipal level. Moreover, the discussion centred around technical measures and physical impacts and less about social drivers and demographic changes. The latter are seen as core aspects of the community’s ability to resist unforeseen threats. Nevertheless, the intense discussion around the proxies suggested by literature displayed vividly the intricacy of social dynamics. New data and methods from the higher administration or crowd-sourced databases are needed to better understand and monitor the indicators [43].

Fifth, it is important to mention that a conflict of goals among indicators can arise and can lead to a competition for the scarce resources. These reciprocal processes cannot be completely avoided. For example: impervious surfaces are seen negative regarding heavy rain, fresh air and heat island effects, but they are necessary for a redundant infrastructure and other urban functions. Another example is provided by Meerow and Newell [35] who analysed the negative correlation of park access and stormwater management goals, concluding that resilience measures create winners and losers. This also requires transparency of the data and the method of the indicator definition to understand the root causes of the conflicting goals and find adequate solutions. Here the Rockefeller [22] approach seems like a black box because it is difficult to deduce what adaptation measures are used as a data basis, and indicator calculations are unclear. During the workshop, several practitioners
mentioned consequently the necessity of transparency and the need for precise communication and non-scientific language.

Sixth, following the previous point, many indicator approaches are used to build a composite index for resilience [19,22,45–47], vulnerability [18,48–52] or risk [53–55]. Specifically, at the scale of urban resilience, indexing across the multitude of action fields was discussed critically. The different scales, topics and units appeared to not be logically linkable. Moreover, a combined index value was seen to not tell much about the level of resilience. It was seen as more important to see the contribution of each action field to the overall resilience. Also, considering the next step of adaptation measures, it is more relevant to have a resilience profile displaying specific topics to be addressed in the municipal context.

Working at the science-policy interface was challenging for all sides. The mixed method approach proved invaluable in finding a common language, tolerance and understanding. This created an environment that allowed for constructive criticism, which is indispensable for finding a compromise.

5. Conclusions

In this study, we developed an indicator set to measure and monitor urban climate resilience for municipalities, thereby assessing the requirements of indicators and implementing a method for adapting global approaches to the local context.

The mixed method approach proved to be essential for the process of indicator development. It provided an adequate frame and time to develop a mutual understanding across disciplines, researchers and practitioners, which is needed in order to select indicators or accept indicators from different fields of expertise. Transparency in the process and the inclusion of feedback builds acceptance and trust. The concept of resilience provided the required assembly hall and saw climate change as the imperative. Even the often-criticized ambiguity of the resilience concept was helpful as it created room for discussion. The number of 24 indicators based on secondary data balanced as well as possible the diverging interests. Amongst the indicators, conflict of goals is unavoidable. Making the conflicts visible is a helpful basis for making informed decisions, which is a strength of this indicator set. In general, the softer and more qualitative aspects of resilience are challenging. They were seen as crucial but very hard to assess by quantitative proxies based on secondary data. Still, representative surveys to cover them in more detail on a regular basis were rejected by municipalities as too expensive and labour-intensive.

Developing an indicator set tends to be easier than assessing the significance or validity of an indicator over time and it requires an extended period of observations to be able to make statements about the significance of a certain indicator. Nevertheless, in order to advance this field of research, it is necessary to pursue this path and start inquiries into the significance or validity of the numerous indicators that are permeating the ongoing discussions. In further research, the indicators need to be tested in reality, and there needs to be more research that addresses the validation of the indicators.

Author Contributions: Conceptualization: D.F., D.W., C.K., T.K., R.G., C.D., and J.B.; data curation: D.F., D.W.; funding acquisition: C.K., T.K., R.G., C.D., and J.B.; methodology: D.F., D.W.; writing—original draft: D.F., D.W.; writing—review & editing: D.F., D.W., C.K., T.K., R.G., C.D., J.B.

Funding: This research received no external funding.

Acknowledgments: The research leading to these results has received funding from the German Federal Ministry of Science and Education (BMBF) for the research Monitoring and Evaluation of climate resilience and urban adaptation measures (MONARES). The paper reflects only the authors’ views, and the German Ministry is not liable for any use that may be made of the information contained herein.

Conflicts of Interest: The authors declare no conflict of interest.

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Erratum

Erratum: Urso, G., et al. Resilience and Sectoral Composition Change of Italian Inner Areas in Response to the Great Recession. *Sustainability* 2019, 11, 2679

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Received: 14 June 2019; Accepted: 19 June 2019; Published: 21 June 2019

The authors would like to make the following corrections to the published paper [1]. The changes are as follows:

1. Replacing the descriptions:

   Figure 2, presented above, can help us distinguish areas as pro-trend vs anti-trend in this way:

   1. If a municipality grows more than the nation in growing sectors at the national level (Area $EC_i^+$), and declines in declining sectors at the national level (Area $EC_i^-$) then it is “pro-trend”.

   2. Oppositely, if most of the excess of change lines are in the Areas $EC_i^+$ and $EC_i^-$, municipalities are defined as “anti-trend”.

   with

   Figure 2, presented above, can help us distinguish areas as pro-trend vs anti-trend in this way:

   - If a municipality grows more than the nation in growing sectors at the national level (Area $EC_i^+$), and declines in declining sectors at the national level (Area $EC_i^-$) then it is “pro-trend”.

   - Oppositely, if most of the excess of change lines are in the Areas $EC_i^+$ and $EC_i^-$, municipalities are defined as “anti-trend”.

The authors and the Editorial Office would like to apologize for any inconvenience caused to the readers by these changes. The changes do not affect the scientific results. The manuscript will be updated and the original will remain online on the article webpage.

References

1. Urso, G.; Modica, M.; Faggian, A. Resilience and Sectoral Composition Change of Italian Inner Areas in Response to the Great Recession. *Sustainability* 2019, 11, 2679. [CrossRef]

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Article

Dynamic Models for Exploring the Resilience in Territorial Scenarios

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Received: 16 October 2019; Accepted: 4 December 2019; Published: 18 December 2019

Abstract: The present paper focuses on the role covered by dynamic models as support for the decision-making process in the evaluation of policies and actions for increasing the resilience of cities and territories. In recent decades, urban resilience has been recognized as a dynamic and multidimensional phenomenon that characterizes urban and metropolitan area dynamics. Therefore, it may be considered a fundamental aspect of urban and territorial planning. The employment of quantitative methods, such as dynamic models, is useful for the prediction of the dynamic behavior of territories and of their resilience. The present work discusses the system dynamics model and the Lotka–Volterra cooperative systems and shows how these models can aid technicians in resilience assessment and also decision makers in the definition of policies and actions, especially if integrated in wide evaluation frameworks for urban resilience achievements. This paper aims to provide an epistemological perspective of the application of dynamic models in resilience assessment, underlying the possible contribution to this issue through the analysis of a real case study and methodological framework. The main objective of this work is to lay the basis for future compared applications of these two models to the same case study.

Keywords: urban resilience; dynamic models; decision making; scenario planning

1. Introduction

Cities and territories across the world are increasingly exposed to a number of risks, hazards and stresses [1,2]. These affect all urban system dimensions, from the environmental to the social and economic [3,4]. Therefore, the concept of resilience is increasingly being used in urban and territorial policy in order to prepare urban systems for hazards and uncertainties [2,5,6]. Urban resilience is defined as a dynamic and multidimensional phenomenon that characterizes metropolitan areas as complex systems at all scale dimensions [7–9]. Urban resilience is related to several disciplines and domains, such as risk reduction, climate change and adaptation strategy. More recently, urban resilience has also been involved in the definition of policies and actions for achieving urban and territorial purposes [2,7,9]. The guidelines for increasing urban resilience are effective planning procedures—the identification and prioritization of which require the involvement of experts with specific competences and from different disciplines in the decision-making process [10]. This paper explores the role of dynamic models in support of the definition of policies and actions to enhance urban resilience. These models belong to the family of mathematical modelling, which is able to simulate the behavior of complex systems over time by using a set of Ordinary Differential Equations (ODEs). In this paper, dynamic models are investigated according to methodological background and operative characteristics. The main aim is to consider their general characteristics and peculiarities in order to underline dynamic model (DM) features that are closely related to the
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decision-making process in territorial and urban planning [11]. DMs are recognized as suitable tools to evaluate policies and actions aimed at increasing urban resilience [12–14]. This property is related to the fact that these models are built and grounded on dimensions related to both urban systems and urban resilience. In fact, during the construction of the model, it is necessary to select and identify which aspects of a territorial system have to be included with reference to the evaluation goal, from the environmental to the economic dimension [11,12,15]. In this sense, DMs are able to reveal both the dynamic behavior of urban and territorial systems and the impacts of policies on the key variables identified.

Specifically, the main aim of this work is to study the principal characteristics of the system dynamics model (SDM) and Lotka–Volterra models (LV) in order to apply both to the same case study. The final purpose of this investigation is to understand the importance of the modelling approach in the field of resilience evaluation.

The paper is structured as follows: Section 2 describes the current state of the art of resilience and urban resilience; Section 3 explains the role of dynamic models—the system dynamic models (SDM) and Lotka–Volterra models (LV)—in the decision-making process and summarizes their methodological background, state of art and some illustrative examples; Section 4 explains how the SDM models and LV models could contribute to urban planning; a comparative matrix is developed to investigate the utility of the considered models in predicting support in the design of future transformation scenarios; and Section 5 includes some final remarks and future perspectives.

2. State of Art of Resilience and Urban Resilience

The concept of resilience is used in a wide range of disciplines and domains such as psychology [16,17], ecology [18], engineering [19,20], socio-ecological systems [21–23], climate change and adaptation [24–26], urban planning [27,28] and disaster risk management [9,29–32]. Furthermore, in the last two decades, resilience has become an important goal for cities that are often theorized as highly complex with an adaptive system [32–34].

The term “resilience” came from the Latin word resilio, which literally means “to bounce back” [35]. However, its origins, meanings and interpretations are quite ambiguous [36,37].

Table 1 summarizes some of the most representative definitions of resilience in different disciplines. It reveals that engineering, ecological and socio-ecological resilience are the most used definitions in literature [38]. Furthermore, this table makes clear the division between the dynamic and the static interpretation of resilience [32].

The static interpretation refers to the engineering definition [9], whereas the dynamic interpretation is related to the socio-ecological perspective [18]. Engineering resilience should be understood as the measure of the speed with which the system can return to its previous equilibrium. Therefore, the engineering perspective does not consider the transformation [32]. On the other hand, the socio-ecological perspective is grounded on the assumption that a return to the previous equilibrium may be not possible in complex ecosystems [32,39]. Socio-ecological resilience refers to the capacity of the system to transform itself, thus returning to a previous equilibrium.
Table 1. Representative resilience definition by different fields (Elaboration from Meerow, 2016 and Bharma et al., 2011).

| Author                  | Field                               | Definition of Resilience                                                                 | Static or Dynamic |
|-------------------------|-------------------------------------|----------------------------------------------------------------------------------------|-------------------|
| Holling, 1973           | Ecology                             | “The ability of these systems to absorb changes of states variables, driving variables, and parameters, and still persist” (p. 17). | Dynamic           |
| Pimm, 1984              | Ecology                             | “How fast the variables return towards their equilibrium following a perturbation” (p. 322). | Static            |
| Carpenter et al., 2001  | Social-ecological systems           | “The magnitude of disturbance that can be tolerated before a socioecological system (SES) moves to a different region of state space controlled by a different set of processes” (p. 765). | Dynamic           |
| Adger, 2000             | Geography                           | “The ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change” (p. 347). | Dynamic           |
| Rose, 2007              | Economics                           | “The speed at which an entity or system recovers from a severe shock to achieve a desired state” (p. 384). | Dynamic           |
| Fiksel, 2006            | Systems engineering                 | “The capacity of a system to tolerate disturbances while retaining its structure and function” (p. 16). | Dynamic           |
| Zhu and Ruth, 2013      | Industrial ecology                  | “The ability [for industrial ecosystems] to maintain their defining feature of eco-efficient material and energy flows under disruptions” (p. 74). | Dynamic           |
| Zeng and colleagues, 2013 | Networks                           | “The critical threshold at which a phase transition occurs from normal state to collapse” (p. 12). | Static            |
| Ouyang, 2014            | Engineering                         | “The joint ability of a system to resist (prevent and withstand) any possible hazards, absorb the initial damage, and recover to normal operation” (p. 53). | Static            |
| Adger, 2000             | Social resilience                   | “Ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change” (p. 347). | Static            |

This recognition is fundamental to understand which perspective may be adopted to analyze an urban system, in order to concern about urban resilience with the correct background.

At the beginning, it was particularly referred to climate change [40,41]. Subsequently, in the latest studies [7,9,42] it has also been related to stresses and hazards which effect the different dimensions of an urban system [33]. From a careful literature review, what emerges clearly about urban resilience are these highlights: (1) The most important study of resilience applied on urban systems is Holling’s studies which referred to socio-ecologic resilience [43]; (2) Urban resilience is defined as a complex and multi-dimensional phenomenon [9]; (3) Urban resilience is not a static condition, but it is a dynamic process in spatial and temporal scales [8]; (4) There is not a unique definition [32]; and (5) Urban resilience has recognized an increase in literature, in academic studies, political studies, social debate and urban planning [9,30,36,44–46].

From these aspects, this paper aims to focus on the definition of urban resilience to highlight the communalities and differences in academic and policy debate. The objective of this analysis is to highlight the malleability of the urban resilience concept and to stress on its implications in policy definition [47]. Table 2 lists a series of definitions on urban resilience by considering academic and political references with the purpose to better understand what the needs and the tools are to be employed as support of the decision-making process for building resilient cities.
This means that building urban resilience requires looking at urban and territorial systems holistically. It is necessary to understand cities in all dimensions and identify interdependencies and risks they may face.

| Authors and Year | Definition | Field |
|------------------|------------|-------|
| Meerow et al., 2016 | “Urban resilience refers to the ability of an urban system—and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity” (p. 39). | Academic |
| 100 Resilient City Campaign, 2013 | “Urban resilience is the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience” (p. 10). | Political |
| UN-Habitat | “Urban resilience is the measurable ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability” (p. 5). | Political |
| Urbact, 2004 | “Urban resilience is the capacity of urban systems, communities, individuals, organisations and businesses to recover, maintain their function and thrive in the aftermath of a shock or a stress, regardless its impact, frequency or magnitude” (p. 6). | Political |
| Desouza and Flanery, 2013 | “Urban resilience is the ability to absorb, adapt and respond to changes in urban systems” (p. 89). | Academic |
| Hamilton, 2009 | “Urban resilience is the ability to recover and continue to provide their main functions of living, commerce, industry, government and social gathering in the face of calamities and other hazards” (p. 109). | Academic |
| Lu and Stead, 2013 | “Urban resilience is the ability of a city to absorb disturbance while maintaining its functions and structures” (p.200). | Academic |
| Thornbush et al., 2013 | “Urban resilience is a general quality of the city’s social, economic, and natural systems to be sufficiently future-proof” (p. 2). | Academic |
| Leichenko, 2011 | “Urban resilience is the ability to withstand a wide array of shocks and stresses” (p. 164). | Academic |
| Romeo—Lankao and Gnatz, 2013 | “Urban resilience is a capacity of urban populations and systems to endure a wide array of hazards and stresses” (p. 358). | Academic |
| OECD, 2016 | “Resilient cities are cities that have the ability to absorb, recover and prepare for future shocks (economic, environmental, social and institutional). Resilient cities promote sustainable development, well-being and inclusive growth”(p.3). | Political |
| Resilience Alliance, 2002 | “A resilient city is one that has developed capacities to help absorb future shocks and stresses to its social, economic and technical systems and infrastructures, so as to still be able to maintain essentially the same functions, structures, systems and identity” (p.4). | Political |
| ICLEI, 2015 | “A resilient city is prepared to absorb and recover from any shocks or stress while maintaining its essential functions, structures and identity as well as adapting and thriving in the face of continual change. Building resilience requires identifying and assessing hazard risks, reducing vulnerability and exposure, and lastly, increasing resistance, adaptive capacity and emergency preparedness” (p.1). | Political |
| C40, 2017 | “Cities are the forefront of experiencing a host of climate impacts, including coastal and inland flooding, heat waves, droughts, and wildfire. As a result, there is widespread need for municipal agencies to understand and mitigate climate risks to urban infrastructure and services and the communities they serve”(p.1). | Political |
| Urban Resilience HUB, 2015 | “The measurable ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability” (p.6). | Political |
| UNISDR, 2015 | “The ability of a system, community or society exposed to hazards, to resist, absorb, accommodate, adapt to, transform and recover from its effects in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management” (p.3). | Political |

These different definitions are listed to underline their communalities and differences in their meaning. They are different from the formal point of view. However, all these definitions concern with the multidimensional and transformative approach of urban resilience [7]. They also focus the attention on the dynamic behavior of resilience processes both in spatial and time scales [6].

This means that building urban resilience requires looking at urban and territorial systems holistically. It is necessary to understand cities in all dimensions and identify interdependencies and risks they may face.
For this application, the definition of Meerow et al. [32] has been considered for its holistical view of urban systems and its attention to both spatial and temporal scales.

Nowadays, the main problems which regard the design of policies and strategies to build urban resilience lies in the difficulty of evaluating this process over time and in spatial dimensions.

This paper explores the DMs in order to verify their efficiency in application in scenario planning, in order to find suitable tools which may support decision makers to define and prioritize strategies and policies to enhance urban resilience.

3. Dynamic Models in the Decision-Making Process

The definition of effective policies needs to be informed by a holistic understanding of the system processes. Their complex interactions and the ways they respond to various changes and inputs have to be evaluated. In this sense, models are, in general, seen as useful tools to aid actors and stakeholders to analyze alternative possible solutions and assess their outcomes. In fact, models generally integrate knowledge developed across a broad range of fields. They are generally used for different purposes. In this section, we focus on their application in management and treatment of uncertainty. Dynamic models cover a number of different methods and approaches able to simulate the behavior of future scenarios. Among the different methods belonging to the family of mathematical modelling, the present paper considers the system dynamics model (SDM) and the Lotka–Volterra model (LV). In this section, the methodological background and the state of art are investigated for both the SDM and LV models with the aim to highlight their fundamental role in the prediction of possible future scenarios for exploring urban resilience. Moreover, an illustration of some relevant applications is proposed in order to explain the methodological steps for the applications and the type of results that can be obtained.

3.1. Urban Simulation Models

In this paragraph, an overview of the urban simulation methods is given. The selected urban simulation methods are here discussed as reliable support in the decision-making process, especially in the case of designing urban and territorial transformations that may solicitate perturbations on the system on its resilience. Starting from a literature review [48], different simulation models have been selected to be analyzed. Table 3 lists the considered models and describes them, considering field and purpose of applications, types of data, treatment of space, time and uncertainty.

| Model                | Field of Application                                                                 | Types of Data         | Treatment of Space | Treatment of Time | Uncertainty                                      |
|----------------------|--------------------------------------------------------------------------------------|-----------------------|--------------------|-------------------|-------------------------------------------------|
| Bayesian networks    | Decision-making and management, Social learning, System understanding, Prediction   | Qualitative and quantitative | Non-spatial       | Non-temporal       | Structural learning from data and knowledge is possible |
| Coupled component models | Prediction, Forecasting, System understanding, Decision-making and management   | Mainly quantitative but qualitative are possible | Comprehensive set of options | Routine            | Comprehensive discrimination tests between alternatives |
| Agent-based models   | Social learning, System understanding                                              | Mainly quantitative   | Limited            | Limited           | Comprehensive discrimination tests between alternatives |
| Knowledge-based models | Decision-making and management, Prediction, Forecasting                          | Qualitative and quantitative | Non-spatial       | Usually non-temporal | Comprehensive discrimination tests between alternatives |

This overview of different models has been useful to support the choice of the model to experiment and use in investigating the urban resilience.

3.2. System Dynamics Model
3.2.1. Methodological Background and State of Art

System dynamics model (SDM) is an operative approach for helping reveal temporal behavior of complex systems considering their non-linearity, time-delay and multi-loop structure [49,50]. SDM is based on the System Dynamics approach which was introduced by Forrester [51,52] for investigating the feedback information of industrial systems and improving the organizational form [53]. SDM is an effective tool for modelling intersectional dynamics, such as the prey–predator models [54,55]. The relationships and interactions between variables in the system are analyzed by this tool (SDM) in order to simulate its dynamic evolutions in terms of processes, information and organizational boundaries [50].

In SDM, complex and dynamic systems are described both in qualitative/conceptual and quantitative representations. The qualitative modelling is performed by the causal loop diagram (Figure 1). This tool is used to graphically represent the feedback loops structure of the system. Causal loop diagram (Figure 1) describes the basic mechanism of the system, in order to represent the causes of its dynamics behavior over time [50,56]. The relationships between the variables can be either positive or negative, as shown in Figure 1. A positive relationship signifies that variables change equally. By contrast, a negative relationship means that the variables change inversely.

![Causal loop diagram](image)

Figure 1. Causal loop diagram (Tan et al., 2018).

Quantitative modelling is represented by stock and flow diagram (Figure 2). Stock is the first basic building block in SDM and it represents the variable which describes the condition of the system at any particular time [12,50,57–59]. Flow is the second block in SDM and it tells how stocks change over time.

![Stock and flow diagram](image)

Figure 2. Stock and flow diagram (Source: Authors elaboration).

From a mathematical point of view, stock and flow diagrams are represented by first-order finite difference equations. These allow to simulate the dynamic behavior of the system. The differential equations which characterize stock and flow can be expressed as:

\[
stock(t) = stock(t_0) + \int_{t_0}^{t} (inflow(t) - outflow(t))dt
\]

and this integration equation in the differential equation form is:

\[
\frac{d(Stock)}{dt} = inflow(t) - outflow(t).
\]

The most frequent type of possible system behavior can be summarized as follows [60]:

- Exponential growth or decline, which is characterized by only positive or only negative feedbacks;
- Goal-seeking behavior, which is created by first-order negative feedback;
• S-shaped growth. This behavior, over time, is created by a combination of positive and negative feedback loops. In this case, both loops struggle for dominance until the struggle ends with a long-term equilibrium;
• Oscillations. This is one of the most common types of dynamic behaviors in the world and it can have different forms, such as (1) sustained oscillations; (2) damped oscillations; (3) exploded oscillations; (4) chaos. The structure that creates oscillations is a combination of negative feedback loops and delay.

Currently, SDMs are used to support policy design and management for sustainable development in those fields characterized by a high level of uncertainty, such as transport management [58,61,62], land use [63], waste management [59] and also sustainable urban development [13,57,64,65]. In the last few decades, an increase of SDM application has been observed in literature [66], especially in the urban development field. Table 4 lists some of the prevalent SDM applications with particular attention to urban system and urban development.

Table 4 shows that SDM is an effective tool for supporting the evaluation of different development scenarios’ performance, considering their possible effects over time. For this reason, it is considered as a useful tool to support decision makers in setting policies.

3.2.2. Illustrative Example

In this section, the application of SDM developed by Tan et al. [13] to the case study of Beijing (China) is considered for the illustration of the fundamental steps of the procedure and the typology of results that the method is able to deliver. In [13], the SDM are applied to simulate the urban sustainability performance of the city, considering three different development scenarios. The SDM has been developed following these steps: (1) identifying the key variables by a review of urban sustainability indicators; (2) building the stock and flow diagram to identify the relationships between the variables; and (3) simulating different scenarios. Figure 3 shows the stock and flow diagram of the social sector. In particular, the stocks of the diagram are (1) Total population, (2) Urbanization rate, and (3) GDP, whereas all the other variables represent the flows. The diagram also shows the relationships that exist among the considered variables. As an example, we can consider the relationship that exists between “local government annual fiscal revenue” and “financial educational investment”. That means the investment in educational fields strictly depends on the availability of government financial resources. It appears clear that the SDM model tries to describe the real-world functioning through its stock and flow diagram, based on real behavior.
Figure 4 illustrates the results of SDM scenarios simulation, gathered by the stock and flow diagram in Figure 3.

![Stock and Flow diagram of social dimension (Source: Tan et al., 2018).](image1)

**Figure 3.** Stock and Flow diagram of social dimension (Source: Tan et al., 2018).

![SDM simulation results of economic, social, resource and environmental index (Source: Tan et al., 2018).](image2)

**Figure 4.** SDM simulation results of economic, social, resource and environmental index (Source: Tan et al., 2018).

These outcomes reveal the evolution of the indicators over time, referred to three different development scenarios (Figure 4). Simulation has been obtained by mathematical equations. For instance, Equation (2) illustrates the equation of annual household waste emission:

\[
HWS = DSWE \text{ per capita } \times \text{ Total population (Unit: ten thousand tons) } \tag{2}
\]

where:

(1) “HWS” is the annual household’s waste emission;
(2) “DSWE” is the domestic solid waste emission.

Specifically, in Figure 5, the SDM simulation results are referred to (1) “Current scenario” which represents no change in urban development actions; (2) “High speed scenario” that is characterized by a faster urbanization process and a higher economic growth rate; and (3) “Slow scenario” in which the urbanization process is limited.
3.3. Lotka–Volterra Cooperative Systems

3.3.1. Methodological Background and State of Art

Lotka–Volterra models (LV) are generally employed in the field of landscape ecology for exploring the prey–predator interactions [67,68]. These models have been integrated only recently in wide integrated evaluation frameworks to better interpret non-linear dynamics of territories, and so, their capability to adapt themselves to natural and/or anthropic disturbances and disasters, thus going beyond the analyses of ecological systems [55].

In fact, the aim of Lotka–Volterra models within territorial and urban planning consist in being a support for the investigation of a given environmental system N and the prediction of possible future transformations.

As shown in Equation (3), these models assume the form of a pair of non-linear Ordinary Differential Equations (ODEs) [69]:

\[
p'_1 = a_1 p_1 + b_1 p_1^2 + a_{12} p_1 p_2 + I_1 \\
p'_2 = a_2 p_2 + b_2 p_2^2 + a_{21} p_1 p_2 + I_2
\]  

(3)

where

- \(a_1\) and \(a_2\) are Malthusian coefficients that consider the dynamic evolutions of the populations \(p_1\) and \(p_2\) in terms of natality and mortality rates;
- \(b_1\) and \(b_2\) are Verhulst coefficients that considers scarce territorial resources, with \(b_1, b_2 < 0\). These coefficients are proportional to carrying capacity \((c_1, c_2)\) with \(b_1 = e / c_1\) and \(b_2 = e / c_2\);
- \(a_{12}\) and \(a_{21}\) are the terms that characterize the interaction between the two populations. In this way, we may consider three cases that correspond to three types of Lotka–Volterra models [69]:

- if \(a_{12}, a_{21} > 0\), \(p_1\) benefits from the presence of the second state variable \(p_2\), then Lotka–Volterra models are defined as “cooperative”;
- if \(a_{12}, a_{21} < 0\), the first state variable competes with the second state variable, then Lotka–Volterra models are “competitive”;
- if \(a_{12} < 0\) (prey), \(a_{21} > 0\) (predator), it means that the two variables are opposite, then Lotka–Volterra models are “prey/predator”.

Lastly, \(I_1\) and \(I_2\) represent the rates of in-migration and out-migration.

Among the types of Lotka–Volterra models, this paper is focused on Lotka–Volterra cooperative type models. An example of a Lotka–Volterra cooperative type model for the state variables \(V\) and \(E\) is:

\[
V' = b(1 - V)V - cV \\
E' = d(1 - E)E - f(1 - V)E
\]  

(4)

where

- \(a_1 = b - c\) \(b_1 = -b\) \(a_{12} = 0\) \(I_1 = 0\)
- \(a_2 = d - f\) \(b_1 = -d\) \(a_{21} = f\) \(I_2 = 0\)

In Table 5, a number of literature contributions are listed, in that the outcome of Lotka–Volterra systems may be interpreted as a resilience factor. More in details, Finotto and Monaco [70] and Gobattoni et al. [71,72] are generally used for developing stability analyses on ecological sectors, thus predicting future possible equilibrium states; Monaco and Servente [69] are used to simulate the population’s mobility and Monaco [73] integrates a synthetic index calculated through a system of indicators for investigating the population’s mobility with respect to Gross Leasable Areas (GLAs); Assumma et al. [74,75] predicts the population’s flow over time in rural landscapes with respect to the economic attractiveness; Assumma et al. [76] simulates the dynamics related to economic attractiveness and ecological quality as resilience factor.
Table 5. Application of Lotka–Volterra models applied to territorial and urban planning (Authors’ elaboration, 2019).

| Authors and Year | Territorial Scale | Method | Outcome |
|------------------|------------------|--------|---------|
| Finotto and Monaco, 2010 | Municipal | Stability analysis for predicting the production and the time variation of bioenergy; Analysis of territorial characteristics using the ecological graph | Identification of interventions to guarantee the ecological functions of the environmental system with attention on the reduction of the urban sprawl. |
| Gobattoni et al., 2012, 2014, 2016 | Provincial | PANDORA model | Stability analysis on ecological equilibria as future ecological scenarios. |
| Assumma, Bottero and Monaco, 2016, 2019 | Sub-regional | Lotka–Volterra models; System of indicators and indices | Simulation of the population’s mobility with respect to the economic attractiveness. |
| Assumma, Bottero, Monaco and Soares, 2018 | Supra-Municipal | Lotka–Volterra models; System of indicators and indices | Simulation of the population’s dynamics related to economic attractiveness and ecological states as resilience factor. |
| Monaco, 2015 | Provincial | Lotka–Volterra models; System of indicators and indices | Customer flow is intended as the attractiveness expressed by a system of Gross Leasable Areas (GLAs) by considering their degree of accessibility. |
| Capello and Faggian, 2002 | Municipal | Lotka–Volterra models of prey–predator type | Urban population, urban rent and production profits are combined for understanding urban dynamics of Italian cities. |

Therefore, Lotka–Volterra models have been employed at different spatial scales with different purposes, thus obtaining useful insights, such as in the field of landscape ecology and landscape economics [77]. In this section, a recent application on a supra-municipal context in Piedmont region (Italy) is proposed [76].

3.3.2. Illustrative Example

In Assumma et al. [76], an extension of a Lotka–Volterra model by Monaco and Rabino [78] was developed (Equation (5)) with the aim at simulating population dynamics as a resilient factor related to ecological and economic states for the territory of the Monferrato Ovadese in Southern Piedmont (Italy). The case study under investigation was intended as a multi-pole territorial system, where the poles refer to 37 municipalities that were grouped into 11 territorial clusters.

\[
P'_i = A_i P_i(t) \left(1 - \frac{P_i(t)}{S_i}\right) + \sum_{j=1}^{n} A_j A_i \left[1 - \left(d_{ij}/d_M\right)\right] P_j(t) \tag{5}
\]

where \(P'_i\) is the state variable of the population \(i\); \(A\) represents a synthetic index of ecological quality and economic attractiveness calculated for the poles \(i\) and \(j\); \(d_M\) consists in the distance recorded between the poles \(i\) and \(j\), whereas \(d_{ij}\) measures the recorded highest distance between the poles; and \(S\) is the carrying capacity, that is intended as the threshold number of people in a given pole.

It has to be noticed that the parameter \(A_i\) was calculated by considering a system of landscape economic indicators and a system of ecological indicators, according to a Multicriteria approach (for more, please see [74,79,80]). The considered systems of indicators and their indices aim to calculate a super-index that measures the overall attractiveness of the territory by considering the ecological quality and the economic attractiveness. The index of overall attractiveness was integrated into the Lotka–Volterra model in order to simulate the trends of populations with respect to both ecological and economic states. The results obtained by an evaluation procedure based on a Multicriteria approach are illustrated in Figure 5, whereas the results of the Lotka–Volterra model simulations are shown in Figure 6.
Figure 5. The histogram illustrates the ecological indices, the economic indices and the Overall Attractiveness index that were calculated for the considered 11 Clusters (Elaboration from Assumma et al. 2018).

Figure 6. Future scenarios simulation of Lotka–Volterra model on population dynamics through Mathematica Software. (Assumma et al., 2018).

The results of the model are useful for predicting possible future evolutions about the mobility of resident populations. As shown in Figure 6, the first group of populations (P1–P4) behave similarly in the transitory time, with an exception for population (P1) because of a consistent degrowth. The second group of populations (P5–P8) behave differently; in fact, the population of the cluster of Novi Ligure (P5) is interested by a slight degrowth, the population of the cluster Lerma (P6) grows significantly and finally, populations of the clusters of Ovada and Predosa (P8 and P9) show similar growing behaviors. In this sense, the poles were intended as receptors of the considered territory that absorb and evolve toward a new state, as already said, with respect to ecological and economic aspects. The predicted scenarios on population dynamics were interpreted as the effects of the non-linear interactions between the ecological and economic components with the multi-pole territorial system. In fact, when the multi-pole territorial system shows a good equilibrium between ecological and economic aspects, the population grows significantly, as in the case of the population of the cluster of Predosa (P8); whereas when one of the considered components records negative values, the population decreases, as in the case of the population of the cluster of Novi Ligure (P1).

4. How Can These Models Contribute for Building Resilient Systems?

SDMs constitutes a family of tools that uses the ODEs to predict the performance of a given criterion over time and more in general cycles that depends on a number of factors, whereas the Lotka–Volterra are models that face more complex problems.
The link between the SDMs and LV models is pointed out by Crookes and Blignaut [55], who stated that prey–predator models are suitable to be used in system dynamics models [54], also finding some applications in the field of economics [81,82], ecology (see e.g., [83,84]), and in multidimensional sectors in a supply chain [85]. The most important commonality of these two methods, especially regarding to the assessment of urban resilience referred to in urban and transformation strategies, is that both the models can consider the interactions between the different elements and sectors in urban contexts. This characteristic represents the real peculiarity of these systems for evaluating urban resilience, in fact, there are no consolidated assessment methods in literature on urban resilience [86].

In this sense, a clarification about specific characteristics of SDM and LV has to be done, before the analysis of their possible contribution in decision-making for resilience enhancing. Indeed, beyond the similarity which concerns the mathematic bases, these models are quite different.

As shown in Table 6, a comparison matrix has been structured with the aim to investigate both commonalities and differences between the SDM and LV models in orienting decision problems related to urban planning, with specific attention to the resilience enhancement.

In particular, a number of criteria have been considered for this analysis. The criteria are selected according to relevant literature review [48,54,55] and to authors’ researches:

- **Nature** highlights the different essence and characteristics of both dynamic models. On one hand, the Lotka–Volterra are models that aim to explore the dynamic functions of a given environmental system N, whereas the SDM models may be considered as a tool used to study and analyze the model or the system.

- **Input** is intended as the modalities to insert and deal with data at different spatial scales, as well as the possibility to integrate the participatory process. Generally, the considered dynamic models allow the insert of only quantitative data and the employment of different spatial scales (from local to regional and superior). As far as the participatory process is concerned in the SDM models, the decision makers may be integrated since the early phases of the process by using causal loops (Figure 1) that facilitate the interpretation of the system functioning and the integration of different stakeholders’ perspectives [14,50]. In the LV models, the participatory process may be integrated only by other evaluation procedures, such as the Multicriteria Analysis (MCA), by using a system of indicators and indices [79,87].

- **Output** refers to the final result produced through the considered dynamic models, such as the scenario simulation, the use of the time scale, the spatial scale, the graphical representation and the sensitivity analysis with the aim to validate the scenarios produced. Particularly, both SDM and LV models simulate possible future scenarios and these represent, generally, the final output through a graphic plot in that the linear function is represented. Unlike the LV models, the SDM models show, since the initial phase, a graphical representation of the relations between the considered variables and they allow to make, after the scenario simulation, a sensitivity analysis. These two DMs use, in different ways the time scale: the SDM model use a real time scale that may be traduced in months, years or centuries, whereas the LV model uses an arbitrary time scale that may be subdivided in an initial phase when the function starts with the state of art conditions \((t_0)\), transitory phase, when the linear function evolves in terms of growth or degrowth, and a final phase, when the linear function became stable. The arbitrary time scale may be traduced in a real time scale by considering the historical series of the analyzed parameters [74]. Sensitivity analysis is a valuable procedure for testing the model response with respect to the variation of parameter values, as well as to identify those parameters that have more impact than the others on the investigated phenomenon [88]. Sensitivity analysis can increase the reliability of the model and thus, reduce the uncertainty of parameters used in the models. A very common sensitivity test is the One-At-Time approach (OAT) [89] that is often used in Multicriteria Analysis as final tuning [75,90,91]. This, in fact, facilitates the scenarios’ assessment when actors and stakeholders are involved in a participatory decision-making process [92,93].

- **Software** refers to the availability of software and the modalities to solve the Ordinary Differential Equations (ODEs). On one hand, the SDM models are characterized by the use of
specific software, such as STELLA, Venism and Powerism, that formulate themselves the ODEs from which the scenarios’ simulations are produced. On the other hand, LV models are generally employed through mathematical software, such as MatLab and Mathematica Software, and these need to write manually the ODEs to obtain the prediction of scenarios (Figure 6). In this sense, both the dynamic models use the ODEs as an output, but in different ways. From the point of view of the availability, both dynamic models may be written through specific packages in open programming languages, such “deSolve” for R, “Simupy” for Python, “Mat Cont for Matlab” and “Nova modeler” for ecological modelling.

- Integration refers to the capability of DMs to integrate different techniques and evaluation methodologies. For instance, the considered dynamic models are a suitable tool to being integrated with Multicriteria Analysis (MCA) [75], as well as with the Agent-Based Models (ABM) [94] and Hedonic Price Model (HPM) [95]. Specifically, MCA can be used at two different phases: (1) at the beginning, to support the problem articulation and the identification of the variables to be included in the model; (2) after the scenarios’ simulation to support the evaluation of the different performances through final score calculation or ranking elaboration. Shafiei et al. [96] integrate SDM and Agent-Based Models to better understand the effects, not only on the system but also on the agent of the transition to sustainable mobility.

- Mapping is intended as the possibility to visualize the scenarios using GIS-based methods and the possibility to interact the dynamic model and the GIS interface through a programming language (e.g., QGIS and Python). Actually, the integration of DMs simulation results into GIS is developed by users in specific plug-ins (e.g., PANDORA 3.0 [97]) or by using specific coding platforms (e.g., QGIS Python console) and to get a spatial visualization of the output. Despite the requirement of specific competences to manage DMs in GIS environment, the users may support decision makers in better interpreting certain dynamics related to urban resilience by visualizing spatially the output of the dynamic model in a final map and therefore, identifying specific policies and solutions.

- Scenario planning refers to the prediction of future scenarios and the definition for each scenario of objectives and strategies. Both SDM and LV models allow to predict the way variables evolve, starting from the state of art conditions (t0) [50]. In this sense, both the SDM and the LV models are useful supports for the decision makers for identifying the most critical areas and adopting specific policies and interventions.

- Scale refers to the application of dynamic models at different scales. Moreover, the SDM considers a system as a whole, analyzing and focusing on its components and sub-components. In fact, SDMs are mostly applied to municipal or metropolitan scales. LV models are generally employed to provincial and sub-regional scales and to those territories with a rural vocation.

Table 6. Lotka–Volterra models and System Dynamic Models: summarizing comparison matrix (Authors’ elaboration, 2019).

|                       | Lotka–Volterra Models | System Dynamic Models |
|-----------------------|-----------------------|-----------------------|
| **Nature**            | Essence and characters * |                       |
| **Input**             | Use of qualitative and quantitative data |                       |
|                       | Participatory process |                       |
|                       | Use of different spatial scales |                       |
| **Output**            | Scenario simulation |                       |
|                       | Time scale |                       |
5. Conclusions and Future Perspectives

This paper explored the role of the family of dynamic models (DMs) and their characteristics as support in the decision-making process for evaluating complex phenomena, as in the case of the resilience of urban and territorial systems. Particularly, the study on the state of the art of resilience, urban resilience, dynamic models and urban simulation methods provided an epistemological contribution to the issue. The examples considered in this paper can be useful to further explore the opportunities of analysis application to investigate the key variables of issues in cities and territories. The comparison matrix highlighted commonalities, differences and potential synergies between the SDM and LV models. Both the SDM and LV models may be considered reliable supporting tools for policy planning, thanks to their ability to predict possible future behaviors of selected key variables, thus helping actors and stakeholders to identify and prioritize shared objectives and strategies for increasing urban resilience. In fact, these DMs are able to integrate the scientific knowledge available in literature within the evaluation procedure with specific expert knowledge elicited in the participatory modelling processes [98]. Some final remarks with respect to building more resilient systems [99] could be:

- These DMs are currently considered as some of the most promising models for understanding multi-dimensional problems related to urban and territorial systems.
- If experiments are impossible in the real world, simulations become the main way we can learn effectively about the dynamics of complex systems. Dynamic models are the most appropriate techniques to simulate complex and dynamic systems with the aim of developing policy and learning to effectively manage the system [50,100].
- These models are able to predict the effects of the actions over time on the state of the system. For this reason, both the DMs considered can be applied to evaluate the possible effects of urban and territorial policies in order to enhance urban resilience.
- The integration of dynamic models with urban simulation methods makes it possible to support data collection and elaboration, problem structuring, and facilitate the involvement of actors and stakeholders [12,88,101–103].
The authors have applied both SDM and LV models to a common case study, of a city with more than 50,000 inhabitants, with the purpose of evaluating urban resilience performance. The aim of the authors consists in effectively testing the multi-scale by aggregating or disaggregating the data as variables of the models [103]. A set of urban development scenarios will be predicted, considering the short-, medium- and long-term period [64] and a set of objectives and strategies for enhancing urban resilience will be prioritized. From the methodological point of view, this will be developed as an interactive procedure through dynamic models that may interact with GIS software from the early stages of the process. Finally, an integrated tool will be developed to evaluate possible effects of natural or anthropic disasters that could compromise the resilience performance of systems, also evaluating the economic losses caused by the perturbations of the system.

**Author Contributions:** All authors contributed equally to the development of this paper: Conceptualization, V.A., M.B., G.D., E.D. and R.M.; Investigation, V.A., M.B., G.D., E.D. and R.M.; Validation, V.A., M.B., G.D., E.D. and R.M.; Writing—original draft preparation, V.A., M.B., G.D., E.D. and R.M.; Writing—review and editing, V.A., M.B., G.D., E.D. and R.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** Part of this research has been financed by Department of Regional Studies and Planning, DIST, Politecnico di Torino within the research project titled VALIUM (Valuation for Integrated Urban Management) [grant number 60_RDI19B0M01].

**Conflicts of Interest:** The authors declare no conflict of interest.

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