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Editorial correspondence
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples
web: www.tema.unina.it
e-mail: redazione.tema@unina.it

The cover image shows the Irpinia hills at sunset, highlighting the enhancement of two renewable energy sources: sun and wind.
The photo was taken by Giuseppe Mazzeo in August 2022, in S. Andrea di Conza, Avellino, Italy.

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Assessing territorial vulnerability

Testing a multidisciplinary tool in Moncalieri, Italy

Simone Beltramino[a], Mattia Scalas, David Javier Castro Rodriguez, Grazia Brunetta[b]*, Franco Pellerey, Micaela Demichela, Angioletta Voghera, Andrea Longhi, Guglielmina Mutani, Ombretta Caldarice, Gaetano Miraglia, Erica Lenticchia, Luigi La Riccia

[a] Responsible Risk Resilience Interdepartmental Centre, Interuniversity Department of Regional and Urban Studies and Planning (DIST) Polytechnic of Turin, Turin, Italy.
e-mail: simone.beltramino@polito.it
ORCID: https://orcid.org/0000-0003-0872-951X

[b] Responsible Risk Resilience Interdepartmental Centre, Interuniversity Department of Regional and Urban Studies and Planning (DIST) Polytechnic of Turin, Turin, Italy.
e-mail: grazia.brunetta@polito.it
ORCID: https://orcid.org/0000-0003-1868-2700
* Corresponding author

Abstract

The challenge to make cities and human settlements inclusive, safe, and resilient, including mitigation and adaptation strategies against disaster, is a central issue in achieving sustainability. This research proposes a tool to measure local vulnerability from a multi-risk approach. The municipality of Moncalieri, Italy, was used as a case study within the research activities of the Responsible Risk Resilience Centre from the Polytechnic of Turin to test the vulnerability matrix. The tool consists of a mathematical framework for the territorial vulnerability assessment that integrates multiple indicators clustered into three factors defined as sensitivity, pressures, and hazards, weighted according to a participatory procedure. Space-dependent analyses using the Geographical Information System were developed from the multiple nested indicators to project the vulnerability index onto a homogeneous grid in the territory of interest. Thematic maps referring to the systemic vulnerability by different sensitivity components were generated. The tool not only contributes to increasing the awareness of territorial vulnerability but also offers support to resilience-based decision-making in designing technical measures of policies at a local scale. Further research is required to implement the framework in different scenarios and develop the model's temporal behaviour.

Keywords

Urban resilience; Spatial planning; Vulnerability; Geographical Information Systems; Multi-risk.

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1. Introduction

Contemporary challenges and uncertainties expose cities and local communities to multiple and non-linear risk factors that require a spatial planning approach to integrate the dimensions of complexity and unpredictability. This situation calls for new methods and tools to frame territorial vulnerability (Brunetta et al., 2019) and thus enhance resilience (Galderisi, 2012) and adaptation in the context of sustainable development goals (Brunetta & Caldarice, 2020). Central to spreading awareness and building adaptation policies is the availability of specific data and analysis to measure resilience. In this sense, vulnerability assessment is the first part of operationalizing resilience, often interpreted as a buzzword and a term challenging to put into an operational context (Brunetta et al., 2020).

Operationalizing the concept of resilience in urban planning procedures remains an open question due to the lack of empirical knowledge on measuring the degree of resilience. This paper considers the debate on this theoretical concept was adopting by Brunetta et al. (2020) definition, which focuses on applying an empirical model to measure the degree of vulnerability.

The paradigm shift brought about by the emergence of resilience as a "new way of thinking" (Folke, 2006) gave a new perspective to planning, surpassing the aim of a "final state of equilibrium" typical of 20th-century planning. This shift favoured a dynamic approach focused on the capacity of systems to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner (IPCC, 2012). Public institutions have also promoted a resilient approach to planning from the international to the local level, such as the 2030 Agenda for Sustainable Development (United Nations, 2015). Other experiences come from non-profits, also spreading thanks to the adaptation support efforts of some Transnational Municipal Networks (TMNs) as the 100 Resilience Cities Network (100RC), Local Governments for Sustainability (ICLEI), C40 or the Global Covenant of Mayors for Climate & Energy (GCOM) (Heikkinen et al., 2020). Despite its success in literature and field experiences, putting resilience into practice is a complex objective to pursue, and this is closely related to the nature of the concept itself: resilience, especially in its urban and territorial understanding, is a multidisciplinary and complex concept by definition (Jabareen, 2013), that frames a "conceptual umbrella" fascinating but slippery and ambiguous (Brunetta & Salata, 2019).

While there is agreement on some essential characteristics of urban resilience, which, if understood in its most recent co-evolutionary sense, is characterized by co-evolution, self-adaptiveness, and learning capacity (Brunetta & Salata, 2019), difficulties in measuring resilience persist. The literature is rich in attempts and methodologies, but comprehensive approaches are still lacking.

This paper assumes that the first step in operationalizing resilience and allowing its normative application in planning is to know and assess territorial vulnerabilities through a multi-risk semi-quantitative methodology based on the calculation of indicators representative of a series of variables characteristic of the territory. Vulnerability, often considered as the counter position to resilience, is to be understood as the predisposition of the elements of the system to be damaged by hazard events, punctuality, or by continuous pressures over time (IPCC, 2012), while resilience is, in fact, the coping capacity of the elements of the system. Consequently, the measurement of vulnerability lends itself to using quantitative methodologies based on multivariate analysis of representative indicators.

This paper aims to illustrate the methodology and initial experimentation of the Territorial Vulnerability Matrix developed by the Risk Resilience Centre (R3C) of Polytechnic of Turin. The Vulnerability Matrix is an assessment tool that makes it possible to identify in a spatially explicit manner the quadrants of the territory that are most vulnerable to a given set of disturbances, divided into punctual and continuous events, concerning the elements of territorial sensitivity. The aim of this matrix developed and tested within the municipality of Moncalieri (northern Italy) is to provide a scalable tool that can be applied in different contexts in order to allow measurement of vulnerability proper to identify strategies and actions for increasing territorial resilience, according to a co-evolutionary and transformative resilience concept.

The measure of vulnerability was obtained from the interaction of selected indicators of sensitivity, pressure, and hazards. The calculation operations were carried out with the help of Geographic Information System (GIS) tools (ESRI ArcGIS 10.7) and spreadsheets. The information was spatialized on a grid of 200x200 meters, making it possible to read the overlapping of the different thematic layers, showing simply the most vulnerable areas in line with the proposed by Pilone et al. (2016). On the other hand, the research group prepared a participatory weighing procedure and an interactive matrix. The results of the first assessment in Moncalieri are hereinafter presented, which, in line with expectations, made it possible to validate the methodology that is replicable to other territories due to its characteristics.
The main findings of this study are a comprehensive assessment of the various vulnerability components of a territorial system to increase vulnerability awareness, support the decision-making process and develop a resilient knowledge of the various vulnerable components of territorial systems. This knowledge can then support urban planners in policy design and land use plans that can adapt to uncertainties and disruptions.
The paper is structured in the following sections: First, a context description is offered. Second, the methodology applied is described, including a detailed mathematical procedure used to evaluate the indicators. Subsequently, the local vulnerability maps produced are presented. Finally, the conclusions about the tool's effectiveness and the possibility of extending the methodology to other territories are discussed.

1.1 State of the art

The issue that Land Use Planning policies in Italy do not deal with the possible consequences of the interaction between technological and natural hazards was a problem introduced by Galderisi et al. (2008). Moreover, it has also been recognized that different typologies of risks are generally handled separately and are analyzed with specific Plans. In addition, there remain some criticalities in the definition of a standard metric for the combined assessment and the weighting of the different categories of exposed elements and to produce results in a form that could be useful to planners. For example, although superordinate and sectorial plans provide prescriptions and recommendations on reducing and containing related risks; however, they cannot directly impose critical areas on the territory or cases of incompatibilities between combined risks and existing urban functions (Pilone et al., 2016). Although the junction point where all risks can be analyzed together is at the local scale, the lack of regulations and methodologies for multi-hazard assessment and the scarcity of technical and scientific knowledge leads to maintaining tools such as the land use plan as a mere sum of prescriptions without analyzing or correlating them in a systemic way (Pilone et al., 2017).
Few referenced methodologies at the Municipal scale are available (Bixler et al., 2021; Galderisi & Limongi, 2021). Moreover, the approaches used at a larger scale for the vulnerability and risk analysis may not be adequate at a minor scale. Likewise, some cases do not reflect the local situation due to the rapidly changing over time, which could negatively affect the vulnerability assessment significance. Consequently, the main hazards that threaten the territory can be identified based on a spatial filter. For example, data collection must be developed based on existing sectoral and emergency plans (Galderisi et al., 2021), and an in-depth direct on-site investigation should be addressed considering stressors associated with climate change (Francini et al., 2021). For this purpose, a helpful checklist could be found in the project ARMONIA (Applied multi–Risk Mapping of Natural Hazards for Impact Assessment) research project funded by the European Community (Menoni et al., 2006), which points out the following natural risks: flood, earthquake, forest fire, volcanoes, and landslide.
Some multi-risk projects have tried to define a framework for vulnerability assessment, defining analytical or qualitative methodologies. As it concerns quantitative methods, there is a general agreement on using vulnerability functions (fragility curves) to express physical vulnerability. In these methods, the input is a single hazard analyzed (e.g. intensity, magnitude, category), and the output is the average loss of a given vulnerable element. However, reliable vulnerability or fragility curves are not available for all risks. In addition, the fragility

curves do not express the vulnerability assessment for social and environmental factors, so it can be challenging to integrate them within a multi-risk framework. In other cases, vulnerability is also defined through semi-quantitative or qualitative methods. Therefore, the elements are described through indicators, which can be weighted and summed up to establish an integrated vulnerability index. One of the guiding principles for the selection of these indicators was the availability and reliability of the data in order to be able to provide brief elaborations and quick responses (Pilone, 2018).

This review aims to analyze the literature on vulnerability measurement in the multi-risk context. It found that the most common approach is preventive assessment, but it has limitations due to the complexity of the study and the multi-hazard analysis.

Although quantitative methods can measure vulnerability, they do not capture intangible elements such as power relations, social capital, and self-sufficiency that distinguish urban resilience. In the vast majority of cases, the indicators are not spatial but purely statistical and thus useful for comparative analysis between different urban areas, but of little use in building a spatial support system to guide the urban agenda of local institutions.

The literature review thus shows that semi-quantitative approaches offer a systematic and reliable way to measure different dimensions of resilience. In this line, the methodology implemented aims to address a gap in the existing planning and risk instruments, increasing the awareness of the local planners about the unexpected effects of multiple risks and providing an essential indication of the priority areas to address technical studies and financial resources.

2. Material and Methods

2.1 Methodology

This work is designed to provide a replicable methodology of the vulnerability matrix, a tool developed by the Responsible Risk Resilience Centre (R3C) from Polytechnic of Turin, to respond to the first objective of the project Measuring Resilience (Brunetta et al., 2019), which consist in the assessment and spatial representation of the systemic vulnerability of a territory.

A vulnerability matrix is a tool analysis that, through a series of recursive calculations, enables to introduce of several input variables projected on a grid that was determined based on specific research needs, to which the calculated systemic vulnerability values were attributed to each cell of the territory (Fig.1).

Conceptually, vulnerability was interpreted as the sum of the interactions between sensitivities, pressures, and hazards. The following steps concern the calculation of the "weighted" relationships between the indicators which define the index. The weighing phase is carried out through a participatory procedure with the research team's involvement.

The R3C Matrix develops a mathematical framework capable of quantifying the vulnerability in a territory, switching not only different stressors and hazards according to the location but also the necessities of the stakeholders. In this case, the territorial vulnerability index was determined by the relation of pressure and hazard index, both affected by a coefficient of interest.

The hazards index was conceptualized to determine how elements of sensitivity are affected by potential natural and anthropic hazards, including a factor that considers the impact of climate change, which was assigned to a fixed value for the present research. Similarly, for the pressure index, the sensitivity elements were affected by persistent chronic stressors in the territory, including a factor that introduces the temporal character of the pressures.

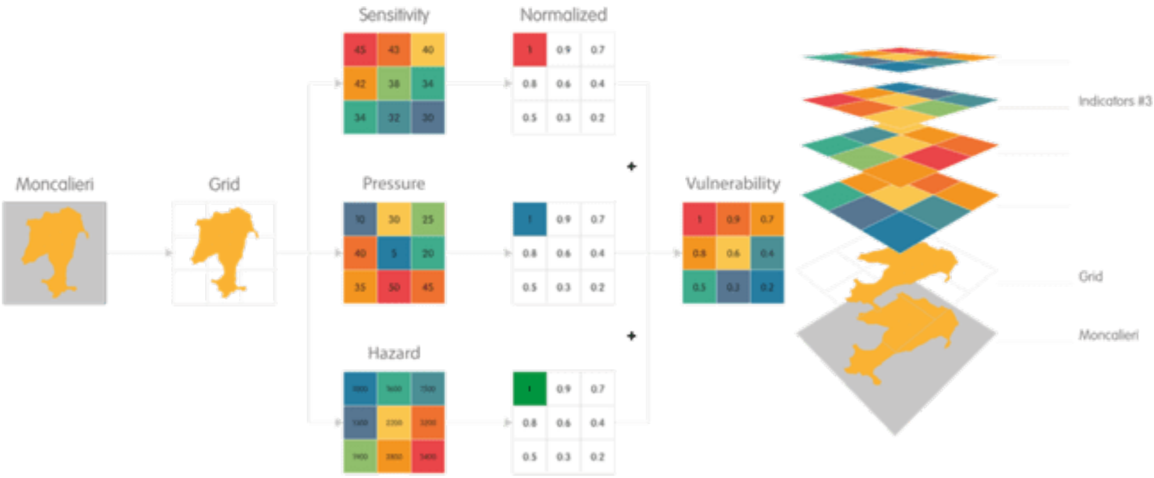


Fig.1 Schematic representation of the methodology

The starting point for the creation of the tool is the selection of a set of sensitivity, pressure, and hazard indicators and their calculation using GIS tools. Space-dependent analyses using GIS were developed from multiple nested indicators of sensitivity, pressures, and hazards, projecting the vulnerability index on a homogeneous grid in the territory of interest. This chapter presents the application of the methodology in the Municipality of Moncalieri, which can be used as a model for future applications in other case studies.

The sensitivity, pressure, and hazard indicators were selected following a discussion with stakeholders from the area under study and a review of the principal spatial government plans and territorial instruments, highlighting Moncalieri Municipality's specificities.

The matrix structure has a specific function in applying the methodology for the participatory weighing of the relationships between the indicators. In particular, the matrix structure is divided into three system components for the sensitivity indicators (rows of the R3C matrix), which in turn are made up of various indicators: Environment and Ecosystem Services (3 indicators); Construction, Infrastructure, Cultural Heritage and Landscape (5 indicators); Economy and Population (4 indicators). Fig.2 better illustrate the before description. Then, these three components intersected with three pressure indicators and six hazards (columns) (Fig.3). The way the indicators are related inside the methodology can be observed in Fig.4.

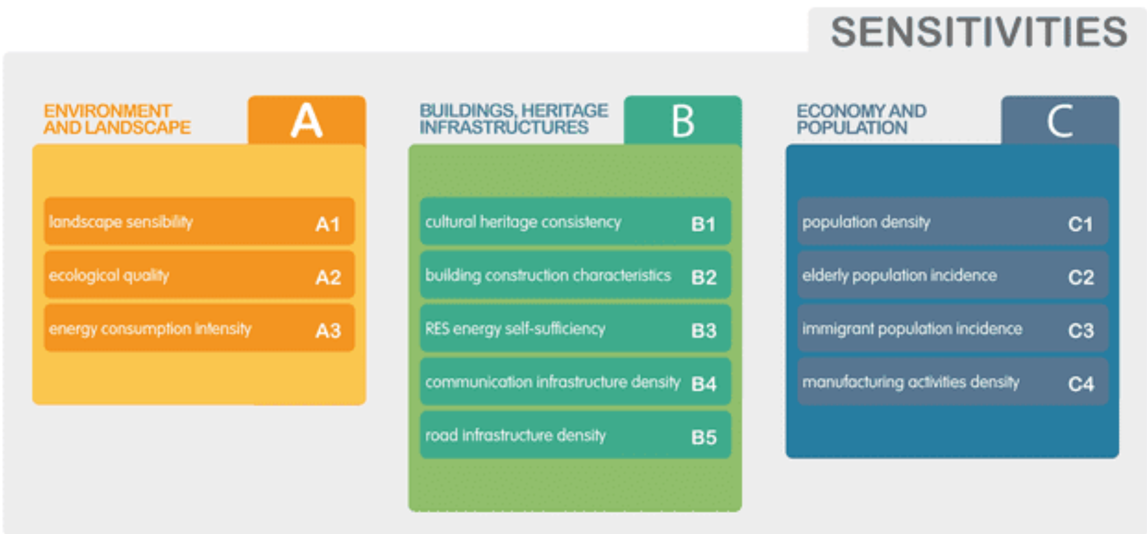


Fig.2 R3C matrix sensitivity indicators for the case study in Moncalieri

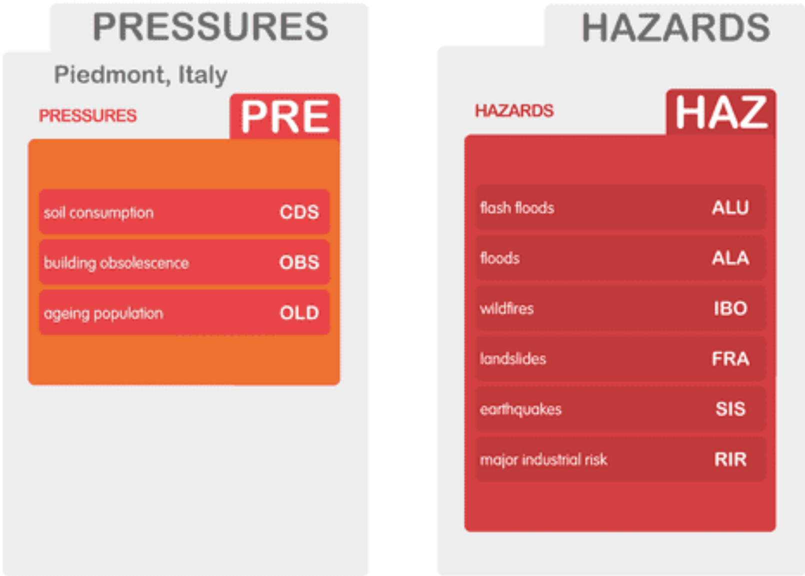


Fig.3 R3C matrix pressure and hazard indicators for the case study in Moncalieri

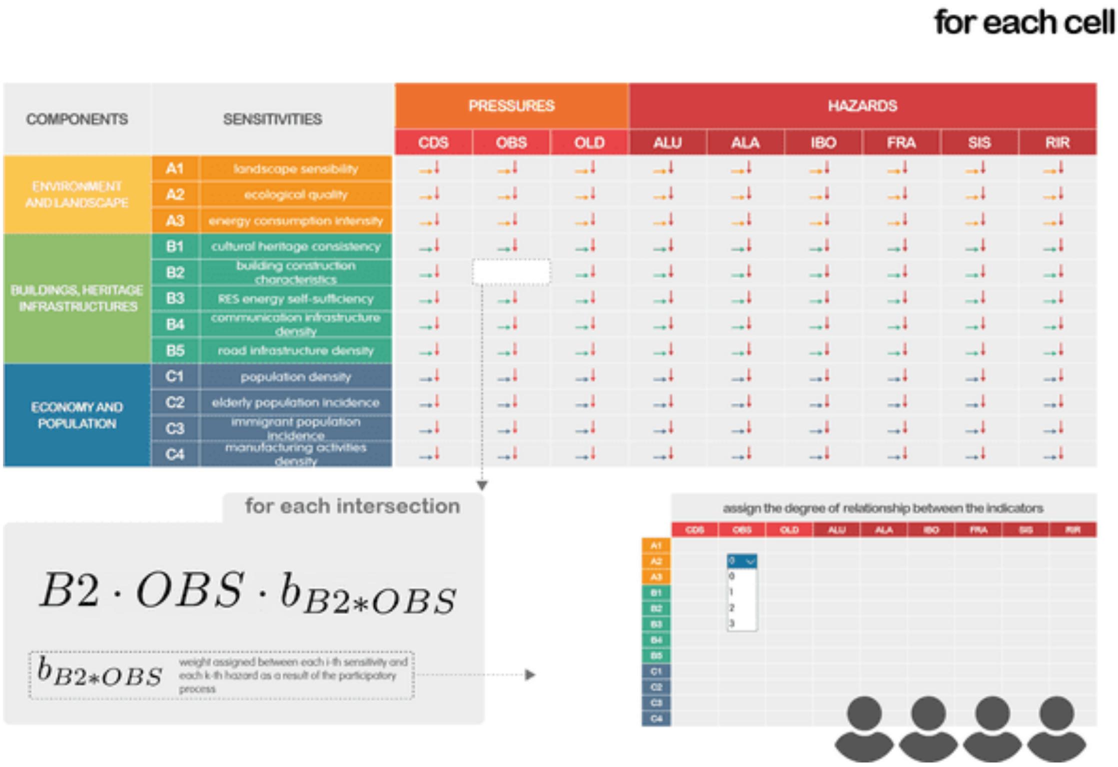


Fig.4 R3C matrix general structure

The definition and calculation of the indicators is the most consistent and time-consuming phase of this work. Each of the 21 indicators has followed a process of data collection, calculation, and attribution to the grid in a GIS environment with spatial join operations through a specific field identifier (FID) assigned to each cell. For a detailed description of each indicator and its calculation procedure see the following sections (Tabb. 1-5).

Depending on the geometry of the input data - point, line, polygon - the attribution of the values obtained for each indicator to the grid was carried out according to five criteria: (i) point count (B1, ALA), (ii) sum of the point values (A3, B3, SIS), (iii) weighted sum of linear (B5) or areal elements (A1, A2, B2, B4, C4, CDS, OBS, IBO, FRA), (iv) average value of areas within the cell (C1, C2, C3, OLD) and (v) intersection between input polygons and each cell (ALU, RIR). The values assigned to the cells of the matrix were normalized to obtain a standard metric that allows the integration among the indicators and the following operations. Partial results were displayed in a 2550-row table – one for each 200x200 m cell that subdivides the territory - with 21 columns corresponding to each indicator (Figg. 2 and 3). The following operationalization of the systemic vulnerability of the territory is described in section "Mathematical framework".

Sensitivity

Susceptibility/fragility in disaster risk management, or sensitivity in climate change adaptation, is considered as the physical predisposition of human beings, infrastructure, and the environment to be affected by a dangerous phenomenon. These affections are associated with a lack of resistance and predisposition of society and ecosystems to suffer harm due to intrinsic and context conditions, making it plausible that such systems, once impacted, will collapse or experience significant harm and damage due to the influence of a hazard event. (Cardona, 1999b; Cardona, 2001; Cardona, 2011; Cardona & Barbat, 2000; Cardona & Hurtado, 2000a,b; McCarthy et al., 2001; Gallopin, 2006; Manyena, 2006; Carreño et al., 2007a; IPCC, 2007; Carreño et al., 2009; ICSU-LAC, 2010; IPCC, 2012; Birkmann et al., 2013; IPCC, 2021). The sensitivity indicators analyzed for each system component, shown in Fig.2 now, are detailed in Tab.1, Tab.2, and Tab.3, respectively.

Sensitivity indicator	**Description**	**Databases and references**
Landscape sensibility (A1)	The indicator identifies areas of higher landscape sensitivity, meaning they have the potential to have a more significant impact on the landscape if changes are made to them. Once a set of significant "viewpoints" for the area under analysis has been defined according to bibliographic, normative, or direct survey criteria, the procedure for calculating the viewshed analysis for each viewpoint is used. The viewsheds identified for each viewpoint are then added together to obtain the area "most visible" from each.	Data: DTM (Digital Terrain Model) Recognized viewpoints/observers at a large scale (regional and national scale) Visual landmarks of the built and natural environment at a large scale (regional and national scale) Visual landmarks identified by the site survey References: Voghera & La Riccia, 2015; Voghera & La Riccia, 2016; Voghera et. al., 2017; Voghera & La Riccia, 2019
Ecological quality (A2)	The indicator uses an ENEA (National Agency for New Technologies, Energy and Sustainable Economic Development) methodology. Based on the land use data, quality scores provided by the agency are assigned. The integrity of its components determines the ecological quality of the territory. The whole non-artificial territory contributes proportionally to the level of ecological quality, to the overall connectivity in terms of an ecological network. The score is given by the sum of the values of Naturalness (1-5), Conservation (1-4), Relevance (1-4), Fragility (1-4), Extroversion (1-5), Irreversibility (1-3). The degree of sensitivity has an absolute score of 5-21 (in 6 classes): Class 1: Poor ecological functionality; Class 6: Optimal ecological quality.	Data: Corine Land Cover for soil coverage References: Voghera & La Riccia, 2015
Energy consumption intensity (A3)	The energy consumption intensity indicator was calculated by geo-referencing the database of electrical energy consumption (point of withdrawal of electricity) in the municipality of Moncalieri. The geocoding of the addresses, obtained from the database (SIATEL), was carried out with the ESRI online service, transforming the addresses into points with precise geographical coordinates. The indicator represents the distribution of the intensity of electricity consumption and related emissions on the municipal territory.	Data: SIATEL database (point of withdrawal of electricity) of the Moncalieri users References: Mutani et al., 2020 a; Mutani et al., 2020b; Brunetta et al., 2021; Mutani et al., 2021

Tab.1 Environment and ecosystem services

Sensitivity indicator	**Description**	**Databases and references**
Cultural heritage consistency (B1)	The indicator consists of the spatialization of the presence of cultural assets, whose value and interest are recognized by institutional documents produced by the Ministry of Culture (bound under the Cultural Heritage and Landscape Code), or by the current instruments of territorial government (whose prerogatives include the recognition of cultural heritage), or by other bodies with authority over the protection and management of cultural heritage (WHL UNESCO, ecclesiastical bodies). Landscape assets within the meaning of the Code are excluded. The different databases are partly overlapping, and a systematization of the data is proposed here.	Data: Constraints on the Web, a portal of the MIBAC (Ministry of Culture) allowing the download of files SIGECWeb, by ICCD BeWeb, a portal for ecclesiastical cultural assets Territorial Coordination Plan of the Metropolitan City of Turin References: Mondino, 2020
Building construction characteristics (B2)	The indicator assigns a score to each building based on its construction characteristics, according to the literature classification: 0.1: (1991-present) Reinforced concrete buildings, adapted to building regulations, insulation 0.33: (1918-1944) Residential frame structures of concrete or mixed brick/concrete materials 0.5: (1880-1918) Buildings constructed mainly of brick; improved structural characteristics due to production in Hoffman kilns 0.66: (Formerly 1860 in historical centers) buildings made of solid brick, usually from kilns 0.83: (Former 1860 in rural areas) Locally available building materials, i.e. unfired bricks, plaster, among others. 1: (1950-1991) Reinforced concrete buildings, inadequate architectural, structural, and construction features.	Data: The age of the building used is derived from an analysis of the variation of the building analyzed through historical maps References: Barreca et al., 2018; De Lucia, 2019
RES energy self-sufficiency (B3)	The indicator represents the ratio between self-consumed energy from renewable sources (SC) and consumed energy (C). The geo-referencing of the databases on electricity consumption (electricity withdrawal point) and current energy production from Renewable Energy Sources (RES) was done through the ESRI online service. Self-sufficiency from renewable energies (SC/C) is represented by the ratio between self-consumption (SC) and consumption (C), calculated on GIS software by reporting the information on the grid. The indicator indicates the share of energy consumption covered by locally produced RES and thus the energy self-sufficiency of the territory from the national grid.	Data: SIATEL database for the (electricity withdrawal point) of the Moncalieri users Atlaimpianti for installed kWp GSE (Gestore Servizi Energetici) report for hours of use of the RES plants References: Mutani et al., 2020; Mutani et al., 2021; Mutani & Todeschi, 2021; Todeschi et al., 2021
Communication infrastructure density (B4)	The indicator calculates the density - expressed in square meters - of communication infrastructures. The following values are assigned for each facility: 1: Fiber routes 0.8: Radio Base Stations for telephony 0.8: TV 0.8: Radio	Data: ARPA Piemonte
Road infrastructure density (B5)	The indicator describes the density of road space occupied in the territory under consideration, assigning the following scores based on the type of road infrastructure: 1: Motorways and railways 0.7: Suburban road 0.5: Local road 0.3: Urban road	Data: Piedmont road network map (BDTRE 2021, official Piedmont cartography)

Tab.2 Construction, Infrastructure, Cultural Heritage, and Landscape

Sensitivity indicator	Description	Databases and references
Population density (C1)	The indicator is obtained from ISTAT (National Institute of Statistics) territorial bases, which give the resident population (P1) per census section that has been divided by the area of the census section.	Data: ISTAT for spatial bases and information on the 2011 censuses
Elderly component (C2)	The indicator is obtained from ISTAT territorial bases. The indicator considers the composition of the population aged ≥ 70 years and is obtained by a procedure like C1.	Data: ISTAT for spatial bases and information on the 2011 censuses
Immigrant component (C3)	The indicator is obtained from ISTAT territorial bases. The indicator considers the density in census sections of the immigrant component (ST15) and is calculated using a procedure like C2.	Data: ISTAT for spatial bases and information on the 2011 censuses
Density of productive activities (C4)	The indicator considers the density of productive activities obtained through the built footprint of the industrial and production activity.	Data: Industrial and production building use obtained from BDTRE 2021

Tab.3 Economy, Population

Pressures

Pressures are linear and predictable trends that affect the system gradually altering its condition (IPCC, 2012). The pressures affecting the components of the system progressively increase their sensitivity, making them more vulnerable to more significant events represented by Hazards. In addition, they follow specific temporal behaviors, in some cases described by literature (i.e., soil consumption and population aging), in other cases more difficult to understand (i.e., obsolescence of buildings). Moreover, pressures enable the construction of future vulnerability scenarios at a given time. A description of the pressure indicators is given in Tab. 4.

Pressure indicator	Description	Databases and references
Soil consumption (CDS)	The indicator was developed from a diachronic analysis of the built environment in which the concentrations of buildings constructed between 1990 and 2021 were measured.	Data: 2021 BDTRE buildings The age of the building used is derived from an analysis of the variation of the building analyzed through historical maps
Building obsolescence (OBS)	The obsolescence of buildings is related to the ageing of their constituent materials. The indicator takes into account the construction age of buildings by assigning a score to each of them: older buildings have a higher pressure value.	Data: 2021 BDTRE buildings The age of the building used is derived from an analysis of the variation of the building analyzed through historical maps
Aging population (OLD)	The indicator was calculated using the ageing rate for the 2001 and 2011 ISTAT censuses, comparing the resident population aged ≥ 65 years for each census section and the population aged 0-14 years, intersecting the two rates obtained to analyze the variation over the period considered. The ageing rate is calculated as the population over 65 divided by the under 14 population sum. The ageing of the population is (the ageing rate in 2011 – the ageing rate in 2001)/ageing rate at 2001.	Data: ISTAT for spatial bases and information on 2001, and 2011 censuses

Tab.4 Pressure indicators

Hazards

Shocks are unpredictable and dangerous events that threaten the system occasionally with a high impact on the environment, settlements, and populations (IPCC, 2021). They are intended as catastrophic events that the system should absorb in case of adverse conditions. Since the occurrence of shocks is viewed over a long-time period, their effects are often unpredictable. The hazards selected for the case study in Moncalieri illustrated in Fig.3 are described in Tab. 5.

Hazard Indicator	Description	Databases and references
Flash floods (ALU)	The indicator is derived from the hazard maps of the flood risk management plans (PAI), which define hazard bands (high, medium, low). The following hazard values have been assigned: 1, high; 0.75, medium; 0.5, low.	Data: Risk maps and Hydrogeological Risk Management Plan (PAI)
Floods (ALA)	Point data referring to the history of flooding incidents were considered. Each incident reported has a value of 1.	Data: Events database from 1800 to present (BDTRE)
Wildfires (IBO)	The indicator was calculated as a modified version of the Specific Hazardousness Index in the Interface Area (IPSI). The calculation classifies the territory into three slope classes, evaluates presence and fuel quality, and crosses these data with the presence of buildings and the percentage of buildings in each cell of the matrix in contact with the combustible material. Compared to IPSI, it does not consider the data relating to the construction characteristics of the roofs.	References: (Bovio et al., 2001) Data: Forest map and land use (Piedmont Geoportal) DTM (Digital Terrain Model) Buildings 2021 (BDTRE)
Lands slides (FRA)	The indicator assigns a score to landslide areas considering the classification made by Del Prete et al. (1992), which distinguishes between active, quiescent, and stabilized landslides based on recurrence, return time, and the last survey, assigning the first maximum score (1) and the last minimum score (0).	References: (Del Prete et al., 1993) Data: Database SIFRAP
Earthquakes (SIS)	Quantify the earthquake, EQE_k, based on peak ground acceleration (PGA-Peak ground Acceleration) expected on the site for a certain probability of exceeding, PGA_k, where the building is located and normalizes its value to the maximum expected value for a probability of exceeding the 5%, $r_k = max: \left\{PGA_{k\|k}\right\}$ in a territorial area of reference. 0 = theoretical minimum PGA in the reference area, 1 = maximum PGA in the reference area. The index $\{EQE_k = \frac{PGA_k}{r_k}\ PGA_k = PGA_{0,k} \cdot S_{s,k} \cdot S_{t,k}\ r_k = max: \left\{PGA_{k\|k}\right\}$ Quantity of input. $PGA_{0,k}$ [m/s^2]: Interpolation in the construction site (indexed by point k), of points with predefined PGA, the function of the probability of exceeding in the reference period of the seismic action (SLO=81%, SLD=63%, SLV=10%, SLC=5%), according to NTC18. It can be estimated from European and Italian regulations and websites, for example, INGV, USGS, CSEM / EMSC, AHEAD, JMA, NIED / BOSAI. Note: Operational Limit State (SLO), Damage Limit State (SLD), Life Limit State (SLV), Collapse Limit State (SLC). $S_{s,k}$ [-]: stratigraphic amplification factor at the site. NTC18. $S_{t,k}$ [-]: topographic amplification factor at the site. NTC18, QGIS.	References: National Technical Construction Regulations 2018 (NTC18) Piedmont Region, List of municipalities seismic classification 2019
Major Industrial Risk (RIR)	The indicator is a classification of industrial activities at major accident risk (Seveso activity) as indicated by the provisions derived from Legislative Decree 26 June 2015, no. 105 and identifies the areas of exclusion and observation considering (Castro et al., 2022).	References: Piedmont Region, Guidelines for the assessment of industrial risk in the context of territorial planning, 2010 Data: The data on the exclusion and observation areas was provided by the Municipal Administration

Tab.5 Hazard indicators

Relative weight among sensitivity, pressures, and hazards

At this stage, the intensity of the relationships between the sensitivity, pressure, and hazard indicators in the matrix was established. In particular, the relationship between each sensitivity indicator and pressure and hazard indicator was weighted using a crossing matrix procedure (row by column). In this phase, a participatory methodology was used, involving a team of 13 researchers participating in the project. Researchers were asked to compile an interactive version of the matrix, evaluating the degree of relationship between each indicator using an ordinal Likert scale, where: 0, no relationship; 1, weak relationship; 2, strong relationship; 3, very close relationship, according to the criteria defined by Hernández (2006) and used in a similar multi-risk context (Pilone, 2018).

After collecting all the contributions, the average of the evaluations was calculated, normalized, and reported interactively on the matrix (see the bottom of the previous Fig.4).
The weighted matrix has been prioritized, and the cells were coloured according to their correlation. A value of close to 0 indicates no relationship between the indicators compared; conversely, the closer the weight is to 1, the more related the indicators are. Consequently, a semaphoric combination of colours was used to establish the priority (green for low, yellow for medium, red for high) according to the dependence index defined using the above procedure. Although not necessary for the calculation, this operation makes it possible to evaluate the choice of indicators.

Mathematical framework

The spatial indicators were discretized into homogeneous cells of 200 by 200 meters to guarantee a homogeneous distribution of the values referring to the different components of the system. The value of systemic vulnerability for each cell has been calculated as described in this section.
First, for each component (A, B or C) of the sensitivities, the indicator of vulnerability due to pressures is calculated as a weighted sum of the products between any specific indicator of pressure on the cell with any specific indicator of sensitivity on the same cell (for all considered pressures and sensitivities). To take in account how strong any pressure reflects on any sensitivity, each of these products (whose value increases as the corresponding pressure or sensitivity in the cell increases) is further multiplied (weighted) by the indicator obtained through the procedure mentioned in Section "Relative weight among sensitivity, pressures, and hazards", which describes how strong is the relationship between such pressure and such sensitivity. Thus, the value of each product is appropriately weighted in the sum, assuming higher values for strong relationships, or lower (possibly null) values when the relationship is weak (or null). The sum of all these terms (concerning all pressures and all sensitivities, thus a double sum) is finally divided by the number of total pairs of pressures/sensitivities (to obtain a normalized value in [0,1]), obtaining the final index of vulnerability due to pressures on the cell. The same procedure is then applied to compute the index of vulnerability due to hazards on the cell. Note that, doing these calculations, one can also consider the temporal nature or the impact of climate change on the effect of each pressure/hazard on each sensitivity. For that, all the products mentioned above can be additionally multiplied by a specific factor that depends on such a temporal nature.
In detail, let us denote with b_{ij} the components of the matrix appearing in Fig.4 and obtained through participatory weighing, i.e., let b_{ij} be the indicator describing the relationship between the sensitivity *i* and the pressure *j*. Similarly, let b_{ik} be the indicator describing the relationship between the sensitivity *i* and the hazard *k*.

Then for each component of the sensitivities (say component A, for example), one can compute the normalized index of pressures $I_{PR(A)}$ on a single cell as a weighted sum of the effects of each pressure, and each sensitivity in component A, using the following formula:

$$I_{PR(A)} = \frac{1}{m_A n} \cdot \sum_{i=1}^{m_A} \sum_{j=1}^{n} K_{ij}(t) \cdot S_i \cdot b_{ij} \cdot PR_j \quad (1)$$

where:

n= number of pressures.

m_A = number of sensitivities in component A.

$K_{ij}(t)$= a factor that depends on the temporal nature of the pressure *j* on sensitivity *i* (at the initial time, t_0=2020 one can fix $K_{ij}(t_0)$= 1).

S_i= indicator of sensitivity *i* in the specific cell.

PR_j = indicator of pressure *j* in the specific cell.

It should be noted that the sum is divided by $m_A\ n$ to normalize the index, i.e., to obtain a quantity assuming values in [0,1] (being a total of $m_A\ n$ summands). Furthermore, observe that each pressure affecting each sensitivity is multiplied by the indicator b_{ij} describing the relationship between each sensitivity and pressure.

Similarly, it is possible to compute the normalized index of hazard $I_{HZ(A)}$ on a single cell as a weighted sum of the effects of each hazard on each sensitivity of component A as follows.

$$I_{HZ(A)} = \frac{1}{m_A p} \cdot \sum_{i=1}^{m_A} \sum_{=k1}^{p} CC(t)_k \cdot S_i \cdot b_{ik} \cdot HZ_k \tag{2}$$

where:

p= number of hazards.

m_A = number of sensitivities in component A.

$CC(t)_k$= a factor that expresses the impact of climate change (for the present case study was considered $CC(t)_k$=1) related to hazard *k.*

S_i= indicator of sensitivity *i* in the specific cell.

HZ_k = indicator of hazard *k* in the specific cell.

For the rest of the sensitivity components (B and C for our study case, but it can be more), the procedure to calculate the index of pressures and the index of hazard is analogous to the one described previously in equations (1) and (2).

Subsequently, one can compute the overall pressure index, for each cell, by summing the indexes referring to every component of the sensitivities (A, B, and C). This sum can be a weighted sum in case one wants to attribute different importance to the different components. Similarly for the overall hazard index.

In detail, the overall pressure index I_{PR} is calculated as described in equation (3).

$$I_{PR} = \sum_{w=1}^{W} \beta_w \cdot I_{PR(w)} \tag{3}$$

where:

W = number of components of sensitivity (in the present case study W = 3; A, B, C).

β_w= weights assigned to every single component of sensitivity. ($\beta_w \in [0,1]$ in the present case study the three components of the sensitivity were weighted with the same value, then β_A; β_B; β_C = 1/3).

The overall hazard index I_{HZ} is calculated as stated in equation (4).

$$I_{HZ} = \sum_{w=1}^{W} \beta_w \cdot I_{HZ(w)} \tag{4}$$

In summary, the equations above can be combined and generalized into equations (5) and (6), respectively, which allows weighing both indexes independently (I_{PR} ,I_{HZ}), for every single cell.

$$I_{PR} = \sum_{w=1}^{W} \frac{\beta_w}{m_w n} \cdot \sum_{i=1}^{m_w} \sum_{j=1}^{n} K_{ij}(t) \cdot S_i \cdot b_{ij} \cdot PR_j \tag{5}$$

and,

$$I_{HZ} = \sum_{w=1}^{W} \frac{\beta_w}{m_w p} \cdot \sum_{i=1}^{m_w} \sum_{k=1}^{p} CC(t)_k \cdot S_i \cdot b_{ik} \cdot HZ_k \tag{6}$$

where:

m_w= number of sensitivities in component *W.* The rest of the terms remain as defined before.

Finally, an overall vulnerability index for each cell is obtained by summing the two overall indexes defined in equations (5) and (6) (one for the pressures and one for the hazards). Again, this sum is a weighted sum, to allow for the case one wants to attribute different importance to pressures and hazards, and assumes values in [0,1]. This can be done by using the formula (7), which enables the measurement of the systemic vulnerability in each territory cell.

$$I_V = \alpha \cdot I_{PR} + (1 - \alpha) \cdot I_{HZ} \tag{7}$$

where:

$\boldsymbol{\alpha}$ = coefficient of "interest" in pressures/hazards; ($\boldsymbol{\alpha} \in [0,1]$: if $\boldsymbol{\alpha}$=0; then "the index considers only the hazards", while if $\boldsymbol{\alpha}$=1; then "the index considers only the pressures"). For the present case study $\boldsymbol{\alpha}$=1/2 (the same weight for pressures and hazards was assigned).

2.2 Case study

The case study of this work is the municipality of Moncalieri. The municipality belongs to the Piedmont Region, in the North-West of Italy, and is part of the metropolitan area of Turin (Fig.5). The municipality has a population of 56,319 inhabitants (ISTAT, 2020) and is the fifth-largest city in the Piedmont region. The territory presents a mixed orography, partly flat in the southern and western areas of the municipality and the Po basin. At the same time, the northern part is characterized by a hilly dorsal that continues in the municipality of Turin. Moncalieri is a medieval town (1230), placed to protect the river Po passage. Controlled by the Savoy dynasty for the following decades, it became a vital court seat: the castle was transformed into a baroque residence and, since 1997, has been on the UNESCO World Heritage List. The city's role in the Savoy Duchy and its proximity to the capital encouraged the work of prestigious patrons who generated a cultural heritage of great value. The settlement system has developed transversally to the north-south axis of the river behind the hill. The settlements are distributed along the main roads in the hilly northern part. The municipality is characterized by a high level of accessibility and infrastructure: the city is located at the entrance to the motorway system of northern Italy. It is directly connected to Turin's ring road network. For this reason, the city has historically seen the development of large industrial areas. Nevertheless, on the other hand, the river Po has historically represented a limit to the development of settlements. The characteristics described making this municipality subject to vulnerabilities of different nature and extent.

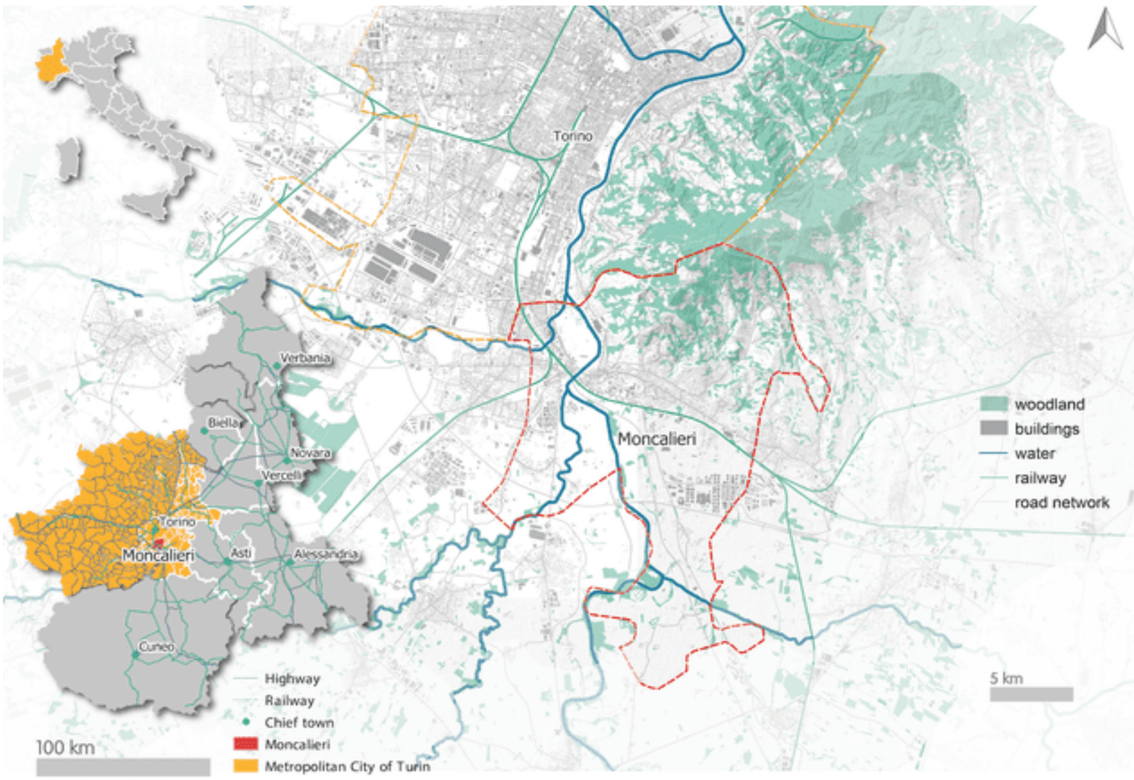


Fig.5 Localization of the Municipality of Moncalieri

3. Results

This section shows the results of the matrix implementation applied to the case study of Moncalieri. The weighted matrix, vulnerability indices by sensitivity components, and the systemic vulnerability index will be presented. Fig.6 shows the weighted matrix following the questionnaire with a participatory methodology, including the team of 13 researchers involved in the project. The result is a matrix representing the intensity of the relationships between the sensitivity, pressure, and hazard indicators. The matrix, with the coloured cells according to their correlation, prioritizes the intensity between indicators from 0 (no relationship) to 1 (intense relationship).

COMPONENTS	SENSITIVITIES		PRESSURES			HAZARDS						
			CDS	OBS	OLD	ALU	ALA	IBO	FRA	SIS	RIR
ENVIRONMENT AND LANDSCAPE	A1	landscape sensibility	0.70	0.21	0.00	0.67	0.61	0.79	0.76	0.48	0.58
	A2	ecological quality	0.79	0.00	0.00	0.73	0.67	0.94	0.76	0.36	0.85
	A3	energy consumption intensity	0.64	0.61	0.21	0.27	0.24	0.18	0.18	0.09	0.21
BUILDINGS, HERITAGE INFRASTRUCTURES	B1	cultural heritage consistency	0.27	0.58	0.06	0.82	0.76	0.61	0.73	0.94	0.52
	B2	building construction characteristics	0.30	0.94	0.00	0.55	0.61	0.39	0.45	0.82	0.33
	B3	RES energy self-sufficiency	0.45	0.79	0.15	0.06	0.09	0.03	0.00	0.12	0.09
	B4	communication infrastructure density	0.61	0.27	0.18	0.61	0.55	0.64	0.64	0.70	0.64
	B5	road infrastructure density	0.73	0.18	0.15	0.85	0.85	0.70	0.73	0.88	0.79
ECONOMY AND POPULATION	C1	population density	0.45	0.18	0.61	0.73	0.70	0.52	0.58	0.91	0.83
	C2	elderly population incidence	0.09	0.09	0.91	0.64	0.64	0.52	0.48	0.70	0.67
	C3	immigrant population incidence	0.21	0.06	0.30	0.27	0.27	0.21	0.21	0.27	0.24
	C4	manufacturing activities density	0.42	0.09	0.12	0.73	0.67	0.58	0.55	0.70	0.82

0.70-1 strong   0.50-0.69 medium   0.00-0.49 low

Fig.6 R3C matrix weighing

The outputs of the Vulnerability Matrix, deriving from the application with GIS tools and the formula described above, are the vulnerability index by component and the systemic vulnerability index, which assume a value in each grid cell. In the case study of Moncalieri, they are as follows:

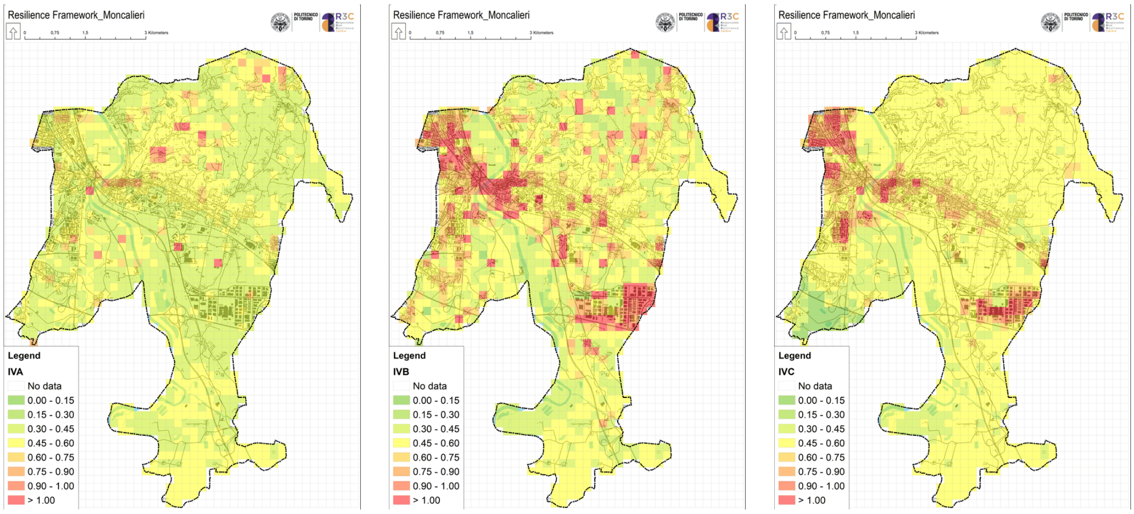
- Vulnerability Index I_{VA} = Overall Vulnerability Index of Component A. Environment and Ecosystem Services (Fig.7a);
- Vulnerability Index I_{VB} = Overall Vulnerability Index of Component B. Construction, Infrastructure, Cultural Heritage and Landscape (Fig.7b);
- Vulnerability Index I_{VC} = Overall Vulnerability Index of Component C. Economy and Population (Fig.7c).
- The sum of the three indices gives I_V = Systemic Vulnerability Index at the municipal scale (Fig.8).

The values obtained, represented in the three maps, show the values of the vulnerability index divided according to the components I_{VA}, I_{VB}, and I_{VC}.

The results have been verified in a retroactive procedure that confirmed consistency concerning the presence of elements and factors determining territorial vulnerability.

The vulnerability index referring to component A shows a concentration of high vulnerability areas (I_{VA}, I_{VB}, I_{VC}>0.75) in the north-northeast region of the study area. This area, characterized by the wooded hills, is notably correlated to the phenomena of land consumption, wildfires, and landslides, especially for the A1 (landscape sensitivity) and A2 (ecological quality) sensitivities.

In component B, the most vulnerable areas are those with the highest density of built-up areas, road infrastructures, and the presence of cultural heritage buildings, with a substantial impact on the pressure indicator OBS (obsolete buildings) and the seismic hazard indicator (SIS). In component C, the most relevant sensitivity in the determination of vulnerability values is constituted by indicator C4 (density of productive activities) concerning the phenomena of the flood (ALU), earthquake (SIS), and risk of major industrial accidents (RIR). Flood and earthquakes also significantly impact indicators C1 and C2 of population density and elderly population.



(a) (b) (c)

Fig.7 Systemic vulnerability maps (a) IVA: vulnerability index component A, (b) IVB: vulnerability index component B, (c) IVC: vulnerability index component C

The result of the work is a map that brings together all the interactions between sensitivities, pressures, and hazards. This synthesis map represented both on a numerical scale (8a) and a qualitative scale (8b), proper to facilitate reading by non-experts, shows the present situation of the municipality and identifies the territorial vulnerability that combines the most relevant aspects, characteristics, and criticalities for the case under study. The systemic vulnerability indicator combines all the relationships and elements examined and allows an overall reading of the critical territorial aspects.

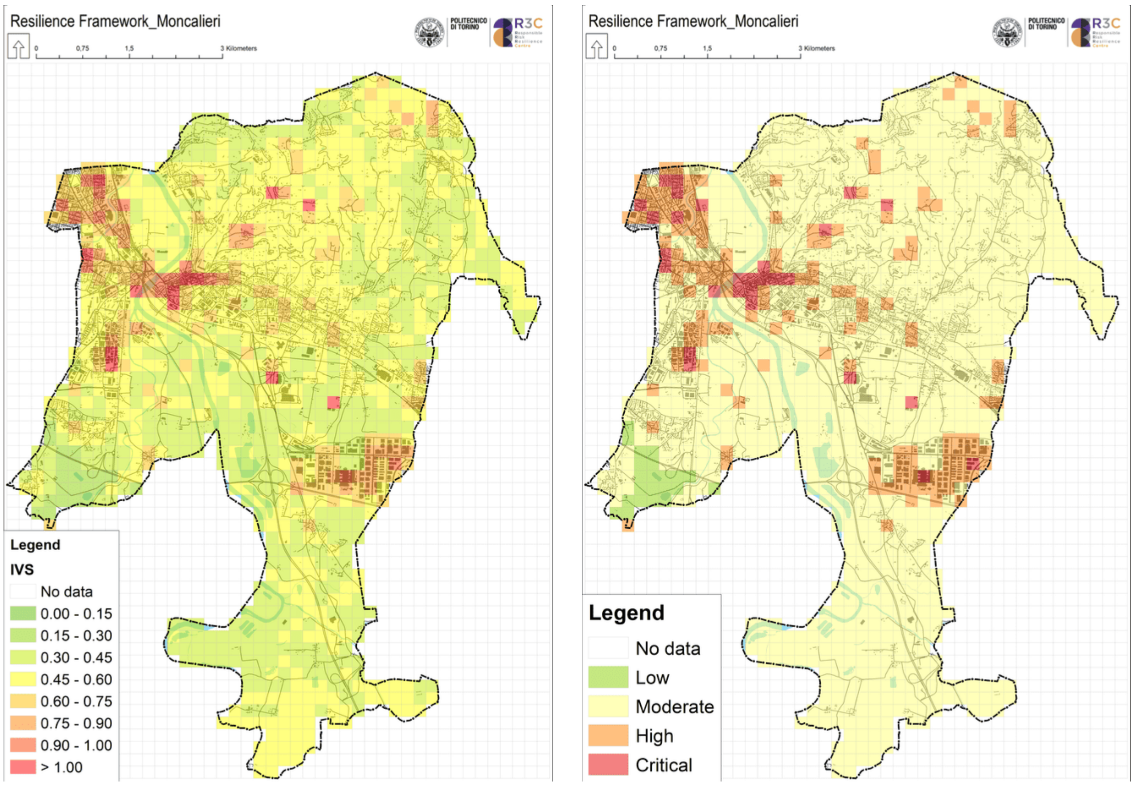


Fig.8 Final systemic vulnerability map (a) numerical scale (b) qualitative scale

The three most vulnerable areas correspond to the historical centre, the industrial areas, and the most anthropized area in the north-north-west. Other scattered areas identify situations characteristic of punctual elements of the territory. Indeed, after the first methodology test, some of these areas were verified by random sampling, confirming the model's results.

4. Discussion

The comparison with the literature and the case studies analyzed (Angiello et al., 2018; Bixler et al., 2021; Galderisi & Limongi, 2022) offers various discussion points. First, it highlights that this work is part of the attempt to define, calculate and spatialize an overall vulnerability index on a territory. Second, it reveals innovative points and possible extensions: the most innovative elements concern the choice of spatial scale, the weighting and calculation process, and the selection of indicators.

A peculiarity of the tool tested in Moncalieri is the use of the spatial grid, which allows the indicators to be reported at a more detailed level than in other cases that rely on - for example - census sections.

Unlike other case studies, the construction of the formula and the matrix allows for overcoming specific difficulties typical of the multivariate approach. In particular, the need to keep groups of indicators separate until an advanced stage of the calculation: the work here presented makes it possible to overtake this problem by clustering the groups of indicators.

Furthermore, the formula is characterized by the possibility of being independent regarding the indicators used and the ability to consider the degree of interaction between the indicators themselves, which are considered by ad hoc coefficients resulting from participatory weighting procedures.

From the earliest stages, the indicator selection process focuses on an analysis of the peculiarities of the specific case study, which make the matrix a tool sensitive to the characteristics of the area of application. The results obtained are encouraging, but it is necessary to emphasize that the matrix results are strictly dependent on the data's quality and level of updating. For instance, in the case study of Moncalieri, the methodology was tested using the current government demographical data provided by the Italian official statistical database, dated 2011. For other indicators, some specific authorizations or local datasets were required. On the other hand, the methodology replicability and the availability of up-to-date data enable the possibility to obtain a contemporary representation of systemic vulnerability.

This site-specific approach, also found in other works, may make it necessary to adjust the indicators selected in the event of other applications: however, the structure of the matrix is designed to make it adaptable to the territory to which it is applied and, therefore, to the indicators that best describe it.

Despite the importance of resilient approaches, they can still not provide practical solutions to the spatial planning process. For example, the lack of information about the system's various components can prevent the strategy's effective implementation.

The spatial measure of vulnerability aims to provide a tool that can help identify areas of vulnerability that are not adequately addressed by current analytical methods. This method should be used in local analysis to implement resilient strategies. In addition to identifying areas of vulnerability, this measure should also help develop effective strategies and implement resilient infrastructures. This work shows that using the map is key to reducing system vulnerability because spatializing interventions in urban areas allows the most appropriate measures to be defined according to the type of vulnerability and degree of priority.

In the case of Moncalieri, the analysis makes it possible to prioritize actions on the areas identified as having the highest vulnerability and needing more attention. Once the areas to intervene are identified, it is necessary to do a backward process to identify the causes, triggers, and measures following superordinate strategies. The primary reference at the national level is the national guidelines for defining Climate Change Adaptation-according to the National Climate Change Adaptation Plan (NCCP, 2016). The Plan includes different types of adaptation measures: "grey or structural measures" that include technical and engineering solutions; "green

or ecosystem-based measures" that involve ecosystem-based approaches; and "soft or light measures" that involve management, legal, and policy approaches. Green and grey measures range from mitigative to long-term adaptive solutions that transform the system to achieve a measurable resilient condition.
This study's main findings aim to develop a resilient knowledge of the various vulnerable components of territorial systems. In future work, this knowledge can be used to design land use plans that can adapt to climate change and identify the appropriate urban planning measures.

5. Conclusions

The tool allows for measuring territorial vulnerability by identifying a set of indicators relevant in the context of the case study for the factors that compose systemic vulnerability. In addition, the tool integrates indicators from different fields of territorial study with a holistic approach, enabling a composite reading of territorial vulnerabilities according to a multi-risk concept.
The territorial vulnerability index methodology sets the relevance between the pressures and hazards relationship and the territory's sensitivity elements. On the other hand, it considers the territorial peculiarities and the stakeholders' interests. These characteristics ensure the scalability and replicability of the matrix on different territories.
Moreover, the tool contributes to increasing territorial vulnerability awareness based on spatial analysis. Specifically, applying the matrix in the Moncalieri case study enables the validation of the calculation model. At the same time, the choosing indicators process allows a spatially explicit measurement. Hence, it is not configured as a statistical index on a municipal basis to compare territories but ensures the visualization of variations in the index within the territory itself.
On the other hand, it is aimed at supporting the elaboration of policies at a detailed scale, configuring itself as a decision support tool for local planning.
Further research needs to be developed on the temporal factors of the formula related to the variations of both the climate change-driven hazards (CC(t)k) and the pressure trends (Kij). Therefore, a deeper analysis should be carried out to evaluate model uncertainties. Likewise, the tool can be applied in the spatial vulnerability assessment of additional case studies.

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References

Angiello, G., Carpentieri, G., Morosini, R., Tremiterra, M. R., & Tulisi, A. (2018). Review Pages: The Resilience City/The Fragile City. Methods, Tools and Best Practices 3 (2018). *TeMA - Journal of Land Use, Mobility and Environment, 11*(3), 361-382. https://doi.org/10.6092/1970-9870/5957

Barreca, A., Curto R., & Rolando, D. (2018). Housing Vulnerability and Property Prices: Spatial Analyses in the Turin Real Estate Market. *Sustainability, 10*(91):3068, 1-20. https://doi.org/10.3390/su10093068

Birkmann, J., Cardona, O.D., Carreño, M.L., Barbat, A., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M. Alexander, D., Zeil P., & Welle, T. (2013). Framing vulnerability, risk and societal responses: the MOVE framework. *Nat Hazards 67*, 193–211. https://doi-org.ezproxy.biblio.polito.it/10.1007/s11069-013-0558-5

Bixler, R.P., Yang, E., Richter, S.M., & Coudert, C. (2021). Boundary crossing for urban community resilience: A social vulnerability and multi-hazard approach in Austin, Texas, USA*, International Journal of Disaster Risk Reduction*, 66, 102613, ISSN 2212-4209, https://doi.org/10.1016/j.ijdrr.2021.102613

Bovio, G., Camia, A., Marzano, R., & Pignocchino, D. (2001). Manuale operativo per la valutazione della pericolosità specifica e per le attività AIB in area di interfaccia. Dipartimento Agroselviter, Università di Torino, Torino.

Brunetta, G., & Caldarice, O. (2020). Spatial Resilience in Planning: Meanings, Challenges, and Perspectives for Urban Transition. In: Leal Filho, W., Marisa Azul, A., Brandli, L., Gökçin Özuyar, P., & Wall, T. (Eds) Sustainable Cities and Communities*. Encyclopedia of the UN Sustainable Development Goals.* Springer, Cham. https://doi.org/10.1007/978-3-319-95717-3_28

Brunetta, G., Mutani, G., & Santantonio, S. (2021). Pianificare per la resilienza dei territori. L'esperienza delle comunità energetiche. *Archivio di Studi Urbani e Regionali*, LII, 131(supl.), 44-70. https://doi.org/10.3280/ASUR2021-131-S1003

Brunetta, G., & Baglione, V. (2013). Resilience in the Transition Towns Movement. Towards a new Urban Governance. *TeMA - Journal of Land Use, Mobility and Environment, 6*(2), 251-264. https://doi.org/10.6092/1970-9870/1524

Brunetta, G., Caldarice, O., Tollin, N., Rosas-Casals, M., & Morató, J. (2020). Urban resilience for Risk and Adaptation Governance. The Resilient Cities book.

Brunetta, G., Ceravolo, R., Barbieri, C.A., Borghini, A., De Carlo, F., Mela, A., Beltramo, S., Longhi, A., De Lucia, G., Ferraris, S., Pezzoli, A., Quagliolo, C., Salata, S., & Voghera, A., (2019). *Territorial Resilience: Toward a Proactive Meaning for Spatial Planning. Sustainability, 11*(8), 2286. https://doi.org/10.3390/su11082286

Brunetta, G., & Salata, S. (2019). Mapping Urban Resilience for Spatial Planning—A First Attempt to Measure the Vulnerability of the System. *Sustainability, 11*(8), 2331. https://doi.org/10.3390/su11082331

Cardona, O. D. (1999). Environmental management and disaster prevention: Two related topics: A Holistic risk assessment and management approach. In J. Ingleton (Eds.) *Natural Disaster Management*, 151-153. Tudor Rose, London.

Cardona, O. D. (2001). Estimación holística del riesgo sísmico utilizando sistemas dinámicos complejos. PhD Thesis, la Universitat Politècnica de Catalunya (UPC). Retrieved from: https://dialnet.unirioja.es/servlet/tesis?codigo=6549

Cardona, O. D. (2011). Disaster Risk and Vulnerability: Notions and Measurement of Human and Environmental Insecurity. In: Coping with Global Environmental Change, Disasters and Security – Threats, Challenges, Vulnerabilities and Risks, (Eds.). Brauch, H. G., Oswald, Ú., Mesjasz, S. C., Grin, J., Kameri-Mbote, P., Chourou, B., Dunay, P., Birkmann, J. Springer Verlag, Berlin Heidelberg. https://doi.org/10.1007/978-3-642-17776-7

Cardona, O.D., & Barbat, A.H. (2000). El riesgo sísmico y su prevención. In El riesgo sísmico y su prevención, 190.

Cardona, O.D., & Hurtado, J.E. (2000). Holistic seismic risk estimation of a metropolitan center. In *Proceedings of 12th world conference of earthquake engineering*. Auckland.

Cardona, O.D., & Hurtado, J.E. (2000). Modelación numérica para la estimación holística del riesgo sísmico urbano, considerando variables técnicas, sociales y económicas. Métodos Numéricos en Ciencias Sociales (MENCIS 2000).

Carreño, M. L., Cardona, O. D., & Barbat, A. H. (2007). Urban Seismic Risk Evaluation: A Holistic Approach*. Natural Hazards, 40* (2007), 137-172. https://doi.org/10.1007/s11069-006-0008-8

Carreño, M. L., Cardona, O. D., Marulanda, M. C., & Barbat, A. H. (2009). Holistic Urban Seismic Risk Evaluation of Megacities: Application and Robustness. In: The 1755 Lisbon Earthquake: Revisited. *Geotechnical, Geological, and Earthquake Engineering*, vol 7. Springer, Dordrecht. https://doi-org.ezproxy.biblio.polito.it/10.1007/978-1-4020-8609-0_10

Castro Rodriguez, D. J., Beltramino, S., Scalas, M., Pilone, E., & Demichela, M. (2022). Territorial Representation of a vulnerability associated with the Seveso installations in a Nord Italian case study. *Proceedings of the 32nd European Safety and Reliability Conference* (ESREL 2022). Published by Research Publishing, Singapore. https://doi.org/10.3850/978-981-18-5183-4_R25-02-574-cd

De Lucia, G. (2019). La conoscenza storica per la valutazione delle vulnerabilità del patrimonio culturale ecclesiastico: un approccio sistemico per strategie di valorizzazione e rigenerazione. BDC. *Bollettino Del Centro Calza Bini 19*(1):75–88. https://doi.org/10.6092/2284-4732/7061

Del Prete, M. (1993). Rischio da frane intermittenti a cinematica lenta nelle aree montuose e collinari urbanizzate della Basilicata: rapporto 1992-U.O. 2.37 / Mario del Prete, Emanuele Giaccari, Giuliana Trisorio-Liuzzi. (Eds.). [S.l : s.n.] (Potenza: Pisani & Iannielli), 1-84.

Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change, 16*(3), 253-267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Francini, M., Chieffallo, L., & Gaudio, S. (2021). Climate change as stressor in rural areas. *TeMA - Journal of Land Use, Mobility and Environment*, 53-71. https://doi.org/10.6093/1970-9870/7422

Galderisi, A., Ceudech, A., & Pistucci, M. (2008). A method for na-tech risk assessment as supporting tool for land use planning mitigation strategies. *Nat Hazards 46*, 221–241. https://doi-org.ezproxy.biblio.polito.it/10.1007/s11069-008-9224-8

Galderisi, A., & Ferrara, F. F. (2012). Enhancing urban resilience in face of climate change: a methodological approach. *TeMA-Journal of Land Use, Mobility and Environment, 5*(2), 69-88. https://doi.org/10.6092/1970-9870/936

Galderisi, A., Guida, G., & Limongi, G. (2021). Emergency and spatial planning towards cooperative approaches. *TeMA - Journal of Land Use, Mobility and Environment*, 73-92. https://doi.org/10.6093/1970-9870/7417

Galderisi, A., & Limongi, G. (2021). A comprehensive assessment of exposure and vulnerabilities in multi-hazard urban environments: A key tool for risk-informed planning strategies. *Sustainability (Basel, Switzerland), 13*(16), 9055.

Gallopín, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, 16 (3), 293-303. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Gazzetta Ufficiale (2015). Attuazione Della Direttiva 2012/18/UE Relativa al Controllo Del Pericolo Di Incidenti Rilevanti Connessi Con Sostanze Pericolose. GU "Gazzetta Ufficiale." Serie Generale n.161 del 14-07-2015 - Suppl. Ordinario n. 38) Retrieved from: https://www.gazzettaufficiale.it/eli/id/2015/07/14/15G00121/sg

Heikkinen, M., Karimo, A., Klein, J., Juhola, S., & Ylä-Anttila, T. (2020). Transnational municipal networks and climate change adaptation: A study of 377 cities, *Journal of Cleaner Production, 257*(120474). ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.120474

Hernández-Sampieri, H., Fernández-Collado, C., & Baptista-Lucio, P. (2006). Research Methodology, 8ª ed., McGraw Hill, Madrid, 2006. ISBN: 970-10-1899-0 (in Spanish).

Huseyin, G. O., Szabolcs V., Huseyin G., & Arif H. (2021). Numerical simulation and parametric study of various operational factors affecting a PV-battery-air conditioner system under prevailing European weather conditions. *Sustainable Cities and Society, 67* (2021), 1-15. https://doi.org/10.1016/j.scs.2021.102754

ICSU - LAC (2010). Science for a Better Life: Developing Regional Scientific Programs in Priority Areas for Latin America and the Caribbean. Volume 1. Kalin T. Arroyo, M., Dirzo, R., Castillas, J.C., Cejas, F., and Joly, C.A. Biodiversity in Latin America and the Caribbean: An Assessment of Knowledge, Research Scope and Priority Areas ICSU - LAC / CONACYT, Rio de Janeiro and Mexico City, 332 pp. ISBN 978-0-930357-74-0

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (Eds.)]. IPCC, Geneva, Switzerland, 104 pp. Retrieved from: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report

IPCC (2012). 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., Tignor, M., & Midgley P.M. (Eds.) Retrieved from Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge CB2 8RU ENGLAND, 582 pp.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B. (Eds.). Cambridge University Press.

Jabareen, Y. (2013). Planning the resilient city: Concepts and strategies for coping with climate change and environmental risk, *Cities*, 31, 220-229, ISSN 0264-2751, https://doi.org/10.1016/j.cities.2012.05.004

Manyena, S. B. (2006). The concept of resilience revisited. *Disasters, 30*(4), 434-450. https://doi.org/10.1111/j.0361-3666.2006.00331.x

Mccarthy, J., Canziani, O., Neil, A., Dokken, D., & White, K. (2001). "Climate Change 2001: Impacts, Adaptation, and Vulnerability." Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change 19. Retrieved from: https://www.ipcc.ch/site/assets/uploads/2018/03/WGII_TAR_full_report-2.pdf

Menoni, S., Galderisi, A., Ceudech, A., Delmonaco, G., & Spizzichino, D. (2006). ARMONIA Deliverable 5.1., Harmonised hazard, vulnerability and risk assessment methods informing mitigation strategies addressing land-use planning and management.

Ministero delle Infrastrutture e dei Trasporti. Aggiornamento Delle «Norme Tecniche per Le Costruzioni». Retrieved from: https://www.gazzettaufficiale.it/eli/gu/2018/02/20/42/so/8/sg/pdf.

Mondino, L. (2020). Beni culturali e territorio per un approccio territorialista allo studio dei beni culturali di interesse religioso (Master Thesis, Politecnico di Torino, Torino). Retrieved from: https://webthesis.biblio.polito.it/16601/1/tesi.pdf.

Mutani G., & Todeschi V. (2021). Optimization of Costs and Self-Sufficiency for Roof Integrated Photovoltaic Technologies on Residential Buildings. *Energies, 14* (13): 4018, 1-25. https://doi.org/10.3390/en14134018

Mutani G., Beltramino S., & Schiavone, M. (2020a). Place-based Atlas for Energy Communities using Energy Performance Certificates Database. IEEE 3rd International Conference and Workshop in Óbuda on Electrical and Power Engineering (CANDO-EPE), 000179-000184. https://doi.org/10.1109/CANDO-EPE51100.2020.9337766

Mutani, G., Santantonio, S., & Goulias, D. (2020b). Environmental protocol for Energy Communities. IEEE 3rd International Conference and Workshop in Óbuda on Electrical and Power Engineering (CANDO-EPE), 000191-000196. https://doi.org/10.1109/CANDO-EPE51100.2020.9337784

Mutani, G., Santantonio, S., Brunetta, G., Caldarice, O., & Demichela, M. (2021). An energy community for territorial resilience: Measurement of the risk of an energy supply blackout. Energy and Buildings, 240 (2021) 110906, 1-28. https://doi.org/10.1016/j.enbuild.2021.110906

Mutani, G., Beltramino, S., & Forte, A. (2020). A clean energy atlas for energy communities in Piedmont Region (Italy). *International Journal of Design & Nature and Ecodynamics 15* (3), 343-353. https://doi.org/10.18280/ijdne.150308

Mutani, G., Santantonio, S., & Beltramino, S. (2021). Indicators and representation tools to measure the technical-economic feasibility of a renewable energy community. The case study of Villar Pellice (Italy). *International Journal of Sustainable Development and Planning, 16* (1), 1-11. https://doi.org/10.18280/ijsdp.160101

Pilone, E., Demichela, M., & Baldissone, G. (2019). The Multi-Risk Assessment Approach as a Basis for the Territorial Resilience. Sustainability, 11 (9):2612, 94-102. https://doi.org/10.3390/su11092612

Pilone, E., Demichela, M., & Camuncoli, G. (2017). Seveso Directives and LUP: The mutual influence of natural and anthropic impacts. Journal of Loss Prevention in the Process Industries, 49 Part A (2017), 94-102. https://doi.org/10.1016/j.jlp.2017.02.027

Pilone, E., Mussini, P., Demichela, M., & Camuncoli, G. (2016). Municipal Emergency Plans in Italy: Requirements and drawbacks. Safety Science, 85 (2016):2612, 163-170. https://doi.org/10.1016/j.ssci.2015.12.029.

Pilone, E. (2018). Risk Management and Land Use Planning for Environmental and Asset Protection Purposes (Doctoral dissertation, Politecnico di Torino).

Todeschi, V., Marocco, P., Mutani, G., Lanzini, A., & Santarelli, M. (2021). Towards energy self-consumption and self-sufficiency in urban energy communities. *International Journal of Heat and Technology, 39* (1), 1-11. https://doi.org/10.18280/ijht.390101

UN General Assembly (2015). Transforming our world: the 2030 Agenda for Sustainable Development, 21 October 2015, A/RES/70/1, Retrieved from: https://www.refworld.org/docid/57b6e3e44.html

Voghera, A., & La Riccia, L. (2015). Urbanistica e reti ecologiche per lo sviluppo urbano e territoriale. In: *Urbanistica Informazioni*, 263, 131-135.

Voghera, A., & La Riccia, L. (2016). Landscape and Ecological Networks: Towards a New Vision of Sustainable Urban and Regional Development. Laborest, 12, 89-93. https://doi.org/10.19254/LaborEst.12.15

Voghera, A., La Riccia, L. (2019). Ecological Networks in Urban Planning: Between Theoretical Approaches and Operational Measures. Chapter. In Calabrò F., Della Spina L., Bevilacqua C. (Eds). New Metropolitan Perspectives. Local Knowledge and Innovation Dynamics Towards Territory Attractiveness Through the Implementation of Horizon/E2020/Agenda 2030 (672-680). Cham, Springer.

Voghera, A., Negrini, G., La Riccia, L., & Guarini, S. (2017). Reti ecologiche nella Pianificazione Locale: Esperienze nella Regione Piemonte. Reticula, 14, 1-9. Retrieved from: https://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/reticula/Reticula_14_2017.pdf

Authors' profile

Simone Beltramino

Ph.D. student in Urban and Regional Development at the Interuniversity Department of Regional and Urban Studies and Planning (DIST) of Politecnico di Torino. His research concerns the topic of energy resilience planning.

e-mail: simone.beltramino@polito.it
ORCID: https://orcid.org/0000-0003-0872-951X

Mattia Scalas

Ph.D. student in Urban and Regional Development at the Interuniversity Department of Regional and Urban Studies and Planning (DIST) of Politecnico di Torino. His research deals with urban resilience planning.

e-mail: mattia.scalas@polito.it
ORCID: https://orcid.org/0000-0002-6912-1287

David Javier Castro Rodriguez

Ph.D. student in Chemical Engineering at the Department of Applied Science and Technology (DISAT) of Politecnico di Torino. His research is about industrial risk within territorial resilience.

e-mail: david.castro@polito.it
ORCID: https://orcid.org/0000-0002-7609-3229

Grazia Brunetta

Full Professor in Urban and Regional Planning at the Interuniversity Department of Regional and Urban Studies and Planning (DIST), and Coordinator of the Responsible Risk Resilience Centre (R3C) at Politecnico di Torino. Her main research activities are in the field of town and regional planning, with a particular focus on the innovation in the theories, methodologies and approaches for spatial planning in both research and academic teaching activity.

e-mail: grazia.brunetta@polito.it
ORCID: https://orcid.org/0000-0003-1868-2700

Franco Pellerey

Full Professor in Probability and Statistics at the Department of Mathematical Sciences "Giuseppe Luigi Lagrange" (DISMA), and member of the Responsible Risk Resilience Centre (R3C) at Politecnico di Torino. His research activity concerns the application of mathematics in industry and society.

e-mail: franco.pellerey@polito.it
ORCID: https://orcid.org/0000-0002-8983-855X

Micaela Demichela

Associate Professor in Theory of the Development of Chemical Processes at the Department of Applied Science and Technology (DISAT), and member of the Responsible Risk Resilience Centre (R3C) at Politecnico di Torino. She is interested in risk assessment, process safety and environmental protection.

e-mail: micaela.demichela@polito.it
ORCID: https://orcid.org/0000-0001-5247-7634

Angioletta Voghera

Full Professor in Urban and Regional Planning at the Interuniversity Department of Regional and Urban Studies and Planning (DIST), and member of the Responsible Risk Resilience Centre (R3C) at Politecnico di Torino. Her main research activities are in the field of Regional and Landscape and Protected Areas Planning, and Urban Design with reference to European contexts.

e-mail: angioletta.voghera@polito.it
ORCID: https://orcid.org/0000-0002-0166-3303

Andrea Longhi

Associate Professor in History of Architecture at the Interuniversity Department of Regional and Urban Studies and Planning (DIST), and member of the Responsible Risk Resilience Centre (R3C) at Politecnico di Torino. He is interested in history of the territory and landscape, deepening the relationships between history and knowledge of regional systems of cultural heritage.

e-mail: andrea.longhi@polito.it
ORCID: https://orcid.org/0000-0001-7101-4168

Guglielmina Mutani

Associate Professor in Environmental Technical Physics at the Department of Energy "Galileo Ferraris" (DENERG), and member of the Responsible Risk Resilience Centre (R3C) at Politecnico di Torino. Her research activities include models of energy consumption for heating buildings at a district and urban scale.

e-mail: guglielmina.mutani@polito.it
ORCID: https://orcid.org/0000-0001-6822-8624

Ombretta Caldarice

Assistant Professor in Urban and Regional Planning at the Interuniversity Department of Regional and Urban Studies and Planning (DIST), and member of the Responsible Risk Resilience Centre (R3C) at Polytechnic of Turin. Her research activity focuses on the interaction between spatial planning and urban resilience through the lens of urban regulation.

e-mail: ombretta.caldarice@polito.it
ORCID: https://orcid.org/0000-0001-6172-908X

Gaetano Miraglia

Research Assistant at the Department of Structural, Geotechnical and Building Engineering (DISEG) at Politecnico di Torino. He is interested in seismic monitoring and evaluation of the architectural heritage and dynamic structural identification.

e-mail: gaetano.miraglia@polito.it
ORCID: https://orcid.org/0000-0002-3611-0215

Erica Lenticchia

Assistant Professor at the Department of Structural, Geotechnical and Building Engineering (DISEG) and member of the Responsible Risk Resilience Centre (R3C) at Politecnico di Torino. Her research concerns the topic of seismic and structural analysis of existing RC and masonry structures, focusing on structural health monitoring, dynamic identification, and assessment and diagnosis of the structural condition of ancient and modern historic buildings.

e-mail: erica.lenticchia@polito.it
ORCID: https://orcid.org/0000-0002-3746-2933

Luigi La Riccia

Member of the SDG11LAB at the Interuniversity Department of Regional and Urban Studies and Planning at Politecnico di Torino. His research interests include landscape and local planning, Geographic Information Systems (GIS), remote sensing and participatory GIS.

e-mail: luigi.lariccia@polito.it
ORCID: https://orcid.org/0000-0002-4800-2641