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# A Method for the Definition of Local Vulnerability Domains to Climate Change and Relate Mapping. Two Case Studies in Southern Italy

Mauro Francini , Lucia Chieffallo , Annunziata Palermo  and Maria Francesca Viapiana \* 

Laboratory of Environment and Land Use Planning, Department of Civil Engineering, University of Calabria, 87036 Arcavacata, Rende CS, Italy; francini@unical.it (M.F.); lucia.chieffallo@unical.it (L.C.); annunziata.palermo@unical.it (A.P.)

\* Correspondence: mf.viapiana@unical.it

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**Abstract:** Climate change is contributing to raising disaster risk, with variable impacts depending on the local level of vulnerability. This paper describes a method for the definition of local vulnerability domains to climate change. The application of the methodology is aimed at building local vulnerability maps. The set of indicators of climate exposure, sensitivity and adaptive capacity, theoretically identified and practically tested on two case studies in southern Italy, contributes to support the territories in identifying the main local vulnerabilities, as well as define, subsequently, a systematic framework for identifying the most suitable mitigation and adaptation measures to climate change according to the specificities of the contexts of interest. In this regard, we consider the framework of risks and related impacts due to climate change on urban infrastructure proposed by the European Commission in order to face common challenges in the EU territories. Specifically, reference is made to three thematic focuses, which are “transport infrastructures”, “energy infrastructures” and “buildings and construction sector”. Although still at an early stage, the results of the research contribute to identifying useful elements of interrelation with the urban context for guiding resilient planning choices and reducing risks.

**Keywords:** vulnerability domains; climate change; disaster risk; mitigation; adaptation; local vulnerability mapping

## 1. Introduction

Climate change is a systemic phenomenon on a global scale [1,2] attributable to anthropogenic and natural causes [3,4]. It covers changes in the average climatic conditions and climate variability and changes in the magnitude and frequency of extreme events. The result is an increase in weather-related disasters. The risks associated with this change are highly uncertain and variable according to the levels of vulnerability that characterize cities and communities [5]. In particular, the urban landscape structure and the characteristics of the urban land surfaces, which contribute to the urban heat island [6], can alter the microclimate aggravating local impacts [7]. In light of the expected evolutions in terms of frequency, timing and intensity of extreme weather events [8], it is necessary to promote the assessment of local vulnerability levels as well as the mitigation and adaptation capacity of places in accordance with sustainable development goals.

In particular, climate change is contributing to raising disaster risk [9,10]. Although this link is widely recognized in the literature [11–13], historically, the work of disaster risk specialists and climate change specialists has too often been isolated and autonomous [14]. The difficulties in integration and collaboration between these two research areas are due to different backgrounds, organizational

frameworks, divergent concerns, and sometimes competing agendas [15] characterizing the two approaches. The first ones focus mainly on the local scale on vulnerability levels and risks in specific areas. The second ones tend to have a long-term vision that starts from the awareness that the current urban model, including a series of secondary effects on natural environments, economies and societies, will be outdated due to climate evolution [16]. However, the integration between these two research approaches is essential to program adequate risk reduction policies, as well as to make more efficient use of scarce resources and avoid overlapping efforts [14].

In order to fill this gap, the research presented intends to integrate the themes of disaster risk reduction (DRR), climate change mitigation (CCM) and climate change adaptation (CCA) from an urban planning viewpoint. DRR refers to the concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events [17]. CCM is a human intervention to reduce the sources or enhance the sinks of greenhouse gases [18]. CCA is in human systems the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities and in natural systems the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate [18].

Therefore, the need to prepare local systems—cities and communities—is argued for what happens and what will happen in relation to climate change within the ordinariness of planning tools and practices. Urban planning is, in fact, a privileged perspective. The planning tools are offered to stakeholders as the only means of regulating the use and management of resources in the different scales of the territorial government to cope with the vulnerabilities and risks they are subjected to.

In light of the global phenomena illustrated and recognizing the need to adapt existing urban planning tools in order to manage the effects of climate change, the paper is organized as explained below.

Section 2 summarizes the main related works obtained from a literature review. In particular, reference is made to the identification of risks related to climate change, to the possible consequences induced on urban elements, to the terminology and containment measures on climate change proposed at the international level with reference to what is proposed by the European Commission in order to face common challenges in the EU territories [19] and to studies on local vulnerabilities. Section 3 describes the method proposed by the authors aimed at the quantitative definition of the local vulnerability domains to climate change and related mapping. The method proposed by the authors is built on the basis of vulnerability definition as a function of the type, magnitude and rate of climate change to which a system is exposed, its sensitivity and its ability to adapt. It is generally accepted that a single definition of vulnerability satisfying all assessment contexts does not exist, especially in the area of climate change [20–22]. According to the Intergovernmental Panel on Climate Change [23], vulnerability to climate change is defined as the degree to which a system is susceptible or unable to cope with the negative effects of climate change, including climate variability and extreme events. Section 4 reports the results obtained from the application of the method in two different contexts located in the province of Cosenza (southern Italy) in order to mapping local vulnerability and start a comparative analysis between the levels of vulnerability obtained in urban and rural areas. Section 5 discusses the results obtained, and Section 6 concludes.

## 2. Related Works

This section summarizes the main related works to the proposed topic of research in order to place it in the broader context of current studies.

The most significant results of a literature review are reported, which highlight why the topic and the methodology proposed are important. In particular, having identified the risks associated with climate change and the potential effects on urban infrastructures, also as a function of land use, the need to define mitigation and adaptation measures to climate change based on studies on local vulnerability emerges. Therefore, national and international studies on climatic vulnerability were

reviewed and briefly summarized in support of the definition of the method proposed by the authors in this paper.

### *2.1. Risks and Related Measure on Climate Change*

Climate change is widely acknowledged as responsible for increasing the scale and intensity of disasters. According to the World Meteorological Organization, climate change can be described through the Global Climate Indicators [24]. They include global mean surface temperature, atmospheric greenhouse gas concentrations, ocean heat content, global sea level, ocean acidification, sea-ice extent and the mass balance of glaciers and ice sheets. Literature shows that extreme weather events [25–30], induced by the increase in temperature and the reduction of precipitation, increase the probability of the occurrence of disaster risks as hurricanes [31–34], typhoons [35], storms [36–38], floods [26,39,40], drought [41–43], landslides [44–46], fires [47,48], heat waves [49–51]. Climate change alters the level of danger, that is, the probability that a phenomenon occurs in a certain place with a certain intensity and in a certain time period. Looking at the Italian case, the Italian National Institute for Environmental Protection and Research [52] observed how the increase in the average temperature recorded in the last thirty years has almost always been higher than the global average on the mainland, with numerous repercussions on territory and cities.

Urban infrastructures that define the urban system and are crucial for supporting the needs of society [24] can be subject to risks of various kinds due to a wide range of extreme events related to climate change. Climate change determines the spatial and temporal distribution of ecosystem services, while land use [53,54] changes impact the ecosystem structure and function [55,56]. For these reasons, ecosystem services provide considerable development opportunities, including incorporating land use planning and enhancing climate change resilience [57]. From the literature, a series of parameters characterizing land use were deduced that could alter the effects of climate change on urban infrastructures. In particular, reference is made to two main macro-domains, which are the environmental and the socioeconomic ones. These macro-domains can determine the significant effects of the microclimate by inducing morphological and functional changes in the urban fabric. For example, the themes of the urban water system [58–68], the energy system [69–72], the green infrastructure system [73–76] under the first domain, while the demographic dimension [77–80] and the system of productive activities [81–83] and transport [84–87] are part of the second one. All these aspects must then be included in the local vulnerability studies.

Land use can, therefore, amplify the effects of climate change as it induces effects on the microclimate with variable outcomes since the characteristics of the local natural and human system vary. Consequent mitigation and adaptation measures to climate change have rapidly become an urgent issue [88]. The mitigation interventions [89–94] act on the causes of climate change, including strategies to reduce anthropogenic emissions, while the adaptation measures [95–100] are aimed at reducing the vulnerability of natural and socioeconomic systems and, therefore, reduce the negative impacts of climate change and increase the resilience of places. Consequently, mitigation can work by estimates, while adaptation requires a deepening of the cognitive framework on the territorial context and downscaling operations on climate knowledge. The internationally defined measures to cope with climate change, which refer to the families of mitigation and adaptation strategies, converge on the need to develop knowledge of climatic and socioeconomic scenarios, to consolidate observation, to take into consideration local specificities.

In order to address the common challenges in the EU territories, the European Commission has proposed a framework of the risks and impacts related to climate change on urban infrastructures [19] that is useful for reviewing possible examples of mitigation and adaptation measures on urban infrastructure. In particular, the European Commission distinguishes three thematic focuses in relation to risks, which are “transport infrastructures”, “energy infrastructures” and the “building and construction sector” (As regards transport infrastructures, the same and the related impacts in terms of stability and management are distinguished by the type of transport, such as rail (railways), road (roads

and motorways in general and specific cases of coastal and mountain roads), navigation (inland and maritime navigation, ports) and aviation (airports). Energy infrastructures are affected by climate change with variable effects in relation to the operations of transmission, distribution, generation and energy demand with substantial differences depending on the different types of energy supply (for example, hydro, wind offshore, biomass, geothermal). Finally, buildings and infrastructures can be vulnerable to climate change depending on their design and location). While climate impacts vary from sector to sector as these first distinctions emerge, mitigation and adaptation measures can include many common challenges. This characteristic suggests the need to build systemic and integrated frameworks of measures necessary to ensure sustainable and resilient development of infrastructures and, in general, of the territory. Below we will refer, by way of example, only to transport infrastructures.

The main effects of climate change that can cause damage to transport infrastructures are temperature increases, variation in the precipitation regime and the increase in sea level. Climate change can therefore have physical effects on infrastructures with variable impacts on the stability, as well as consequent influence on the management and safety of transport systems. It is, therefore, necessary to plan mitigation measures in order to reduce anthropogenic pressures on the environment and adaptation, in order to decrease the vulnerability of natural and socioeconomic systems. These measures can be associated with structural or nonstructural actions. The former is intended as physical and technological solutions to improve infrastructure, the latter as regulatory and management solutions to be adopted for more sustainable planning of the territory. In relation to transport infrastructures, a systematic framework of mitigation and adaptation measures is reported in Table 1, accompanied by some examples of actions. In particular, the mitigation measures are attributable to the European avoid-shift-improve (ASI) approach [101], while the adaptation measures summarize the risk framework proposed by the European Commission [19].

**Table 1.** Systematic framework of climate change mitigation and adaptation measures for transport infrastructures.

Mitigation (M) and Adaptation (A) Measures	Examples of Structural (S) and Nonstructural (NS) Actions
Avoid the demand for private motorized mobility (M)	Promote integrated transport planning (NS) Support the implementation of urban plans for sustainable mobility (NS) Encourage the construction and the development of infrastructure for cycle and pedestrian mobility (S)
Shift mobility quotas towards more sustainable forms (M)	Promote intermodality through the improvement of services (NS) Improve the attractiveness of local public transport (NS) Promote modal interchange (NS) Redevelop railway stations and their accessibility (S)
Improve the environmental performance of vehicles (M)	Promote incentives to reduce the cost/performance ratio on electric vehicles (NS) Renewal of the public vehicle fleet and support for the renewal of the private vehicle fleet in circulation (S) Development of a widespread network of electric charging points and distribution of biofuels (S)
Contain damage to infrastructure (A)	Redevelopment and maintenance of roads, the railway network and stations (S)
Reduce the impact on mobility management (A)	Promote integrated planning and effective management of mobility and transport data (NS) Support the implementation of urban plans for sustainable mobility (NS) Development of ICT technologies to support infomobility (S)
Reduce negative security impacts (A)	Enhance the synergies between sustainable mobility and road safety objectives (NS) Promote environmentally sustainable behaviors (NS)

The actions reported in Table 1 have been proposed at a theoretical and regulatory level for the planning of some Italian regions, including Emilia Romagna and Veneto [102–104]. These could be

shared in other contexts in order to increase resilience, after a more detailed study on the specificities of local vulnerability, which guides choice towards the most appropriate action or set of actions.

## 2.2. The Need for Local Climate Vulnerability Studies

As stated above, understanding vulnerability is crucial to support local and regional planning in defining mitigation and adaptation measures. However, despite increased awareness and assessments of the processes that produce vulnerability, disaster risks prevail. This raises questions on the effectiveness of vulnerability assessments and their applications for hazard mitigation and adaptation. The international literature includes a range of vulnerability assessment methods, wherein frequently the selection of any particular method is governed by the research objectives [105]. The estimation approach climate vulnerability based on the aggregation of specific indicators relating to the various components appears to be appropriate and widely spread [106]. Vulnerability assessments are increasingly becoming interdisciplinary, considering more contextualized variables and management alternatives. Given the complex nature of climate change vulnerability, efforts to quantify vulnerability to specific climatic events often use multi-variate statistical analysis to estimate the contribution of sociodemographic and built environment characteristics to a population's sensitivity to and capacity to recover from exposure to that event [107,108]. As an example, the component of climate change exposure can be measured by a variety of climate change metrics [109–112]. Climate change metrics are either calculated for a single locality, that is at the local level or for a set of localities, that is at the regional level [113].

Among the different national and international studies and methodologies [114–122] used for the assessment of local climate vulnerability, some of them have constituted a useful reference for the methodological approach presented in this paper.

The first was proposed by the European Spatial Planning Observation Network (ESPON) [114]. It suggests a combination of potential regional impacts of climate change with the regional capacity to adapt to climate change to produce the vulnerability map. In particular, the aggregate potential impact of climate change is determined by exposure and sensitivity and the overall capacity to adapt to climate change by calculating a weighted combination of economic capacity, infrastructural capacity, technological capacity, knowledge and awareness and institutional capacity, with the weights being based on a Delphi survey of the ESPON monitoring committee.

Another methodological reference is constituted by the European Environment Agency (EEA) [115] that defines the potential vulnerability to climate change as the result of the combination of aggregate impacts and adaptive capacity. The adaptive capacity was defined by indicators on knowledge and awareness, economic resources as well as technological, infrastructural and institutional capacity to adapt to climate change. The aggregate impacts include:

- Potential physical impacts related to physical structures such as settlements, roads, railways, airports, harbors, thermal power plants and refineries;
- Potential social impacts of climate change, related to Europe's population, which is also mainly sensitive to extreme events that are driven by climate change: coastal storm surges exacerbated by sea-level rise, increases in river flood heights, increasing flash floods, but also increasing heat events. Sensitivity to these changes is a matter of location, age group distribution, but also the density and size of urban areas that create urban heat island (UHI) effects;
- Potential cultural impacts of climate change, focused on tangible cultural assets because intangibles like norms and attitudes were considered part of the adaptive capacity of a region;
- Potential economic impacts of climate change were analyzed in regard to especially climate-sensitive economic sectors, namely agriculture and forestry, energy production and consumption as well as summer and winter tourism;
- Potential environmental impacts analyzed relate to protected natural areas, soil organic carbon content and the propensity of soil erosion and forest fires.

The Report on the state of scientific knowledge on impacts, vulnerability and adaptation to climate change in Italy [116] was also analyzed, although not based on a system of indicators, which constitutes the knowledge base of the National Strategy for Adaptation to Climate Change [123].

The analysis of these studies has brought out two reflections—the first concerns the observation scale of the phenomena, the second the available data. Considering the large-scale vulnerability assessment [122] can only provide an understanding of impact. These research results cannot be transformed into local policies or measures because they do not understand specific socioeconomic or natural conditions of cities. Then a local observation scale [117] is needed. Overall, these indicators quantitatively summarize the combined effect of territorial variables connected to subsets of climatic factors, elaborating them on the basis of various models consolidated. However, a critical aspect of the local vulnerability assessment concerns the availability of adequate starting data in terms of space–time scales and themes. In Italy, a database aimed at these specific needs is not yet operational although, thanks to an effort of homogenization and standardization by the regional and central administrations today, there are databases and geoportals containing a significant number of environmental and territorial data spatialized with the possibility of advanced services to support various processing that may employ thematic and numerical cartography technologies, GIS, and or that can be combined with analysis of aerospace remote sensing, an indispensable prerequisite for the construction of specific indicators at the urban scale.

### 3. Methods

The 2030 Agenda addressed the issue of climate change also in the context of the Sustainable Development Goals 2015–2030 (SDGs) and in particular with objective 13, which mentions “take urgent actions to combat climate change and its impacts” [124] to which national governments and locals are called upon to contribute. The EU, recognizing the complex problems related to climate change affecting all the areas of competence, has long since begun to set ambitious measures and goals to be achieved within predefined time thresholds. In December 2019, the European Commission presented the European Green Deal [125] as a chance to transform the challenges related to climate change into opportunities for a sustainable future. The proposed research, incorporating these guidelines, is aimed at providing a new expeditious method for the definition of local vulnerability domains to climate change and the related mapping. The general objective is to support the territories in identifying the main local vulnerabilities, as well as subsequently define the most suitable mitigation and adaptation measures to climate change according to the specificities of the contexts of interest.

#### 3.1. Climate Change Vulnerability Domain

The methodology considers climate exposure, sensitivity and adaptive capacity as defining components of the domain of vulnerability to climate change [23]. The authors propose to evaluate each component on the basis of a system of indicators, appropriately chosen at the urban scale and transformed through normalization operations, in order to construct summary indicators capable of quantifying the relative variations with reference to sub-municipal territorial units. In particular, for the choice of indicators, the authors reworked and referred to the themes proposed by different literature studies and sector documents [126–128] in addition to those already provided in the previous section. In particular, the studies by the Expert Team on Climate Change Detection and Indices and by the Italian National Institute for Environmental Protection and Research [129] were the reference for the choice of indicators characterizing the climate exposure component, while the provisions of the Italian National Strategy for Adaptation to Climate Change [123] and the Life Master Adapt Project [126] for the choice of indicators relating to the components of sensitivity and adaptive capacity.

As anticipated, the procedure is rapid and is capable of providing useful results powered only by the information available on a local scale, but which has been built to be updated and improved over time. The procedure is also characterized by being replicable as it is based on information available for the entire territory and consequently can be used in different urban contexts.

### 3.1.1. Climate Exposure Component

Climate exposure, representing a vulnerability component, summarizes the information necessary for the construction of the climatic profile of the context of interest. The knowledge of the climate allows the identification of impacts induced by climate change and is based on the monitoring of meteorological variables. For the construction of the local climatic profile, the methodology refers to indicators attributable to temperature and precipitation values. In particular, the time series of the climatic data considered are elaborated through statistical methods and models in order to consider representative indicators of the extreme values. These represent, in fact, the most frequent cause of negative impacts on the environment and, in general, on the territory.

The Expert Team on Climate Change Detection and Indices (ETCCDI) of the CCL/CLIVAR Working Group on Climate Change Detection has defined a set of 27 indicators [130], suitable for describing extremes of temperature and precipitation in terms of frequency, intensity and duration. These indicators are divided into categories. Some indicators are defined by a fixed threshold value; others are absolute indicators; others are based on percentiles; still, others express duration. Compared to the total of indicators identified by ETCCDI, the methodology considers 18 indicators (Table 2) defined among the most representative of the Italian climate by the Italian National Institute for Environmental Protection and Research [126] and divided into three categories, that are cold extremes indicators (FD0, TR20, TNx, TNn, TN10p, TN90p), indicators of the extremes of heat (SU25, TXx, TXn, TX10p, TX90p, WSDI) and indicators of the extremes of precipitation (RX1day, Rx5day, R10, R20, R95p, SDII).

**Table 2.** Climate exposure indicators.

Code	Name	Definition
FD0	Frost days	Annual count when TN (daily minimum) < 0 °C
TR20	Tropical nights	Annual count when TN (daily minimum) > 20 °C
TNx	Max Tmin	Annual maximum value of daily minimum temperature
TNn	Min Tmin	Annual minimum value of daily minimum temperature
TN10p	Cold nights	Percentage of days when TN < 10th percentile
TN90p	Warm nights	Percentage of days when TN > 90th percentile
SU25	Summer days	Annual count when TX (daily maximum) > 25 °C
TXx	Max Tmax	Annual maximum value of daily maximum temperature
TXn	Min Tmax	Annual minimum value of daily maximum temperature
TX10p	Cold days	Percentage of days when TX < 10th percentile
TX90p	Warm days	Percentage of days when TX > 90th percentile
WSDI	Warm spell duration indicator	Annual count of days with at list 6 consecutive days when TX > 90th percentile
RX1day	Max 1-day precipitation amount	Annual maximum 1-day precipitation
RX5day	Max 5-day precipitation amount	Annual maximum consecutive 5-day precipitation
R10	Number of heavy precipitation days	Annual count of days when PRCP ≥ 10 mm
R20	Number of very heavy precipitation days	Annual count of days when PRCP ≥ 20 mm
R95p	Very wet days	Annual total PRCP when RR > 95th percentile
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP ≥ 1 mm) in the year

In particular, the annual temperature indicators FD0, TR20 and SU25 and the precipitation indicators R10 and R20 are defined by a fixed threshold value with respect to which their variation can have a significant impact on both society and the natural environment. The TNx, TNn, TXx and TXn temperature indicators and the RX1day and RX5day precipitation indicators represent the highest or lowest recorded over the course of a month or year; they are therefore absolute indicators. The TN10p, TN90p, TX10p, TX90p and R95p indicators are percentile-based indicators. They allow evaluation of

the evolution of moderate climate systems by counting the excesses with respect to threshold values defined in terms of frequency on the distribution of events in the reference climatological period. The WSDI indicator is a duration indicator aimed at quantifying prolonged and intense periods of heat. The SDII indicator does not fall within the aforementioned categories, but by measuring the intensity of rainfall, it allows for a complete picture of the evolution of the precipitation extremes to be obtained. For application purposes, the historical series considered to evaluate the indicators refer to the data collected by monitoring stations equipped with a thermometer and a rain gauge and are the following in the time period from 2010 to 2019: the series of minimum daily temperatures, the series of maximum daily temperatures and the series of accumulated daily rainfall.

### 3.1.2. Sensitivity Component

Sensitivity is a component of vulnerability to climate change, understood as the degree to which a system or species is affected, both adversely and beneficially, by climate variability or climate change [23]. Looking at the urban system, the impacts generated by climate change vary according to a complex set of contextual elements that the proposed methodology distinguishes (Table 3) into elements characterizing the environmental capital (EnvC-1, EnvC-2, EnvC-3, EnvC-4, EnvC-5, EnvC-6), the share capital (SocC-1 and SocC-2) and the economic capital (EcoC-1, EcoC-2, EcoC-3, EcoC-4, EcoC-5).

**Table 3.** Sensitivity indicators.

Code	Name	Definition
EnvC-1	Areas submitted to landscape bound	Military architecture and Byzantine monuments, waterways, buildings and areas of public interest, alpine and Apennine territories, territories bordering lakes, coastal territories, architectural constraints
EnvC-2	Wetlands	Wetlands (Level 1), inland and maritime wetlands (Level 2) (CORINE Land Cover)
EnvC-3	Urbanized areas of residential type	Artificial surfaces (Level 1), urban fabric (Level 2), continuous and discontinuous urban fabric (Level 3) (CORINE Land Cover)
EnvC-4	Wooded territories and semi-natural environments	Forest and semi-natural areas (Level 1), forest, scrub and/or herbaceous vegetation associations, open spaces with little or no vegetation (Level 2) (CORINE Land Cover)
EnvC-5	Areas under environmental protection	Site of community interest (SCI), national interest site (NIS), regional Interest Site (RIS), special protection area (SPA)
EnvC-6	Landslide and hydraulic risk area	Areas at high and very high risk from landslides or flooding (Hydrogeological Plan)
SocC-1	Elderly population	Percentage of the population over 65 years of age (Italian National Statistics Institute)
SocC-2	Young population	Percentage of the population under the age of 24 (Italian National Statistics Institute)
EcoC-3	Utilized agricultural areas	Agricultural areas (Level 1), arable land, permanent crops, pastures, heterogeneous areas (Level 2) (CORINE Land Cover)
EcoC-4	Unemployment rate	Ratio of the unemployed to the corresponding labor force (Italian National Statistics Institute)
EcoC-5	Impact of households with potential economic distress	Percentage ratio of the number of households with children to the reference person aged up to 64 in which no person is employed or retired from work and total households (Italian National Statistics Institute)

The selected indicators contribute to assessing the sensitivity of the context to certain impacts. Sensitivity is identified according to the categories that refer to specific properties of the reference system. The impacts generated by climate change may impact both natural resources and buildings and infrastructures, as well as the population settled in social and economic terms. The category of environmental capital refers to natural factors through the EnvC-1, EnvC-2, EnvC-4, EnvC-5, EnvC-6 indicators, and to urban-morphological factors through the EnvC-1 and EnvC-3 indicators.

The category of social capital summarizes the characteristics of the population above all from a demographic point of view as the physiological state of the population can make it more or less susceptible to climate change. Specifically, the SocC-1 indicator influences sensitivity in a negative way; on the contrary, the SocC-2 indicator in a positive way. This difference will influence, as explained below, the assessment of the direction of the indicator values in the normalization process. The category of economic capital refers to aspects related to agricultural economic activity, as well as to the economic condition of families, respectively, through the EcoC-3, EcoC-4 and EcoC-5 indicators.

### 3.1.3. Adaptive Capacity Component

Adaptive capacity refers to the “ability of a system to adapt to climate change—including climate variability and extremes—to moderate potential damage, exploit opportunities or cope with consequences.” [131] Each urban settlement expresses a capacity response called adaptive capacity that can favor the containment of some impacts. This is a concept that includes the intrinsic characteristics of the system, including the ability to analyze and implement adaptation strategies, as well as to manage any events. In this sense, for evaluation purposes, the degree of awareness of citizens, the ability to govern and the resources available to local administrations are also influential. The indicators selected (Table 4), therefore, refer to the categories of knowledge (KnoC-1, KnoC-2, KnoC-3) and resources (ResC-1, ResC-2, ResC-3).

**Table 4.** Adaptive capacity indicators.

Code	Name	Definition
KnoC-1	Level of education and literacy rate	The share of the population aged 25–64 with at least one higher secondary education qualification and reading and writing skills
KnoC-2	Internet connection	Optical fiber and ADSL coverage
KnoC-3	Planning of climate actions	Level of awareness, cooperation, communication and dissemination of information on climate change adaptation and mitigation actions
ResC-1	Peripherality level from services	Distance measured in journey times from essential health, education and mobility services
ResC-2	State of conservation of residential buildings	Presence of buildings for residential use in good or excellent condition
ResC-3	Green areas in urban centers	Identification of green areas included in urban centers obtained from the comparison of the municipal urban and satellite images

In particular, the KnoC-1 and KnoC-2 indicators refer to knowledge that can facilitate access to and interpretation of information. The KnoC-3 indicator considers attention paid in the context of municipal planning instruments to the expected impacts due to climate change with reference to the Italian Strategic Environmental Assessment [132]. The ResC-1 indicator refers to the level of the municipal periphery of the supply and service centers measured in travel times. In particular, the classification adopted by the Italian National Strategy for Inner Areas [52] considers three main services, which are health, education and mobility. The ResC-2 and ResC-3 indicators quantify, respectively, the presence of residential buildings in a good state of conservation and the green areas as elements capable of reducing urban vulnerability.

### 3.2. Synthesis and Elaboration of Vulnerability Map

Vulnerability is defined as a function of exposure to climate stimuli, sensitivity and adaptive capacity of the system to adapt to climate change. The local vulnerability assessment proposed by the authors is based on quantitative analysis. The vulnerability values are associated with a scale of values between zero and one. The higher values correspond to a higher level of climatic vulnerability; the lower values correspond to a lower level of climatic vulnerability. In order to summarize the collected data, assess the vulnerability and then elaborate the local vulnerability maps, the following procedure is planned:

1. Assessment of the indicators of climate exposure, sensitivity and adaptive capacity;

2. Association of the indicator information to minimum territorial units by geographic information system (GIS);
3. Normalization of data;
4. Calculation of the three synthetic indicators ( $I_{exp}$ ,  $I_{sens}$ ,  $I_{ad\ cap}$ );
5. Estimation of the local vulnerability level.

As regards the first phase, the indicators were chosen to be available on the municipal scale through the territorial information systems and local statistical databases. These data must subsequently be associated in a GIS environment with minimum territorial units or the smallest area to which the data can be associated. For example, the census sections (In Italy, the census sections constitute the minimum unit of data collection by the municipality. Starting from the census sections, the higher level geographical and administrative entities such as inhabited localities, sub-municipal areas, electoral districts and others can be reconstructed) represent the minimum survey unit associated with sociodemographic data.

The next step is to normalize the indicators. Normalization is required before any data aggregation as the measures in the dataset are frequently associated with different measurement units. There are numerous methods of normalization [133–135]. Min–max method normalizes the measures to have an identical range (from 0 to 1) by subtracting the minimum value and dividing it by the range of the measured values.

$$x_{i,1} = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (1)$$

In formula (1)  $x_i$  represents the individual data point to be transformed,  $x_{min}$  the lowest value for that indicator,  $x_{max}$  the highest value for that indicator and  $x_{i,1}$  the normalized value within the range of 0 to 1.

The normalization process is very delicate. In fact, lower values should reflect positive conditions in terms of vulnerability and higher values, more negative conditions. It is, therefore, important to pay attention to the direction of the indicator values. If the direction of the indicator's value range is negative, the vulnerability increases as the indicator value decreases and vice versa. Hence, in this case, the range of values of the indicator should be inverted so that the lowest value is represented by the standardized value 1 and the highest by the standardized value 0. To achieve this, we simply subtract the value from 1 to determine the final standardized value. In particular, this procedure is indispensable for some sensitivity indicators as well as for indicators relating to the ability to adapt.

After normalizing the data, it is necessary to calculate the synthetic indicator for each component by aggregating the results of the individual indicators.

$$I_C = \frac{w_1 \cdot x_{1,1} + w_2 \cdot x_{2,1} + \dots + w_n \cdot x_{n,1}}{\sum_1^n w} \quad (2)$$

Formula (2) allows estimation of the synthetic indicator of the  $I_C$  component by combining the normalized values of the indicators  $x_{i,1}$  previously weighted by associating the relative weights  $w_i$ . By applying a uniform weighting, the indicators are simply summed and divided by the number of indicators.

The last step involves estimating local vulnerability to climate change ( $V$ ), such as:

$$V = \frac{w_{exp} \cdot I_{exp} + w_{sens} \cdot I_{sens} + w_{ad\ cap} \cdot I_{ad\ cap}}{w_{exp} + w_{sens} + w_{ad\ cap}} \quad (3)$$

In Formula (3)  $I_{exp}$ ,  $I_{sens}$  and  $I_{ad\ cap}$  represent the synthetic indicators for the components climate exposure, sensitivity and adaptive capacity,  $w_{exp}$ ,  $w_{sens}$  and  $w_{ad\ cap}$  represent the relative weights.

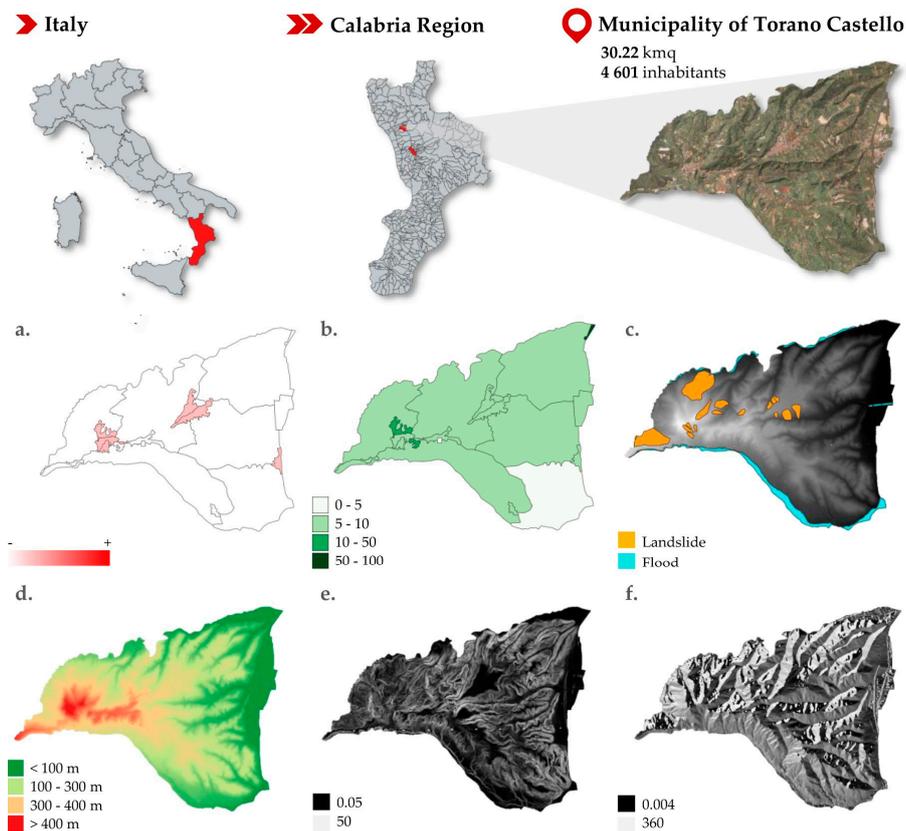
Implementation in a GIS environment allows data to be processed and returned in graphic form through vulnerability maps. These are tools known to the literature [136], which make it possible to classify and identify the most vulnerable territorial elements in the specific case with respect to the

risks induced by climate change. The possibility of quantifying and locating the main critical issues in a territory is offered as a necessary condition for planning adequate strategies and interventions for the implementation of targeted mitigation and adaptation measures [137,138] as well as for playing an educational role for social learning of the mechanisms through which climate change can interact with anthropogenic and natural systems [139].

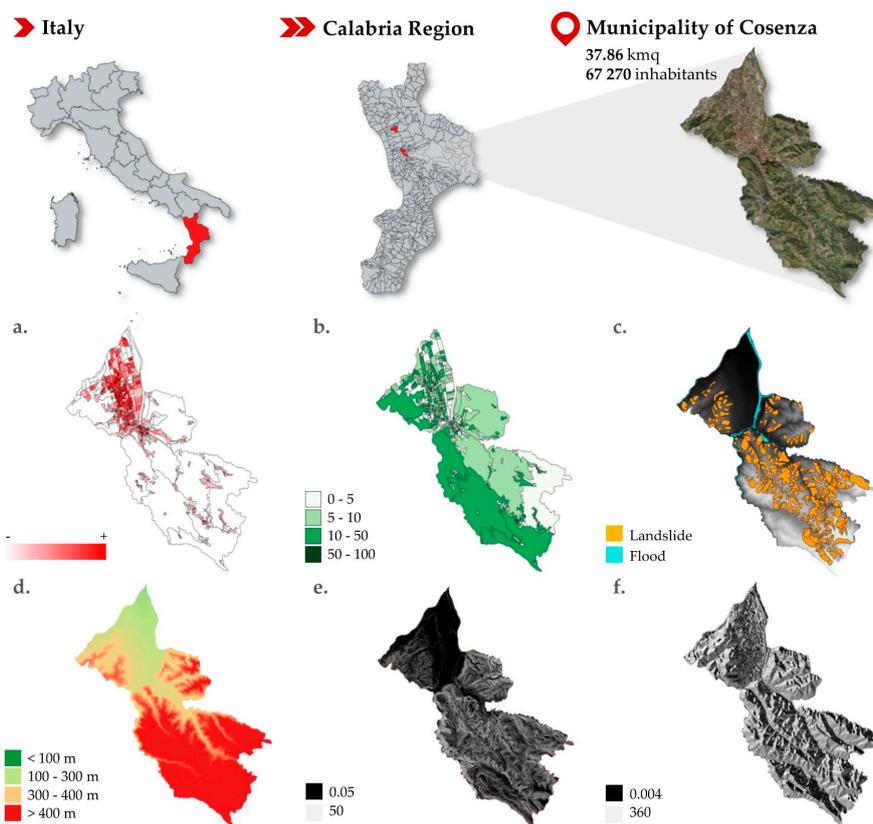
#### 4. Results

The methodology described was tested in two contexts located in the province of Cosenza in southern Italy. The contexts analyzed are an intermediate rural area (PSR 2014–2020), the municipality of Torano Castello and an urban area, the municipality of Cosenza.

Figures 1 and 2 show the main settlement and morphological characteristics of the two Municipalities. In particular, the differences between the two municipalities are evident in terms of population density, diffusion and location of hydrogeological phenomena, as well as the different altimetry. The two municipalities are approximately 25 km apart as the crow flies and are associated with a similar climatological profile. According to OBC Transeuropa [140], the difference between the average temperature recorded in the period 1961–1970 and 2009–2018 is equal to 2.63 °C for Torano Castello and 2.41 °C for Cosenza.



**Figure 1.** Geolocation and morphological characteristics of the municipality of Torano Castello: population density (a), population > 65 years (b), landslide and flood risks (c), altitude (d), slope (e) and exposure (f).



**Figure 2.** Geolocation and morphological characteristics of the municipality of Cosenza: population density (a), population > 65 years (b), landslide and flood risks (c), altitude (d), slope (e) and exposure (f).

The choice of applying the same model to two areas that are characterized by a similar climatological situation, consistent settlement and morphological differences is aimed at investigating and emphasizing the influence of settlement development and land management models on vulnerability to climate change. In this regard, it is necessary to remember that the general objective proposed by the authors is to address the issue of climate change from an urban point of view, focusing subsequently on urban infrastructures in order to integrate the ordinary planning tools of mitigation and adaptation measures. In this sense, then, the comparison between the results obtained for the two study areas is interesting.

#### 4.1. Vulnerability Domains

Below are the specific results obtained from the application of the proposed methodology to the two case studies for the assessment of the components of climate exposure, sensitivity and adaptive capacity, as well as for the development of the related local vulnerability maps.

##### 4.1.1. Local Climate Profiles Assessment

The evaluation of the local climate profiles in accordance with the provisions of the proposed methodology allows identification of the factors of exposure to local climate change. The period 2010–2019 was chosen as the reference climatological period. Both Municipalities host measurement stations belonging to the Regional Environmental Protection Agency (region of Calabria) equipped with a thermometer and rain gauge. Figures 3 and 4 show the results obtained by processing the minimum and maximum daily temperature series and the cumulative daily precipitation series for the two case studies and normalizing the data with respect to the reference climatological period.

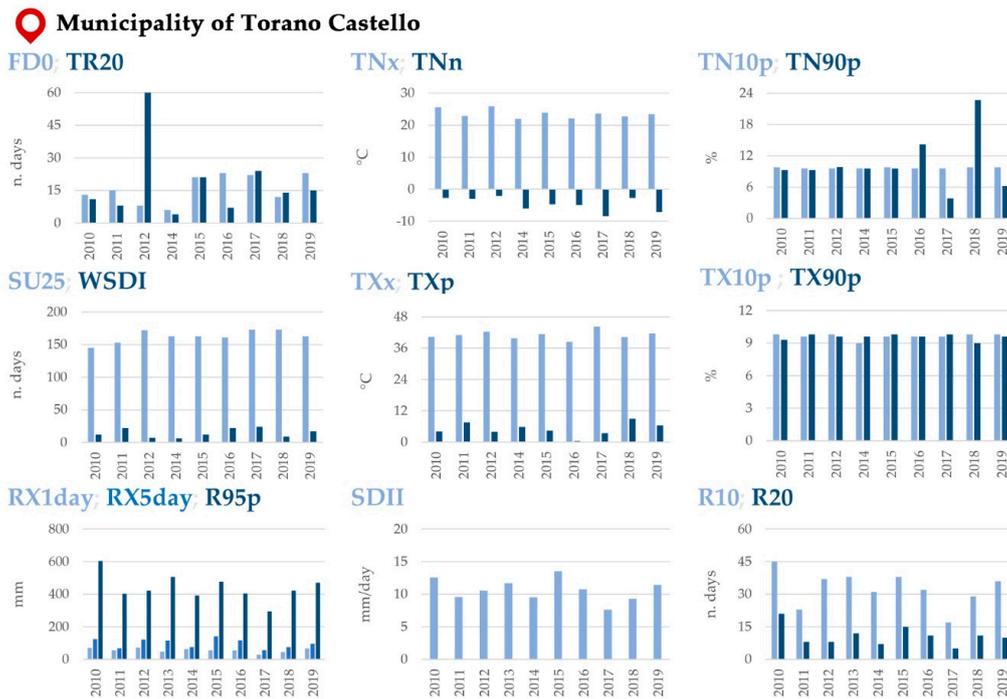


Figure 3. Municipality of Torano Castello’s climate profile assessment.

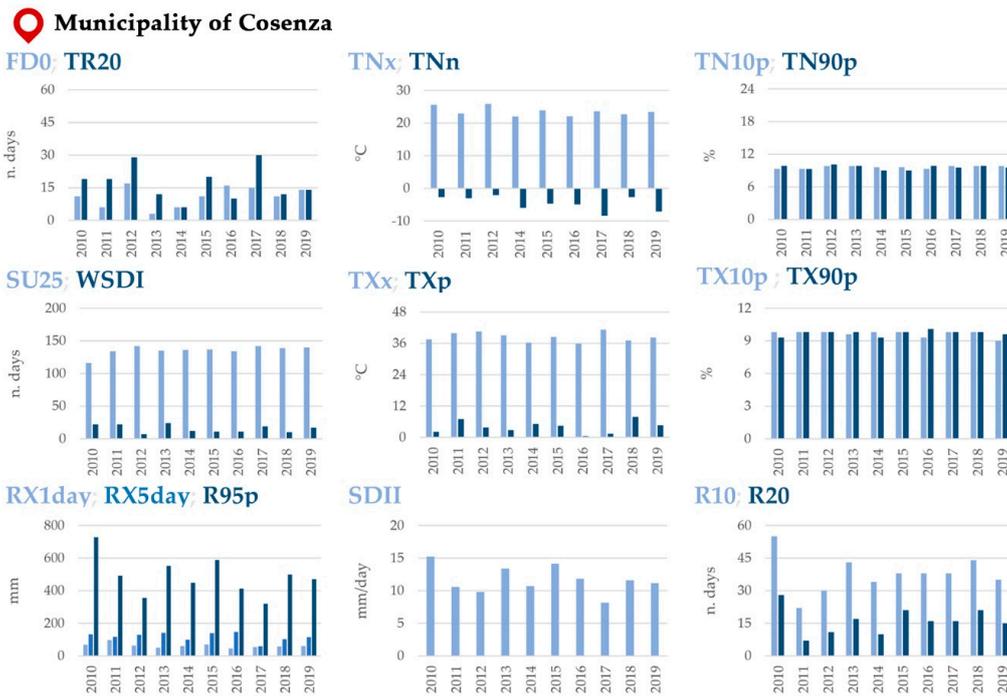


Figure 4. Municipality of Cosenza’s climate profile assessment.

From the comparison between the calculations obtained in the two case studies, on average, no differences are evident. In particular, the indicators of the heat and precipitation extremes show how the municipality of Torano Castello is characterized by a slightly warmer climate and a lower intense rainfall regime. The values of the synthetic index relating to climate exposure are equal to 0.48 for the municipality of Cosenza and 0.51 for the municipality of Torano Castello.

4.1.2. Local Sensitivity Profiles Assessment

The profiles of local sensitivity depend, in accordance with the proposed methodology, on elements that characterize the environmental capital, the social capital and the economic capital. In particular, the main sources of data retrieval are the representation of the Corine Land Cover [141] land use, which allows the definition of the occupation of the territories by artificial and natural surfaces, the local urban planning tools, the Hydrogeological Plan [141] and socioeconomic data, financial statements provided by the Italian National Statistics Institute [142]. Figures 5 and 6 show the results obtained for the two municipalities.

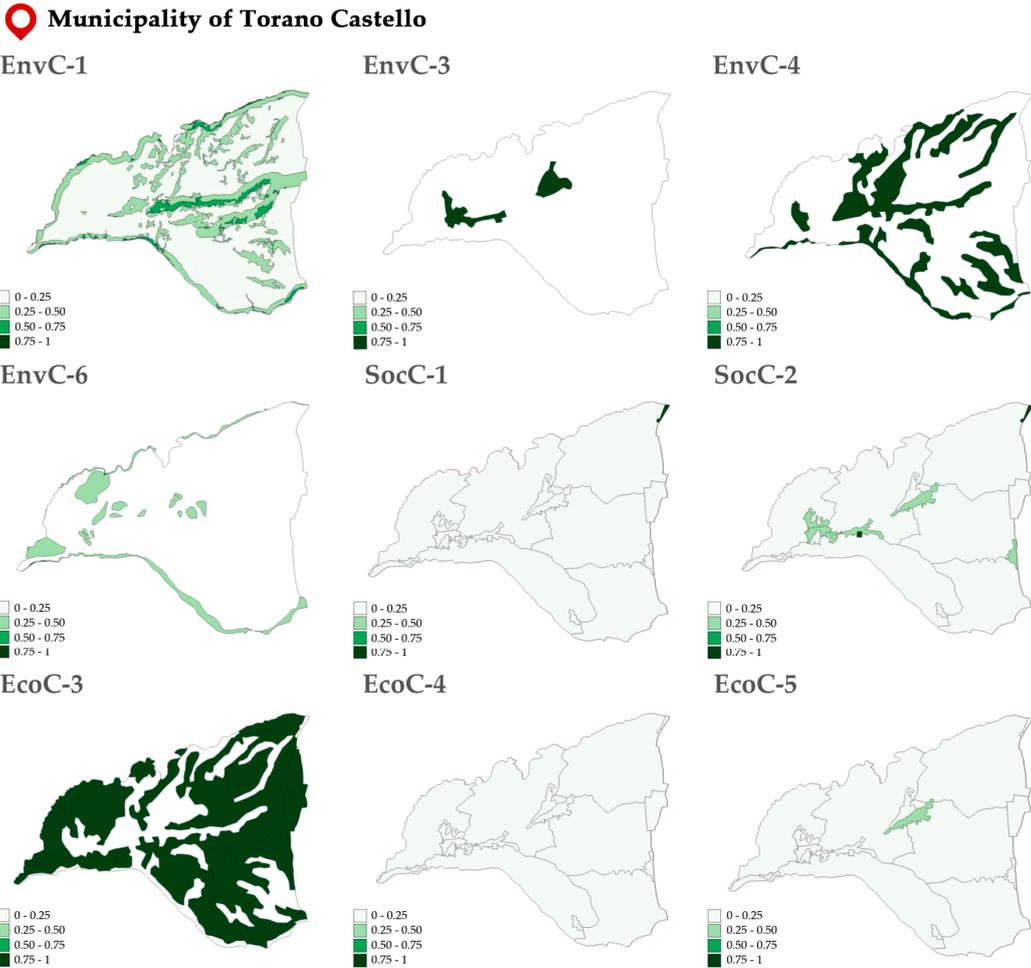


Figure 5. Municipality of Torano Castello’s sensitivity assessment.

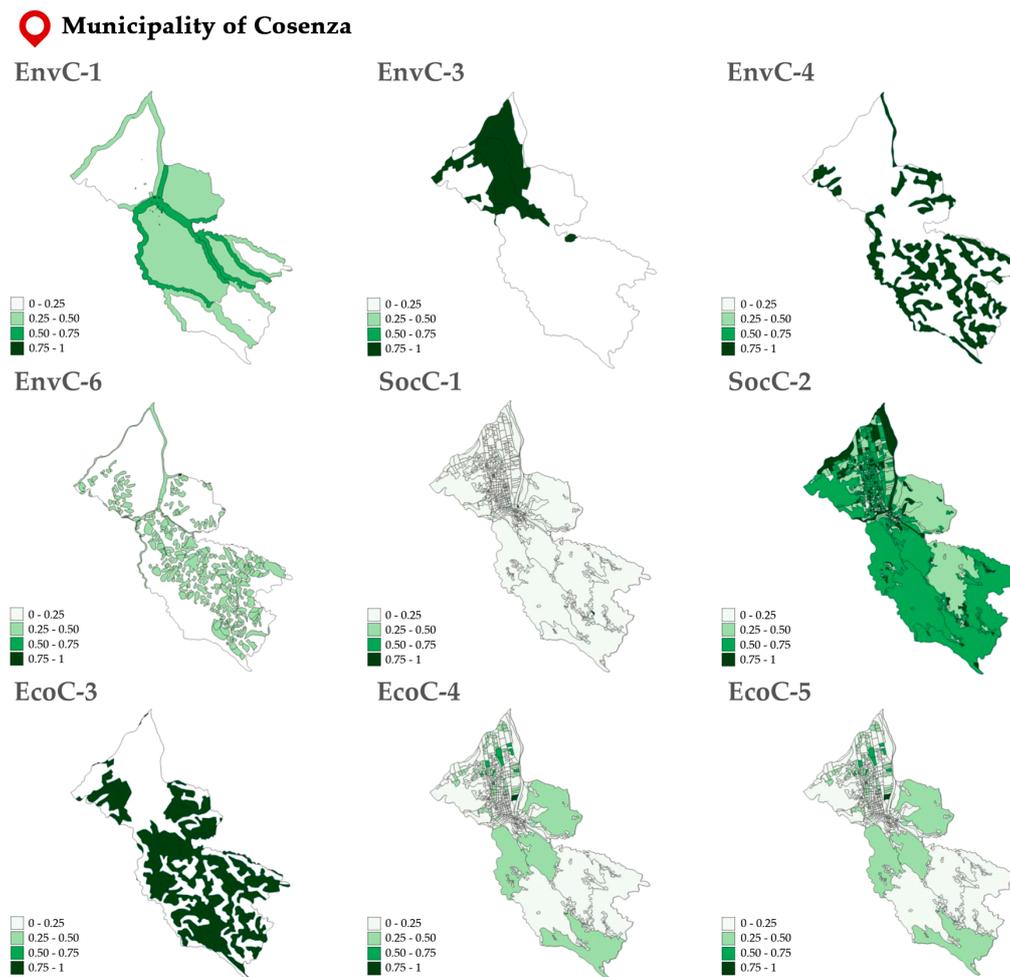


Figure 6. Municipality of Cosenza's sensitivity assessment.

Specifically, the municipality of Torano Castello is characterized from an environmental point of view by the minimal presence of artificial surfaces, which are essentially represented by residential areas. Much of the territory is occupied by wooded areas and semi-natural environments as well as by agroforestry and agricultural surfaces (arable land, annual and permanent crops). The territory is widely affected by flood risk areas near the stream and landslide risk areas, also near residential areas. The social and economic capital is characterized by a predominantly elderly population, an unemployment rate equal to 20.5% and values of the incidence of families with potential economic hardship growing from 1991 to 2011 with a value at the last census of 5.6 compared to the national value equal to 2.7.

From an environmental point of view, the municipality of Cosenza is characterized by the presence of areas subject to landscape constraints, in particular architectural constraints and buildings of public interest in the historic center of the city, due to the presence of a large residential area located to the north and of an area mainly occupied by wooded territories and semi-natural environments as well as by agroforestry and agricultural surfaces in the south landslides. The social and economic capital is characterized by an unemployment rate of 19.3% and values of the incidence of families with potential economic hardship that has been growing since 2001 with a value at the last census of 4.6 compared to the national value of 2.7.

#### 4.1.3. Local Adaptive Capacities Assessment

In order to evaluate the elements that influence the adaptive capacity of the territories, reference was made to the data provided by the Italian National Statistics Institute, municipal bodies, municipal planning tools and satellite images. Figures 7 and 8 show the results obtained.

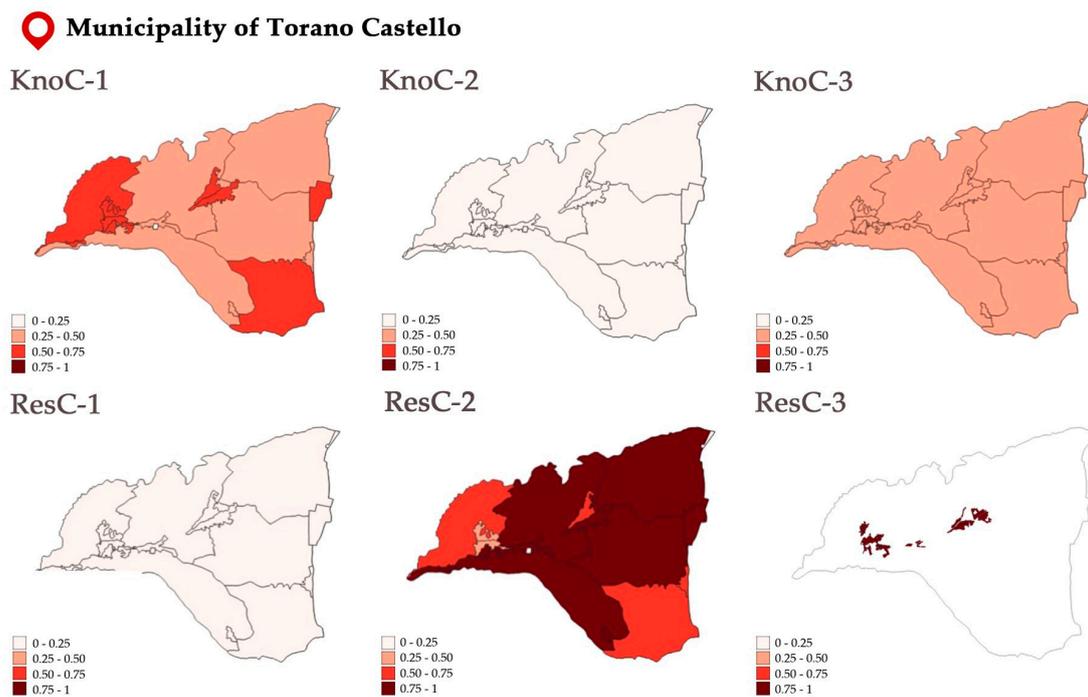


Figure 7. Municipality of Torano Castello's adaptive capacity assessment.

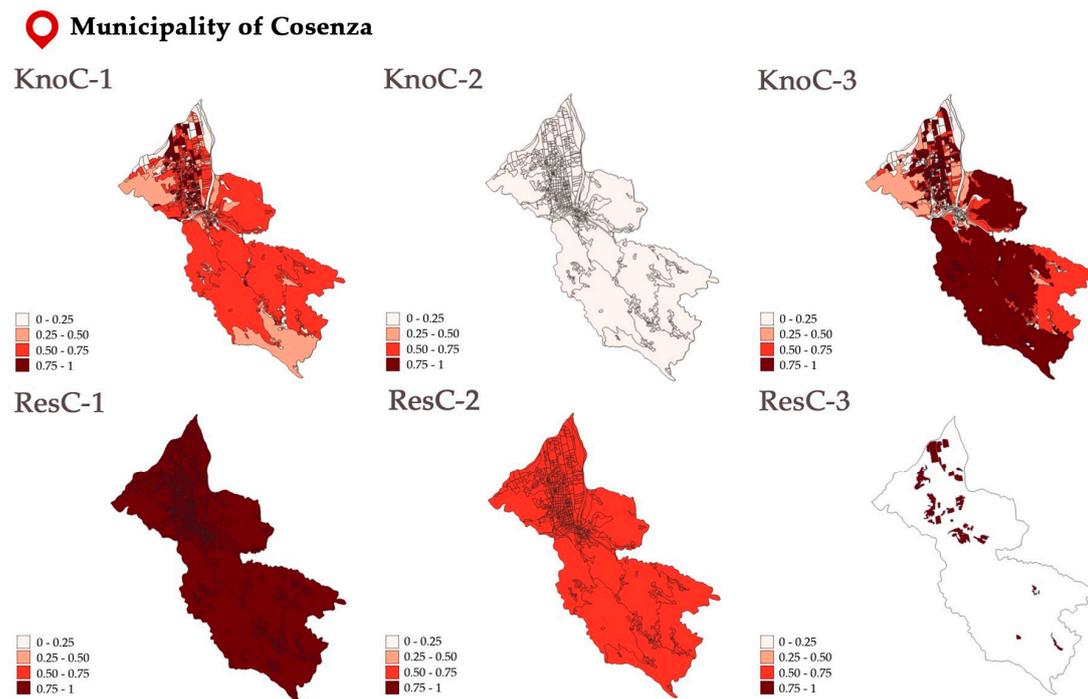


Figure 8. Municipality of Cosenza's adaptive capacity assessment.

The municipality of Cosenza shows an overall better adaptive capacity than the municipality of Torano Castello. All the selected indicators, with the exception of the presence of green areas in the urban area, support this result on average. In fact, although there are numerous and widespread examples of urban green areas in the urban area, these are included in the inhabited center with albeit positive effects but limited in terms of environmental and ecological parameters compared to the municipality of Torano Castello, which is characterized by a rural vocation.

#### 4.1.4. Vulnerability Maps Elaboration

In order to elaborate the vulnerability maps useful for identifying the priority intervention areas, in accordance with the methodology proposed for simplicity, the three components of climate exposure, sensitivity and adaptive capacity have not been weighted. Therefore, that reported in formula (4) was assumed.

$$w_{exp} = w_{sens} = w_{ad\ cap} \tag{4}$$

This simplification is justified by the desire not to alter the consistency of one component with respect to the others. By the will of the authors, the procedure is characterized by being quick. The weight calculation should include further applications of statistic weighting methods such as conjoint analysis and scaling techniques.

The results obtained are shown in Figures 9 and 10. A more intense and widespread climatic vulnerability condition is evident with large areas of high and medium-high vulnerability in the case of the urban area of Cosenza, compared to the case of the rural area of Torano Castello.

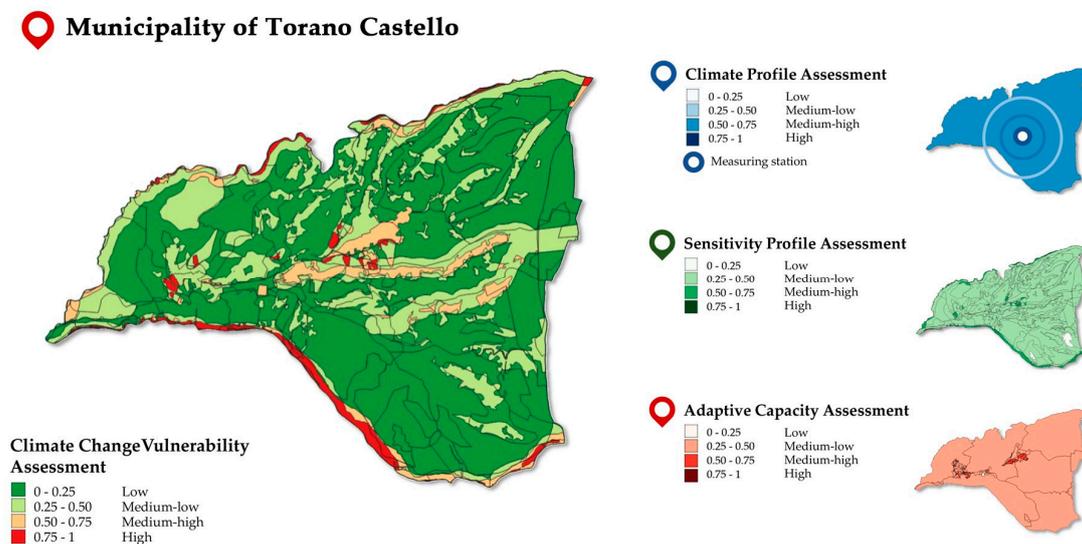


Figure 9. Municipality of Torano Castello’s local climate change vulnerability assessment.

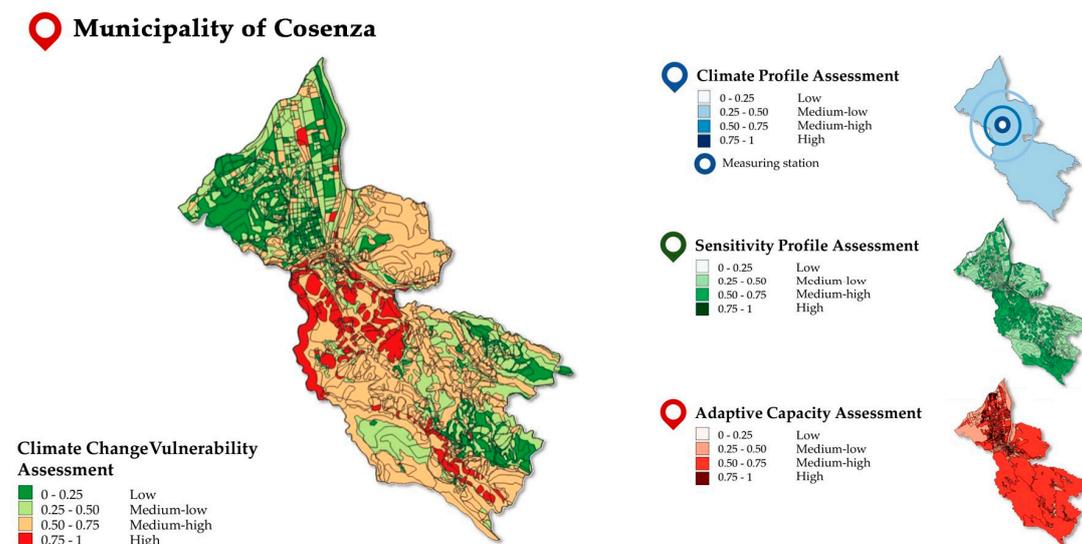


Figure 10. Municipality of Cosenza’s local climate change vulnerability assessment.

## 5. Discussion

The proposed research, starting from the definition of the three vulnerability domains—climate exposure, sensitivity and adaptive capacity—evolves in the elaboration of vulnerability maps by starting a comparative analysis between different territorial contexts, in particular urban and rural ones. The mapping represents the reference for identifying urban infrastructures affected by conditions of greater vulnerability requiring the adoption of adequate mitigation and adaptation measures.

The development of vulnerability maps is a rather complex process for which it is necessary to discuss the working hypotheses proposed by the authors in relation to the vulnerability domains, especially in order to guide possible future research developments.

The climate exposure domain suggests, first of all, a reflection on the construction of the local climate profile. Important information could be deduced considering a climatological period longer than the 10 years considered and based on the forecasts provided by mathematical climate models to consider future climatic variability (climate projection) and not only on the recorded climatic variability. The aspects relating to exposure also highlight the significant problem of downscaling climate models that are currently set up for large territories, which in the case studies presented coincide with the municipal dimension. In fact, we were able to consider only one measurement station for each municipality. The support of specialized scientific expertise could provide local administrations with more specific and useful information at the sub-urban scale as well as on the reliability of the data.

Regarding the other two domains, sensitivity and adaptive capacity, general indicators were considered in this phase that could be satisfied by the information already present in the municipal cognitive frameworks, avoiding choosing indicators that are difficult to manage and compile. This concept inevitably refers to the need to update and increase the available data. For example, in assessing sensitivity, a more detailed survey could provide for the choice of specific indicators that give an indication of the types of areas and populations that could be most affected by a specific impact. Just as, as far as adaptive capacity is concerned, current adaptive capacity was considered to assess current vulnerability, considering future adaptive capacity, combined with future climate exposure, would allow the assessment of future vulnerability, thus orienting urban practices and policies in a more resilient way both in the construction phase of new infrastructures and in the transformation of existing ones.

## 6. Conclusions

This study addresses the issue of risks related to climate change, placing itself within the framework of the urban planning discipline. The authors support the integration of the mitigation and adaptation measures based on the assessment of local vulnerabilities that the effects of climate change suggest within the ordinariness of the tools and planning practices. Starting from this general assumption, the paper includes:

- An examination of the scientific literature analyzed through a systematic literature review process useful for contextualizing the research topic addressed (Section 2);
- The quantitative definition of the three vulnerability domains—climate exposure, sensitivity and adaptive capacity—as well as the process of synthesis and mapping of local vulnerability on the territory (Section 3);
- The application of the proposed method on two case studies (Section 4).

The results presented show how urban planning, among the so-called relevant planning areas, represents a privileged field for understanding the level of local vulnerability, the expected impacts and, therefore, the priorities for action. The reconnaissance effort to integrate the three components of climate exposure, sensitivity and adaptive analysis recalls the centrality of governance. Urban settlements are the typical context in which the involvement of actors and resources is essential to jointly tackle similar issues. Therefore, the need to activate collaborations and coordination also emerges between

competing competences and between institutional subjects in order to define systematic frameworks of mitigation and adaptation measures.

Similar approaches, both in terms of elaborating vulnerability maps and defining systematic frameworks of measures, are particularly useful for those territories that have not yet bridged the existing gap with more advanced regions that have long been measured with the issue of climate change from a strategic and regulatory point of view. For example, with reference to the national case, in Italy, there is no legislation on adaptation to climate change and, therefore, there are no specific objectives set or obligations for the regions to adopt a planning tool on this issue. Although the National Strategy for Adaptation to Climate Change was approved in 2015, which aims to outline a national vision and provide a framework for adaptation, the implementation translation of the strategy is slow in coming. The preparation of the National Plan for Adaptation to Climate Change has been undertaken but is still being approved. What we know is that the strategy encourages more effective cooperation between institutional actors at all levels (state, regions, municipalities) and promotes the identification of territorial and sectoral priorities. The proposed research is grounded in this context as the first step in addressing the need to integrate, pending sector regulations, the ordinary urban planning tools by looking positively at the issue of climate change as an opportunity for resilient development of territories, starting from the assessment of local climate vulnerability.

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## References

1. Veizer, J.; Godderis, Y.; François, L.M. Evidence for decoupling of atmospheric CO<sub>2</sub> and global climate during the Phanerozoic eon. *Nat. Cell Biol.* **2000**, *408*, 698–701. [[CrossRef](#)]
2. Jasanoff, S. A New Climate for Society. *Theory Cult. Soc.* **2010**, *27*, 233–253. [[CrossRef](#)]
3. Stott, P.A.; Tett, S.F.B.; Jones, G.S.; Allen, M.R.; Ingram, W.J.; Mitchell, J.F.B. Attribution of twentieth century temperature change to natural and anthropogenic causes. *Clim. Dyn.* **2001**, *17*, 1–21. [[CrossRef](#)]
4. Stern, D.I.; Kaufmann, R.K. Anthropogenic and natural causes of climate change. *Clim. Chang.* **2014**, *122*, 257–269. [[CrossRef](#)]
5. Houghton, A.; Castillo-Salgado, C. Analysis of correlations between neighborhood-level vulnerability to climate change and protective green building design strategies: A spatial and ecological analysis. *Builde. Environ.* **2020**, *168*, 106523. [[CrossRef](#)]
6. Osborne, P.E.; Sanches, T. Quantifying how landscape composition and configuration affect urban land surface temperatures using machine learning and neutral landscapes. *Comput. Environ. Urban Syst.* **2019**, *76*, 80–90. [[CrossRef](#)]
7. Logan, T.; Zaitchik, B.; Guikema, S.; Nisbet, A. Night and day: The influence and relative importance of urban characteristics on remotely sensed land surface temperature. *Remote. Sens. Environ.* **2020**, *247*, 111861. [[CrossRef](#)]
8. Chen, C.; Wang, B.; Feng, P.; Xing, H.; Fletcher, A.L.; Lawes, R.A. The shifting influence of future water and temperature stress on the optimal flowering period for wheat in Western Australia. *Sci. Total. Environ.* **2020**, *737*, 139707. [[CrossRef](#)]
9. Osipov, V.I.; Rummyantseva, N.A.; Eremina, O.N. Living with risk of natural disasters. *Russ. J. Earth Sci.* **2019**, *19*, 1–10. [[CrossRef](#)]
10. Acharjee, S. Urban land use and geohazards in Itanagar, Arunachal Pradesh, India: The need for geotechnical intervention and geoethical policies in urban disaster resilience programmes in a changing climate. *Geol. Soc. Lond. Spec. Publ.* **2015**, *419*, 63–68. [[CrossRef](#)]

11. Yasuhara, K.; Nhuan, M.T.; Truc, N.N. Adaptation to climate change-induced geodisasters in coastal zones of the Asia-Pacific region. In *Engineering Geology for Society and Territory*; Lollino, G., Manconi, A., Clague, J., Shan, W., Chiarle, M., Eds.; Springer: Cham, Germany, 2015; Volume 1, pp. 149–152. [CrossRef]
12. Khadka, D.; Pathak, D. Climate change projection for the marsyangdi river basin, Nepal using statistical downscaling of GCM and its implications in geodisasters. *Geoenviron. Disasters* **2016**, *3*, 15. [CrossRef]
13. Islam, S.; Chu, C.; Smart, J.C.R.; Liew, L. Integrating disaster risk reduction and climate change adaptation: A systematic literature review. *Clim. Dev.* **2019**, *12*, 255–267. [CrossRef]
14. Islam, S.; Chu, C.; Smart, J.C. Challenges in integrating disaster risk reduction and climate change adaptation: Exploring the Bangladesh case. *Int. J. Disaster Risk Reduct.* **2020**, *47*, 101540. [CrossRef]
15. Fleming, K.C.; Abad, J.; Booth, L.; Schueller, L.; Baills, A.; Scolobig, A.; Petrovic, B.; Zuccaro, G.; Leone, M. The use of serious games in engaging stakeholders for disaster risk reduction, management and climate change adaptation information elicitation. *Int. J. Disaster Risk Reduct.* **2020**, *49*, 101669. [CrossRef]
16. Bertin, M.; Maragno, D.; Musco, F. Pianificare l'adattamento al cambiamento climatico come gestione di una macro-emergenza locale. *Territorio* **2019**, *89*, 138–144. [CrossRef]
17. 2009 UNISDR Terminology on Disaster Risk Reduction. Available online: <https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-reduction> (accessed on 5 November 2020).
18. Intergovernmental Panel on Climate Change. Glossary of terms. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*; Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., et al., Eds.; A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC); Cambridge University Press: Cambridge, UK; New York, NY, USA, 2012; pp. 555–564. ISBN 978-1-107-60780-4.
19. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. An EU Strategy on Adaptation to Climate Change. Available online: <https://eur-lex.europa.eu/legal-content/IT/ALL/?uri=CELEX:52013SC0137> (accessed on 30 October 2020).
20. Fussler, H.-M. Vulnerability: A generally applicable conceptual framework for climate change research. *Glob. Environ. Chang.* **2007**, *17*, 155–167. [CrossRef]
21. Kasperson, J.X.; Kasperson, R.E.; Turner, B.; Hsieh, W.; Schiller, A. Vulnerability to Global Environmental Change. In *The Social Contours of Risk*; Kasperson, R.E., Ed.; Taylor and Francis: Oxford, UK, 2012; Volume II, pp. 245–285. ISBN 9781849772549.
22. Ludena, C.E.; Yoon, S.W.; Sánchez-Aragón, L.; Miller, S.; Yu, B.K. Vulnerability indicators of adaptation to climate change and policy implications for investment projects. *Int. Am. Dev. Bank* **2015**, *858*, IDB-TN-858.
23. Pachauri, R.K.; Allen, M.R.; Barros, V.R.; Broome, J.; Cramer, W.; Christ, R.; Church, J.A.; Clarke, L.; Dahe, Q.; Dasgupta, P.; et al. *Climate Change 2014: Synthesis Report*; Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; IPCC: Geneva, Switzerland, 2014; ISBN 978-92-9169-143-2.
24. World Meteorological Organization. *WMO Statement on the State of the Global Climate in 2019*; WMO: Geneva, Switzerland, 2020; p. 1248. ISBN 978-92-63-11248-4.
25. Thaler, T.; Seebauer, S. Bottom-up citizen initiatives in natural hazard management: Why they appear and what they can do? *Environ. Sci. Policy* **2019**, *94*, 101–111. [CrossRef]
26. Botzen, W.J.W.; Bergh, J.C.V.D.; Bouwer, L.M. Climate change and increased risk for the insurance sector: A global perspective and an assessment for the Netherlands. *Nat. Hazards* **2009**, *52*, 577–598. [CrossRef]
27. Jacobsen, J.K.S.; Leiren, M.D.; Saarinen, J. Natural hazard experiences and adaptations: A study of winter climate-induced road closures in Norway. *Nor. Geogr. Tidsskr. Nor. J. Geogr.* **2016**, *70*, 292–305. [CrossRef]
28. Takemi, T.; Okada, Y.; Ito, R.; Ishikawa, H.; Nakakita, E. Assessing the impacts of global warming on meteorological hazards and risks in Japan: Philosophy and achievements of the SOUSEI program. *Hydrol. Res. Lett.* **2016**, *10*, 119–125. [CrossRef]
29. Pregolato, M.; Dawson, D.A. Adaptation investments for transport resilience: Trends and recommendations. *Int. J. Saf. Secur. Eng.* **2018**, *8*, 515–527. [CrossRef]
30. Doktycz, C.; Abkowitz, M.D. Loss and Damage Estimation for Extreme Weather Events: State of the Practice. *Sustainability* **2019**, *11*, 4243. [CrossRef]
31. Petrova, E.G. Natural factors of technological accidents: The case of Russia. *Nat. Hazards Earth Syst. Sci.* **2011**, *11*, 2227–2234. [CrossRef]

32. Pinnegar, J.K.; Engelhard, G.H.; Norris, N.J.; Theophille, D.; Sebastien, R.D. Assessing vulnerability and adaptive capacity of the fisheries sector in Dominica: Long-term climate change and catastrophic hurricanes. *ICES J. Mar. Sci.* **2019**, *76*, 1353–1367. [[CrossRef](#)]
33. Scyphers, S.; Beck, M.W.; Furman, K.L.; Haner, J.; Josephs, L.I.; Lynskey, R.; Keeler, A.G.; Landry, C.E.; Powers, S.P.; Webb, B.M.; et al. A Waterfront View of Coastal Hazards: Contextualizing Relationships among Geographic Exposure, Shoreline Type, and Hazard Concerns among Coastal Residents. *Sustainability* **2019**, *11*, 6687. [[CrossRef](#)]
34. Pi, Y.; Yu, Y.; Zhang, Y.; Xu, C.; Yu, R. Extreme Temperature Events during 1960–2017 in the Arid Region of Northwest China: Spatiotemporal Dynamics and Associated Large-Scale Atmospheric Circulation. *Sustainability* **2020**, *12*, 1198. [[CrossRef](#)]
35. Ross, M.; Santiago, J.; Lagmay, A.M. Integrating and Applying Technology in Response to the Super Typhoon Bopha Disaster. *Procedia Eng.* **2015**, *107*, 100–109. [[CrossRef](#)]
36. Rodolfo, K.S.; Lagmay, A.M.F.; Eco, R.C.; Herrero, T.M.; Mendoza, J.E.; Minimo, L.G.; Santiago, J.T. The December 2012 Mayo River debris flow triggered by Super Typhoon Bopha in Mindanao, Philippines: Lessons learned and questions raised. *Nat. Hazards Earth Sys.* **2016**, *16*, 2683–2695. [[CrossRef](#)]
37. Luu, T.A.; Nguyen, A.T.; Trinh, Q.A.; Pham, V.T.; Le, B.B.; Nguyen, D.T.; Hoang, Q.N.; Pham, H.T.; Nguyen, T.K.; Luu, V.N.; et al. Farmers' Intention to Climate Change Adaptation in Agriculture in the Red River Delta Biosphere Reserve (Vietnam): A Combination of Structural Equation Modeling (SEM) and Protection Motivation Theory (PMT). *Sustainability* **2019**, *11*, 2993. [[CrossRef](#)]
38. Salomon, F.; Bernal-Casasola, D.; Díaz, J.J.; Lara, M.; Domínguez-Bella, S.; Ertlen, D.; Wassmer, P.; Adam, P.; Schaeffer, P.; Hardion, L.; et al. High-resolution late Holocene sedimentary cores record the long history of the city of Cádiz (south-western Spain). *Sci. Drill.* **2020**, *27*, 35–47. [[CrossRef](#)]
39. Van Ackere, S.; Beullens, J.; Vanneuville, W.; De Wulf, A.A.; De Maeyer, P. FLIAT, An Object-Relational GIS Tool for Flood Impact Assessment in Flanders, Belgium. *Water* **2019**, *11*, 711. [[CrossRef](#)]
40. Weber, K.; Wernhart, S.; Stickler, T.; Fuchs, B.; Balas, M.; Hübl, J.; Damyanovic, D. Risk Communication on Floodings: Insights into the Risk Awareness of Migrants in Rural Communities in Austria. *Mt. Res. Dev.* **2019**, *39*. [[CrossRef](#)]
41. Magalhães, S.D.S.; Miranda, D.K.; Miranda, D.M.; Malloy-Diniz, L.F.; Romano-Silva, M.A. The Extreme Climate Event Database (EXCEED): Development of a picture database composed of drought and flood stimuli. *PLoS ONE* **2018**, *13*, e0204093. [[CrossRef](#)]
42. Parker, L.; Bourgoin, C.; Martinez-Valle, A.; Läderach, P. Vulnerability of the agricultural sector to climate change: The development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making. *PLoS ONE* **2019**, *14*, e0213641. [[CrossRef](#)]
43. Zhao, Y.; Yang, N.; Wei, Y.; Hu, B.; Cao, Q.; Tong, K.; Liang, Y. Eight Hundred Years of Drought and Flood Disasters and Precipitation Sequence Reconstruction in Wuzhou City, Southwest China. *Water* **2019**, *11*, 219. [[CrossRef](#)]
44. Do, X.K.; Kim, M.; Nguyen, H.T.; Jung, K. Analysis of landslide dam failure caused by overtopping. *Procedia Eng.* **2016**, *154*, 990–994. [[CrossRef](#)]
45. Andres, N.; Badoux, A. The Swiss flood and landslide damage database: Normalisation and trends. *J. Flood Risk Manag.* **2018**, *12*, e12510. [[CrossRef](#)]
46. Vaculisteanu, G.; Niculita, M.; Mărgărint, M.C. Natural hazards and their impact on rural settlements in NE Romania A cartographical approach. *Open Geosci.* **2019**, *11*, 765–782. [[CrossRef](#)]
47. Lader, R.; Bhatt, U.S.; Walsh, J.E.; Rupp, T.S.; Bieniek, P.A. Two-Meter Temperature and Precipitation from Atmospheric Reanalysis Evaluated for Alaska. *J. Appl. Meteorol. Clim.* **2016**, *55*, 901–922. [[CrossRef](#)]
48. Nel, J.L.; Le Maitre, D.C.; Nel, D.C.; Reyers, B.; Archibald, S.; Van Wilgen, B.W.; Forsyth, G.G.; Theron, A.K.; O'Farrell, P.J.; Kahinda, J.M.; et al. Natural Hazards in a Changing World: A Case for Ecosystem-Based Management. *PLoS ONE* **2014**, *9*, e95942. [[CrossRef](#)] [[PubMed](#)]
49. Kothawale, D.R.; Revadekar, J.V.; Kumar, K.R. Recent trends in pre-monsoon daily temperature extremes over India. *J. Earth Syst. Sci.* **2010**, *119*, 51–65. [[CrossRef](#)]
50. Grothmann, T.; Leitner, M.; Glas, N.; Prutsch, A. A Five-Steps Methodology to Design Communication Formats That Can Contribute to Behavior Change. *SAGE Open* **2017**, *7*, 2158244017692014. [[CrossRef](#)]
51. Zander, K.K.; Wilson, T.; Garnett, S.T. Understanding the role of natural hazards in internal labour mobility in Australia. *Weather. Clim. Extremes* **2020**, *29*, 100261. [[CrossRef](#)]

52. Punziano, G.; Urso, G. Local development strategies for inner areas in Italy. A comparative analysis based on plan documents. *Ital. J. Plan. Pract.* **2016**, *6*, 76–109.
53. Tiainen, J.; Hyvönen, T.; Hagner, M.; Huusela-Veistola, E.; Louhi, P.; Miettinen, A.; Nieminen, T.; Palojarvi, A.; Seimola, T.; Taimisto, P.; et al. Biodiversity in intensive and extensive grasslands in Finland: The impacts of spatial and temporal changes of agricultural land use. *Agric. Food Sci.* **2020**, *29*, 68–97. [[CrossRef](#)]
54. Dalsgaard, B. Land-Use and Climate Impacts on Plant–Pollinator Interactions and Pollination Services. *Diversity* **2020**, *12*, 168. [[CrossRef](#)]
55. Zhao, W.W.; Liu, Y.; Feng, Q.; Wang, Y.P.; Yang, S.Q. Ecosystem services for coupled human and environment systems. *Prog. Geog.* **2018**, *37*, 139–151. [[CrossRef](#)]
56. Dai, E.; Yin, L.; Wang, Y.; Ma, L.; Tong, M. Quantitative Assessment of the Relative Impacts of Land Use and Climate Change on the Key Ecosystem Services in the Hengduan Mountain Region, China. *Sustainability* **2020**, *12*, 4100. [[CrossRef](#)]
57. Mngumi, L.E. Ecosystem services potential for climate change resilience in peri-urban areas in Sub-Saharan Africa. *Landsc. Ecol. Eng.* **2020**, *16*, 1–12. [[CrossRef](#)]
58. Devi, R.M.; Sinha, B.; Bisaria, J.; Saran, S. Multitemporal analysis of forest cover change using remote sensing and GIS of kanha tiger reserve, Central India. *ISPRS Int. Arch. Photogramm.* **2018**, 211–219. [[CrossRef](#)]
59. Groisman, P.Y.; Bulygina, O.; Henebry, G.M.; Speranskaya, N.; Shiklomanov, A.; Chen, Y.; Tchebakova, N.; Parfenova, E.; Tilinina, N.; Zolina, O.; et al. Dryland belt of Northern Eurasia: Contemporary environmental changes and their consequences. *Environ. Res. Lett.* **2018**, *13*, 115008. [[CrossRef](#)]
60. Lieu, J.; Spyridaki, N.-A.; Tinoco, R.A.; Van Der Gaast, W.; Tuerk, A.; Van Vliet, O. Evaluating Consistency in Environmental Policy Mixes through Policy, Stakeholder, and Contextual Interactions. *Sustainability* **2018**, *10*, 1896. [[CrossRef](#)]
61. Zhou, C.W.; Yang, R.; Yu, L.F.; Zhang, Y.; Yan, L.B. Hydrological and ecological effects of climate change in Caohai watershed based on SWAT model. *Appl. Ecol. Environ. Res.* **2019**, *17*, 161–172. [[CrossRef](#)]
62. Jiang, X.; Shen, W.; Bai, X. Response of net primary productivity to vegetation restoration in Chinese Loess Plateau during 1986–2015. *PLoS ONE* **2019**, *14*, e0219270. [[CrossRef](#)]
63. Zhang, X.; Zhang, B.; Feeley, K.J.; Wang, G.G.; Zhang, J.; Zhai, L. Ecological contingency in species shifts: Downslope shifts of woody species under warming climate and land-use change. *Environ. Res. Lett.* **2019**, *14*, 114033. [[CrossRef](#)]
64. Yang, H.; Huntingford, C.; Wiltshire, A.; Sitch, S.; Mercado, L. Compensatory climate effects link trends in global runoff to rising atmospheric CO<sub>2</sub> concentration. *Environ. Res. Lett.* **2019**, *14*, 124075. [[CrossRef](#)]
65. De Caro, M.; Perico, R.; Crosta, G.B.; Frattini, P.; Volpi, G. A regional-scale conceptual and numerical groundwater flow model in fluvio-glacial sediments for the Milan Metropolitan area (Northern Italy). *J. Hydrol. Reg. Stud.* **2020**, *29*, 100683. [[CrossRef](#)]
66. Labat, M.M.; Foldes, G.; Kohnova, S.; Hlavcova, K. Land use and climate change impact on runoff in a small mountainous catchment in Slovakia. *IOP Conf. Series Earth Environ. Sci.* **2020**, *444*, 012036. [[CrossRef](#)]
67. Touseef, M.; Chen, L.; Masud, T.; Khan, A.; Yang, K.; Shahzad, A.; Ijaz, M.W.; Wang, Y. Assessment of the Future Climate Change Projections on Streamflow Hydrology and Water Availability over Upper Xijiang River Basin, China. *Appl. Sci.* **2020**, *10*, 3671. [[CrossRef](#)]
68. Xu, D.; Lyon, S.W.; Mao, J.; Dai, H.; Jarsjö, J. Impacts of multi-purpose reservoir construction, land-use change and climate change on runoff characteristics in the Poyang Lake basin, China. *J. Hydrol. Reg. Stud.* **2020**, *29*, 100694. [[CrossRef](#)]
69. Holland, R.A.; Beaumont, N.; Hooper, T.; Austen, M.; Gross, R.J.; Heptonstall, P.J.; Ketsopoulou, I.; Winskel, M.; Watson, J.; Taylor, G. Incorporating ecosystem services into the design of future energy systems. *Appl. Energy* **2018**, *222*, 812–822. [[CrossRef](#)]
70. Vaughan, N.E.; Gough, C.; Mander, S.; Littleton, E.W.; Welfle, A.; Gernaat, D.E.H.J.; Van Vuuren, D.P. Evaluating the use of biomass energy with carbon capture and storage in low emission scenarios. *Environ. Res. Lett.* **2018**, *13*, 044014. [[CrossRef](#)]
71. Creutzig, F.; Breyer, C.; Hilaire, J.; Minx, J.C.; Peters, G.P.; Socolow, R.H. The mutual dependence of negative emission technologies and energy systems. *Energy Environ. Sci.* **2019**, *12*, 1805–1817. [[CrossRef](#)]
72. Randle-Boggis, R.; White, P.; Cruz, J.; Parker, G.; Montag, H.; Scurlock, J.; Hooper, T. Realising co-benefits for natural capital and ecosystem services from solar parks: A co-developed, evidence-based approach. *Renew. Sustain. Energy Rev.* **2020**, *125*, 109775. [[CrossRef](#)]

73. Knight, T.; Price, S.; Bowler, D.; King, S. How effective is 'greening' of urban areas in reducing human exposure to ground-level ozone concentrations, UV exposure and the 'urban heat island effect'? A protocol to update a systematic review. *Environ. Évid.* **2016**, *5*, 8. [[CrossRef](#)]
74. Lin, B.B.; Meyers, J.; Beaty, R.M.; Barnett, G.B. Urban Green Infrastructure Impacts on Climate Regulation Services in Sydney, Australia. *Sustainability* **2016**, *8*, 788. [[CrossRef](#)]
75. Boeri, A.; Gaspari, J.; Gianfrate, V.; Longo, D. Accelerating Urban Transition: An approach to greening the Built Environment. *WIT Tr. Ecol. Envir.* **2017**, *223*, 3–14. [[CrossRef](#)]
76. Tor-Ngern, P.; Leksungnoen, N. Investigating carbon dioxide absorption by urban trees in a new park of Bangkok, Thailand. *BMC Ecol.* **2020**, *20*, 20. [[CrossRef](#)]
77. Kloster, S.; Mahowald, N.M.; Randerson, J.T.; Lawrence, P.J. The impacts of climate, land use, and demography on fires during the 21st century simulated by CLM-CN. *Biogeosciences* **2012**, *9*, 509–525. [[CrossRef](#)]
78. Uriarte, M.; Schwartz, N.; Powers, J.S.; Marín-Spiotta, E.; Liao, W.; Werden, L.K. Impacts of climate variability on tree demography in second growth tropical forests: The importance of regional context for predicting successional trajectories. *Biotropica* **2016**, *48*, 780–797. [[CrossRef](#)]
79. Sleeter, B.M.; Wilson, T.S.; Sharygin, E.; Sherba, J.T. Future Scenarios of Land Change Based on Empirical Data and Demographic Trends. *Earth's Futur.* **2017**, *5*, 1068–1083. [[CrossRef](#)]
80. Hong, J.-W.; Hong, J.; Kwon, E.E.; Yoon, D. Temporal dynamics of urban heat island correlated with the socio-economic development over the past half-century in Seoul, Korea. *Environ. Pollut.* **2019**, *254*, 112934. [[CrossRef](#)] [[PubMed](#)]
81. Bamber, N.; Jones, M.; Nelson, L.; Hannam, K.; Nichol, C.; Pelletier, N. Life cycle assessment of mulch use on Okanagan apple orchards: Part 1 Attributional. *J. Clean. Prod.* **2020**, *267*, 121960. [[CrossRef](#)]
82. Pihlainen, S.; Zandersen, M.; Hyytiäinen, K.; Andersen, H.E.; Bartosova, A.; Gustafsson, B.; Jabloun, M.; McCrackin, M.L.; Meier, H.M.; Olesen, J.E.; et al. Impacts of changing society and climate on nutrient loading to the Baltic Sea. *Sci. Total. Environ.* **2020**, *731*, 138935. [[CrossRef](#)]
83. Rabin, S.S.; Alexander, P.; Henry, R.; Anthoni, P.; Pugh, T.A.M.; Rounsevell, M.; Arneth, A. Impacts of future agricultural change on ecosystem service indicators. *Earth Syst. Dyn.* **2020**, *11*, 357–376. [[CrossRef](#)]
84. Fischer, S.; Pietroń, J.; Bring, A.; Thorslund, J.; Jarsjö, J. Present to future sediment transport of the Brahmaputra River: Reducing uncertainty in predictions and management. *Reg. Environ. Chang.* **2016**, *17*, 515–526. [[CrossRef](#)]
85. Inturri, G.; Ignaccolo, M.; Le Pira, M.; Capri, S.; Giuffrida, N. Influence of Accessibility, Land Use and Transport Policies on the Transport Energy Dependence of a City. *Transp. Res. Procedia* **2017**, *25*, 3273–3285. [[CrossRef](#)]
86. Lewis, R.; Zako, R.; Biddle, A.; Isbell, R. Reducing greenhouse gas emissions from transportation and land use: Lessons from West Coast states. *J. Transp. Land Use* **2018**, *11*, 343–366. [[CrossRef](#)]
87. Chalov, S.; Golosov, V.; Collins, A.; Stone, M. Preface: Land use and climate change impacts on erosion and sediment transport. *Proc. Int. Assoc. Hydrol. Sci.* **2019**, *381*, 1. [[CrossRef](#)]
88. Yasuhara, K.; Komine, H.; Murakami, S.; Chen, G.; Mitani, Y.; Duc, D. Effects of climate change on geo-disasters in coastal zones and their adaptation. *Geotext. Geomembranes* **2012**, *30*, 24–34. [[CrossRef](#)]
89. Fournier, M.; Larrue, C.; Alexander, M.; Hegger, D.L.T.; Bakker, M.H.N.; Pettersson, M.; Crabbé, A.; Mees, H.; Choryński, A. Flood risk mitigation in Europe: How far away are we from the aspired forms of adaptive governance? *Ecol. Soc.* **2016**, *21*. [[CrossRef](#)]
90. Longo, D.; Boeri, A.; Gianfrate, V.; Palumbo, E.; Boulanger, S.O. Resilient cities: Mitigation measures for urban districts. a feasibility study. *Int. J. Sustain. Dev. Plan.* **2018**, *13*, 734–745. [[CrossRef](#)]
91. Mori, S.; Washida, T.; Kurosawa, A.; Masui, T. Assessment of mitigation strategies as tools for risk management under future uncertainties: A multi-model approach. *Sustain. Sci.* **2018**, *13*, 329–349. [[CrossRef](#)] [[PubMed](#)]
92. Moon, D.R.; Taverna, G.S.; Anduix-Canto, C.; Ingham, T.; Chipperfield, M.P.; Seakins, P.W.; Baeza-Romero, M.-T.; Heard, D.E. Heterogeneous reaction of HO<sub>2</sub> with airborne TiO<sub>2</sub> particles and its implication for climate change mitigation strategies. *Atmos. Chem. Phys. Discuss.* **2018**, *18*, 327–338. [[CrossRef](#)]
93. Sareen, S.; Rommetveit, K. Smart gridlock? Challenging hegemonic framings of mitigation solutions and scalability. *Environ. Res. Lett.* **2019**, *14*, 075004. [[CrossRef](#)]
94. Tica, G.; Grubic, A.R. Mitigation of climate change from the aspect of controlling F-gases in the field of cooling technology. *Mater. Sci. Eng.* **2019**, *477*, 012056. [[CrossRef](#)]

95. Abarca-Álvarez, F.J.; Navarro-Ligero, M.L.; Valenzuela-Montes, L.M.; Campos-Sánchez, F.S. European Strategies for Adaptation to Climate Change with the Mayors Adapt Initiative by Self-Organizing Maps. *Appl. Sci.* **2019**, *9*, 3859. [[CrossRef](#)]
96. Thaler, T.; Attems, M.-S.; Bonnefond, M.; Clarke, D.; Gatién-Tournat, A.; Gralepois, M.; Fournier, M.; Murphy, C.; Rauter, M.; Papathoma-Köhle, M.; et al. Drivers and barriers of adaptation initiatives How societal transformation affects natural hazard management and risk mitigation in Europe. *Sci. Total. Environ.* **2019**, *650*, 1073–1082. [[CrossRef](#)]
97. Becsi, B.; Hohenwallner-Ries, D.; Grothmann, T.; Prutsch, A.; Huber, T.; Formayer, H. Towards better informed adaptation strategies: Co-designing climate change impact maps for Austrian regions. *Clim. Chang.* **2019**, *158*, 393–411. [[CrossRef](#)]
98. Karki, S.; Burton, P.R.; Mackey, B. Climate change adaptation by subsistence and smallholder farmers: Insights from three agro-ecological regions of Nepal. *Cogent Soc. Sci.* **2020**, *6*, 1720555. [[CrossRef](#)]
99. Rasmus, S.; Turunen, M.T.; Luomaranta, A.; Kivinen, S.; Jylhä, K.; Räihä, J. Climate change and reindeer management in Finland: Co-analysis of practitioner knowledge and meteorological data for better adaptation. *Sci. Total. Environ.* **2020**, *710*, 136229. [[CrossRef](#)] [[PubMed](#)]
100. Rasul, G.; Pasakhala, B.; Mishra, A.; Pant, S. Adaptation to mountain cryosphere change: Issues and challenges. *Clim. Dev.* **2019**, *12*, 297–309. [[CrossRef](#)]
101. Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I). 2012. Available online: [https://ledsgp.org/wp-content/uploads/2016/01/SUTP\\_GIZ\\_FS\\_Avoid-Shift-Improve\\_EN.pdf](https://ledsgp.org/wp-content/uploads/2016/01/SUTP_GIZ_FS_Avoid-Shift-Improve_EN.pdf) (accessed on 5 November 2020).
102. Cavalieri, C. Extreme-city-territories. Coastal geographies in the Veneto region. *J. Urban. Int. Res. Placemaking Urban Sustain.* **2020**, 1–19. [[CrossRef](#)]
103. Maragno, D.; Ruzzante, F.; Negretto, V.; Musco, F. Climate Proof Planning: l'uso del remote sensing a supporto della vulnerabilità a scala urbana. *GEOmedia* **2019**, *23*, 6–11.
104. Nistor, M.-M.; Mîndrescu, M. Climate change effect on groundwater resources in Emilia-Romagna region: An improved assessment through NISTOR-CEGW method. *Quat. Int.* **2019**, *504*, 214–228. [[CrossRef](#)]
105. Khan, S. Vulnerability assessments and their planning implications: A case study of the Hutt Valley, New Zealand. *Nat. Hazards* **2012**, *64*, 1587–1607. [[CrossRef](#)]
106. Harvey, A.; Hinkel, J.; Horrocks, L.; Klein, R.; Lasage, R.; Hodgson, N.; Sajwaj, T.; Benzie, M. *Preliminary Assessment and Roadmap for the Elaboration of Climate Change Vulnerability Indicators at Regional Level*; AEA: London, UK, 2009.
107. Schmeltz, M.; Marcotullio, P.J. Examination of Human Health Impacts Due to Adverse Climate Events Through the Use of Vulnerability Mapping: A Scoping Review. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3091. [[CrossRef](#)]
108. Natividade-Jesus, E.; Almeida, A.; Sousa, N.; Coutinho-Rodrigues, J. A Case Study Driven Integrated Methodology to Support Sustainable Urban Regeneration Planning and Management. *Sustainability* **2019**, *11*, 4129. [[CrossRef](#)]
109. Bellard, C.; Leclerc, C.; Leroy, B.; Bakkenes, M.; Veloz, S.; Thuiller, W.; Courchamp, F. Vulnerability of biodiversity hotspots to global change. *Glob. Ecol. Biogeogr.* **2014**, *23*, 1376–1386. [[CrossRef](#)]
110. Dawson, T.P.; Jackson, S.T.; House, J.I.; Prentice, I.C.; Mace, G.M. Beyond Predictions: Biodiversity Conservation in a Changing Climate. *Science* **2011**, *332*, 53–58. [[CrossRef](#)] [[PubMed](#)]
111. Li, D.; Wu, S.; Liu, L.; Zhang, Y.; Li, S. Vulnerability of the global terrestrial ecosystems to climate change. *Glob. Chang. Biol.* **2018**, *24*, 4095–4106. [[CrossRef](#)] [[PubMed](#)]
112. Hoffmann, S.; Beierkuhnlein, C. Climate change exposure and vulnerability of the global protected area estate from an international perspective. *Divers. Distrib.* **2020**, *26*, 1496–1509. [[CrossRef](#)]
113. Garcia, R.A.; Cabeza, M.; Rahbek, C.; Araújo, M.B. Multiple Dimensions of Climate Change and Their Implications for Biodiversity. *Science* **2014**, *344*, 1247579. [[CrossRef](#)] [[PubMed](#)]
114. ESPON. Climate Change May Hamper Territorial Cohesion. 2013. Available online: [https://www.espon.eu/sites/default/files/attachments/ESPON\\_MoM\\_190112.pdf](https://www.espon.eu/sites/default/files/attachments/ESPON_MoM_190112.pdf) (accessed on 5 November 2020).
115. Füssel, H.M.; Jol, A.; Hildén, M. *Climate Change, Impacts and Vulnerability in Europe 2012; An Indicator-based Report 12/2012*; European Environment Agency: Copenhagen, Denmark, 2012. [[CrossRef](#)]
116. Castellari, S.; Venturini, S.; Ballarin Denti, A.; Bigano, A.; Bindi, M.; Bosello, F.; Carrera, L.; Chiriaco, M.V.; Danovaro, R.; Desiato, F.; et al. *Rapporto sullo Stato delle Conoscenze Scientifiche su Impatti, Vulnerabilità ed Adattamento ai Cambiamenti Climatici in Italia*; Ministero dell'Ambiente e della Tutela del Territorio e del Mare: Roma, Italia, 2014.

117. Hallegatte, S.; Corfee-Morlot, J. Understanding climate change impacts, vulnerability and adaptation at city scale: An introduction. *Clim. Chang.* **2010**, *104*, 1–12. [[CrossRef](#)]
118. Lankao, P.R.; Qin, H. Conceptualizing urban vulnerability to global climate and environmental change. *Curr. Opin. Environ. Sustain.* **2011**, *3*, 142–149. [[CrossRef](#)]
119. McCormick, S.A. Assessing climate change vulnerability in urban America: Stakeholder-driven approaches. *Clim. Chang.* **2016**, *138*, 397–410. [[CrossRef](#)]
120. El-Zein, A.; Tonmoy, F.N. Assessment of vulnerability to climate change using a multi-criteria outranking approach with application to heat stress in Sydney. *Ecol. Indic.* **2015**, *48*, 207–217. [[CrossRef](#)]
121. Tapia, C.; Abajo, B.; Feliu, E.; Mendizabal, M.; Martinez, J.A.; Fernández, J.G.; Laburu, T.; Lejarazu, A. Profiling urban vulnerabilities to climate change: An indicator-based vulnerability assessment for European cities. *Ecol. Indic.* **2017**, *78*, 142–155. [[CrossRef](#)]
122. Lioubimtseva, E. A multi-scale assessment of human vulnerability to climate change in the Aral Sea basin. *Environ. Earth Sci.* **2014**, *73*, 719–729. [[CrossRef](#)]
123. Strategia Nazionale di Adattamento ai Cambiamenti Climatici. Available online: <https://www.minambiente.it/notizie/strategia-nazionale-di-adattamento-ai-cambiamenti-climatici-0> (accessed on 31 October 2020).
124. Transforming Our World: The 2030 Agenda for Sustainable Development. Available online: [https://www.un.org/ga/search/view\\_doc.asp?symbol=A/RES/70/1&Lang=E](https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E) (accessed on 31 October 2020).
125. The European Green Deal Sets Out how to Make Europe the First Climate-Neutral Continent by 2050, Boosting the Economy, Improving People’s Health and Quality of Life, Caring for Nature, and Leaving No One Behind. Available online: [https://ec.europa.eu/commission/presscorner/detail/e%20n/ip\\_19\\_6691](https://ec.europa.eu/commission/presscorner/detail/e%20n/ip_19_6691) (accessed on 31 October 2020).
126. Alexander, L.V.; Zhang, X.; Peterson, T.C.; Caesar, J.; Gleason, B.; Tank, A.M.G.K.; Haylock, M.; Collins, D.; Trewin, B.; Rahimzadeh, F.; et al. Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res. Space Phys.* **2006**, *111*. [[CrossRef](#)]
127. MASTER ADAPT. MAInSTreaming Experiences at Regional and Local Level for ADAPTation to Climate Change. Available online: <https://masteradapt.eu/strumenti/> (accessed on 16 June 2020).
128. Giordano, F.; Sebbio, C.; Antolini, G.; Botarelli, L.; Flapp, F.; Bonati, V.; Onorato, L.; Loglisci, N.; Priod, G.; Pelosini, R.; et al. Criteri per la definizione di indicatori prioritari di impatto dei cambiamenti climatici: Verso un set a livello nazionale. *Ingegneria dell’Ambiente* **2018**, *5*, 213–227. [[CrossRef](#)]
129. Variazioni e Tendenze Degli Estremi di Temperatura in Italia. Available online: <https://www.isprambiente.gov.it/it/pubblicazioni/stato-dellambiente/variazioni-e-tendenze-degli-estremi-di-temperatura-e-precipitazione-in-italia> (accessed on 31 October 2020).
130. Peterson, T.; Folland, C.; Gruza, G.; Hogg, W.; Mokssit, A.; Plummer, N. *Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998–2001*; World Meteorological Organization: Geneva, Switzerland, 2001.
131. Mackay, A.W. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *J. Environ. Qual.* **2008**, *37*, 2407. [[CrossRef](#)]
132. Baresi, U.; Vella, K.; Sipe, N.G. Bridging the divide between theory and guidance in strategic environmental assessment: A path for Italian regions. *Environ. Impact Assess. Rev.* **2017**, *62*, 14–24. [[CrossRef](#)]
133. Joint Research Centre-European Commission. *Handbook on Constructing Composite Indicators: Methodology and User Guide*; OECD Publishing: Paris, French, 2008; ISBN 978-92-64-04345-9.
134. Freudenberg, M. *Composite Indicators of Country Performance: A Critical Assessment*; OECD Publishing: Paris, French, 2003. [[CrossRef](#)]
135. Jacobs, R.; Smith, P.C.; Goddard, M. *Measuring Performance: An Examination of Composite Performance Indicators: A Report for the Department of Health. Centre for Health Economics*; Technical Paper; Series 29; University of New York: New York, NY, USA, 2004.
136. Sheppard, S.R. Landscape visualisation and climate change: The potential for influencing perceptions and behaviour. *Environ. Sci. Policy* **2005**, *8*, 637–654. [[CrossRef](#)]
137. Preston, B.L.; Brooke, C.; Measham, T.G.; Smith, T.F.; Goddard, R. Igniting change in local government: Lessons learned from a bushfire vulnerability assessment. *Mitig. Adapt. Strat. Glob. Chang.* **2008**, *14*, 251–283. [[CrossRef](#)]

138. Clark, G.E.; Moser, S.C.; Ratick, S.J.; Dow, K.; Meyer, W.B.; Emani, S.; Jin, W.; Kasperson, J.X.; Kasperson, R.E.; Schwarz, H.E. Assessing the Vulnerability of Coastal Communities to Extreme Storms: The Case of Revere, MA, USA. *Mitig. Adapt. Strat. Glob. Chang.* **1998**, *3*, 59–82. [[CrossRef](#)]
139. Lynch, A.H.; Tryhorn, L.; Abramson, R. Working at the Boundary: Facilitating Interdisciplinarity in Climate Change Adaptation Research. *Bull. Am. Meteorol. Soc.* **2008**, *89*, 169–179. [[CrossRef](#)]
140. European Data Journalism Network. Il Riscaldamento Climatico in Europa, Comune per Comune. Available online: <https://www.europeandatajournalism.eu/ita/Notizie/Data-news/Il-riscaldamento-climatico-in-Europa-comune-per-comune> (accessed on 31 October 2020).
141. Geoportale della Regione Calabria. Available online: <http://geoportale.regione.calabria.it/opendata> (accessed on 6 November 2020).
142. Open Data in ISTAT. Available online: <https://www.istat.it/it/dati-analisi-e-prodotti/open-data> (accessed on 6 November 2020).

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