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SPOKE 7 "Territorial Sustainability"

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Executive summary

The present Interactive Maps on Local Vulnerability constitutes the second Deliverable (D.7.3.2.) of the WP3 Area Specific Planning and is fully within the actions related to the Milestone M.7.3.2. Completion of local data collection and integration to WP1 data for each case study (M18).

The main activities are related to Tasks 7.3.1, 7.3.2, 7.3.3, 7.3.4 and 7.3.7 of the WP3, which were conducted in parallel by the research units of UNIBA, POLIMI, UNINA, UNIBO, UNIVE:

- Task 7.3.1, Integrate data from WP1 with local level data and analysis to define detailed vulnerability maps for specific case studies;
- Task 7.3.2, Identify infrastructures and services digitalization policies to reduce divides between city centers. suburbs. and outskirts;
- Task 7.3.3, Analyze the role of infrastructures and related services on urbanization. residential choices. mobility patterns and choices. firms' relocation decisions and urban economic integration of inner and marginal areas. also through lab-in the field experiments and design thinking approach involving local actors;
- Task 7.3.4, Estimate the additional costs (network infrastructures. energy. transport) due to insularity or peripherality conditions;
- Task 7.3.7, Design of area-specific strategies for gap/vulnerability reduction and equalization policies.

The work carried out up to the 18th month by the working group was to define for each selected indicator the specific object to which a measurable condition of vulnerability is recognized and to identify the type of threats with respect to which vulnerability is defined (i.e. the extent of damage that such threats could cause to the object referred to in the previous point). The reasons regarding the relevance of the selected indicator with respect to the indicated theme are also explained with reference to existing literature, in line with the most consolidated definition of vulnerability.

This document shows 53 vulnerability maps grouped into 9 main themes each contained in a dossier. For each map represented, the main metadata relating to the simple and composite indicators that make up the map are indicated. There is also a reclassification of these indicators by homogeneous territorial areas, toghether with methodological indications on the construction of the map and a specific bibliography to the topic covered.

Each dossier defines the main composite indicators used for describe the specific vulnerability for each topic. It also presents the vulnerability maps at municipal level with the methodologies adopted in coherence with the main literature.

The research team's choice was to create maps for the entire national territory at municipal level (where data were not available some maps are at provincial level) to offer a detailed and complete picture of vulnerabilities in Italy.

At the end of the work there is a link to the GIS geopackage in which all the maps are presented in an interactive form that can be queried by the user.

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1. Spoke 7 Territorial Sustainability

1.1 WP3 Area-specific planning

The WP3 intends to identify challenges for the transition towards sustainable. attractive. and smart cities and territories with a focus to specific territorial typologies: inner regions. islands. large urban areas and the so-called "Intermediate Italy". i.e. urban areas including mid-size cities and their wider polycentric and low-density urban systems. To this scope. recent trends in living. working. mobility and tourism has been considered for testing their impact in different territorial areas.

The activities were required to address the following main tasks:

- Integrate data from WP1 with local level data and analysis to define detailed vulnerability maps for specific case studies;
- Identify infrastructures and services digitalization policies to reduce divides between city centers. suburbs. and outskirts;
- Analyze the role of infrastructures and related services on urbanization. residential choices. mobility patterns and choices. firms' relocation decisions and urban economic integration of inner and marginal areas. also through lab-in the field experiments and design thinking approach involving local actors.
- Estimate the additional costs (network infrastructures. energy. transport) due to insularity or peripherality conditions;
- Design of area-specific strategies for gap/vulnerability reduction and equalization policies.

The first part of the work was dedicated to defining a taxonomy of the concept of general vulnerability to be subsequently declined on the various topics addressed for the deliverable.

1.2 Deliverable 3.2 - Interactive Maps on Local Vulnerability

The document is composed of an introductory part and 9 dossiers with the related maps.

In the first part of the work (par. 1.3) the concept of vulnerability is described by defining a general taxonomy of the phenomenon and declining it for the social sciences and economics.

The 9 dossiers relate to the following thematic areas of vulnerability and their respective maps:

- Dossier A: Vulnerability of School infrastructure and Educational Offer (4 maps);
- Dossier B: Housing vulnerability (4 maps);
- Dossier C: Vulnerability of agro-forestry capital (4 maps)
- Dossier D: Vulnerability from natural phenomena (landslide and earthquake) (10 maps)
- Dossier E: Vulnerability of the transport network (12 maps)

- Dossier F: International business local vulnerability (5 maps)
- Dossier G: Climatic vulnerability (6 maps)
- Dossier H: Urban and Territorial Health vulnerability (7 maps)
- Dossier I: Digital vulnerability (1 map)

Each dossier presents a framework of the topic covered with references to the relevant literature and multiple vulnerability maps at national level, with granularity of municipal data, relating to the topic.

For each map, the metadata of each simple and/or composite indicator with which the map is constructed is indicated in the table. The indicator data are then reclassified into the 13 classes of the taxonomy corresponding to the specific areas (see Deliverable 3.1): Internal Areas, Intermediate Italy and Metropolitan Areas. The calculation methodology of each indicator and its description and meaning are illustrated. Finally, reference literature is provided for further information.

At the end of the work (cap. 11) there is the complete map list and the link to the GIS geopackage in which all the maps are presented in an interactive form that can be queried by the user.

1.3 The concept of vulnerability: background and interpretations

1.3.1. Introduction to the concept of vulnerability

Scholars across diverse social disciplines employ varied interpretations and frameworks for the concept of territorial vulnerability, resulting in diverse measurement approaches. This work critically reviews the literature to elucidate the distinct definitions and measurement methodologies employed. Discrepancies among these disciplines can be attributed to their proclivity for emphasizing distinct facets of risk, individuals' reactions to risk, and overall welfare outcomes.

In both sociological and planning studies, risk conditions occur in the presence of threats and the inability of the people and anthropic systems exposed to those hazards to resist and cope with them. In this sense, the concept of vulnerability is fundamental for identifying and, where possible, measuring the damage that a specific unwanted event can cause to people, their assets and activities. Vulnerability is a phenomenon that is also considered and studied in analysing territorial systems as a quantity positively correlated with environmental risks. This concept has been widely used both regarding social policies, territorial and sectoral planning specially related to the so-called "natural disasters".

As recalled by Istat in the report entitled *Vulnerability measures*: *an application to different territorial areas* (2020), with the Human Development Report *Sustaining Human Progress*: *Reducing Vulnerabilities and Building Resilience* (2014), the United Nations proposed to consider vulnerability by first identifying the weakest social categories (poor, disabled, immigrants, children, elderly and young people) and subsequently analysing the potential consequences that unwanted events could have concerning their life cycle. Moreover, in the field of landscape planning, vulnerability is defined as the "potential negative impact" of planned activities, but also of climate change, on environmental, perceptive and cultural values. The concept of vulnerability has also been applied in other fields such as education, housing and transport/mobility with meanings that are not always convergent.

With the advent of the Covid-19 pandemic, attention to the topic of vulnerability has taken on even more prominence within an increasingly "multidimensional" perspective. In September 2023 the United Nations published the *Final Report of High Level Panel on the Development of a Multidimensional Vulnerability Index* in which it is stated that "The international community has now acknowledged vulnerability as a serious obstacle to development due to the damage caused by exogenous shocks and stressors to which countries are increasingly being exposed. These shocks span diverse domains such as terms of trade fluctuations, natural disasters, supply disruptions, conflicts, civil unrest, and unprecedented shocks such as the COVID-19 pandemic."

1.3.2. Territorial vulnerability in the social sciences and economics

The term "vulnerability" is employed broadly to encompass all the factors influencing the outcome of a hazard event, considering its nature and severity. It involves properties inherent to a system, independent of the specific hazards it faces, which play a crucial role in mediating the consequences of a hazardous event. This broad perspective can include environmental variables and measures of exposure (Adger, 1999). For instance, a country's vulnerability to a particular hazard across its territory is not only a function of the percentage of the population residing in the affected area but also the extent to which individuals and sub-national systems within that area are exposed to the primary impacts of the hazard. Socially determined factors heavily influence exposure, such as where populations choose to live, settlement construction, community development, and livelihood choices.

Several definitions exist for vulnerability, each tailored to specific contexts and disciplines (refer to Adger (1999) for a comprehensive overview). In essence, vulnerability refers to the susceptibility of a system, population, or individual to harm from a given threat. This susceptibility can vary significantly depending on socio-economic factors and environmental conditions.

In social science, vulnerability typically encompasses socio-economic determinants that influence people's ability to withstand stress or adapt to change (Allen, 2003). This perspective emphasizes the role of income, education, accessibility to resources, and social support networks in shaping vulnerability. Conversely, in climate science, vulnerability is often framed regarding the probability and consequences of weather and climate-related events (Nicholls et al., 1999). Climate scientists focus on understanding how environmental factors and climatic phenomena exacerbate vulnerability, particularly in regions prone to natural hazards.

While these definitions may differ in emphasis, they ultimately converge on the fundamental concept of susceptibility to harm (or shocks, in economic terminology). Integrating social and climate sciences insights provides a holistic understanding of vulnerability, encompassing socio-economic, environmental, and climatic dimensions. This interdisciplinary approach is essential for developing comprehensive strategies to address vulnerability and enhance resilience across diverse contexts and populations (Adger & Agnew, 2004).

Indeed, as originally rooted in natural science, vulnerability signifies the extent or likelihood of multiple system damages resulting from adverse events like disasters, conflicts, pandemics, and, more generally, unexpected and impactful events. In 1999, the United Nations Development Plan formally introduced the concept of economic vulnerability. This concept predominantly addresses the resilience of an economic entity when confronted with unforeseen external shocks and can be quantified using the economic vulnerability index (Guillaumont, 2014). Comprising shock (magnitude and probability of natural or external shocks) and exposure (structural susceptibility to these shocks), this index serves as a weighted average incorporating factors such as population, export concentration, agriculture, forestry, fisheries, natural disasters, and exports of goods and services.

The economic vulnerability of a country, or more generally of a territory, is commonly linked to its exposure to detrimental external economic shocks (Röhn et al., 2015; Briguglio, 2016). This exposure may be inherent, reflecting the country's structural characteristics, or "self-inflicted" due to inappropriate macroeconomic or industrial policies. In contrast, economic resilience can be inherent, not responsive to policy measures, or nurtured through strategic policy choices

(Briguglio et al., 2014). It is essential to note that there needs to be a match between a country's exposure to external shocks and its resilience capacity to address vulnerability effectively. This equilibrium is particularly critical in export dynamics, where a country's susceptibility to market fluctuations must be balanced by robust resilience strategies to ensure sustained economic performance and competitiveness.

The author's work on the economic vulnerability index posits that vulnerability arises from inherent economic features, including high degrees of economic openness, export concentration, and dependence on strategic imports (Briguglio et al., 2014). First, a high degree of economic openness renders a country susceptible to external economic conditions. Economic openness is largely structural, as it is conditioned by the size of the domestic market in the case of exports and by the availability of natural resources in the case of imports. Second, export concentration in countries or sectors can be a possible source of vulnerability. Structural, the lack of export diversification poses risks, particularly for small economies facing challenges in diversifying exports. Third, dependence on strategic imports, measured, for instance, as the ratio of energy or food imports to total imports or GDP, is inherently related to a country's natural endowments (Röhn et al., 2015). Studies on these variables often conclude that small developing states exhibit higher vulnerability than other country groups (Briguglio, 1995; Armstrong & Read, 2002).

Inherently tied to the coping ability of an economically vulnerable area, economic resilience is defined as the capacity to recover from or adapt to the adverse effects of external economic shocks. Also, the economic resilience of a country can be classified as either inherent or nurtured (Briguglio et al., 2014). Inherent resilience is essentially the opposite of inherent vulnerability; countries inherently resilient should exhibit low vulnerability scores on the index. On the other hand, nurtured resilience is a quality that can be cultivated and controlled, making it responsive to policy measures. In this context, a country can implement policies to build resilience, facilitating its ability to manage and navigate the adverse effects of inherent vulnerability. Conversely, a country may adopt policies that worsen the negative impacts associated with its intrinsic vulnerability.

2. Dossier A – Vulnerability of School infrastructure and Educational offer

The dossier dedicated to the educational vulnerability of territories starts from the observation of territorial contexts through the concept of the 'educational landscapes' (Coelen et al. 2019; Jahnke et al. 2019; Pacchi 2021). In the broad socio-political debate on educational poverty (Save the Children 2022; OECD, 2020), the role of space and the urban context as two crucial components of education has become evident. At the same time, education has been gradually seen as a key lever for urban and spatial development (Cavalari Neto, Berger 2024).

The concept of 'educational landscape' refers to: the broader educational environment within which a long-life learning process takes place, encompassing the material infrastructures (not only schools, but also public libraries, sports and cultural centres, etc.), the subjects involved directly and indirectly (not only teachers and pupils, but also the so-called extended educational community, local administrations, enterprises and stakeholders), the system of rules and policies (of education, accessibility, etc.) that enable or condition this educational process (Argentin 2021). Therefore, looking at the vulnerability of territories starting from the educational dimension makes it possible to grasp some conditions and dynamics of great relevance for the country's "good health" and quality of life in the multiplicity of its local contexts (Banca d'Italia 2024). The indicators proposed here compare built infrastructures, user, and accessibility conditions.

The first theme concerns the condition of the built stock of the school infrastructure (Fondazione Agnelli 2019), posing the question of obsolescence, the equipment of pertinence (gymnasium/pool, assembly hall/auditorium, canteen/refectory), the size and adequacy of the structures from a seismic/ earthquake and energy efficiency point of view. The second theme confronts the school and educational offer on a municipal basis to grasp the capacity of territories to provide a complete and diversified educational offer. We consider the completeness of the school offer in the different cycles and school grades, full-time sections in primary schools (both a.m. and p.m. courses), the musical track in secondary schools, and the presence of almost one civic library in the municipality. The third theme concerns accessibility and the minimum distance from the school, considering the different school orders: it allows us to address the crucial issue of proximity within isochrones suitable for sustainable and active mobility.

From this partial but significant thematization, sets of simple indicators were identified that contribute to the definition of 4 complex indicators, which can be further specified and refined, and which pose the issue of educational vulnerability through three perspectives:

A.1_ Vulnerability of accessibility to school offer;

A.2_ Vulnerability of educational landscapes;

A.3_ Vulnerability of maintenance of school infrastructure;

A.4_ Vulnerability of governance of school infrastructure.

2.1 Map A.1 – Vulnerability of accessibility to school offer

This complex indicator takes into account the vulnerability of territories starting from the minimum average distance to the nearest schools for the first cycle (primary and secondary) and for the second cycle (high) school orders calculated on a municipal basis. The indicator is the result of distance indicators on a municipal basis, identified for each school order and allows to capture the vulnerability related to the accessibility of the school offer of cycle I (6-13 years) and II (14-18 y.).

The calculation of distances was done by taking into consideration the maximum distances identified in the ministerial decree of 18 December 1975 ("Updated technical standards for school buildings, including the indices of didactic, building and urban functionality, to be observed in the execution of school building works). Point 1.1.3 of the decree, which is currently the reference standard for school buildings, defines 'Maximum distances and travel times, in relation to modes of travel and types of school' and identifies 300 m for kindergartens; 500 m on foot (or 15 minutes by public transport) for primary schools; 1000 m on foot (or 15-30 minutes by public transport) for first grade secondary schools; 20-45 minutes (maximum travel time by public transport) for first grade secondary schools.

Starting from these optimum maximum measures, each indicator is dedicated to one school grade, focusing the analysis on state primary, lower secondary and upper secondary schools. Pre-schools have not been taken into account as the distribution and location of state pre-schools in the country is strongly - and traditionally - flanked by municipal and parochial schools. The indices were constructed with a high level of precision, calculating minimum distances from census sections, then weighted by municipality. This method of using data makes it possible to go beyond the municipal perimeters, which in the construction of school catchment areas and student mobility are limiting for a precise and exhaustive interpretative picture.

Geographies of great interest emerge, highlighting not only the peripheral conditions of parts of inland Italy, but also conditions of widespread vulnerability (Pucci et al. 2021) that increases as the school grade increases.

Indicator dimensions

Society, Infrastructure

Type of indicator

Status

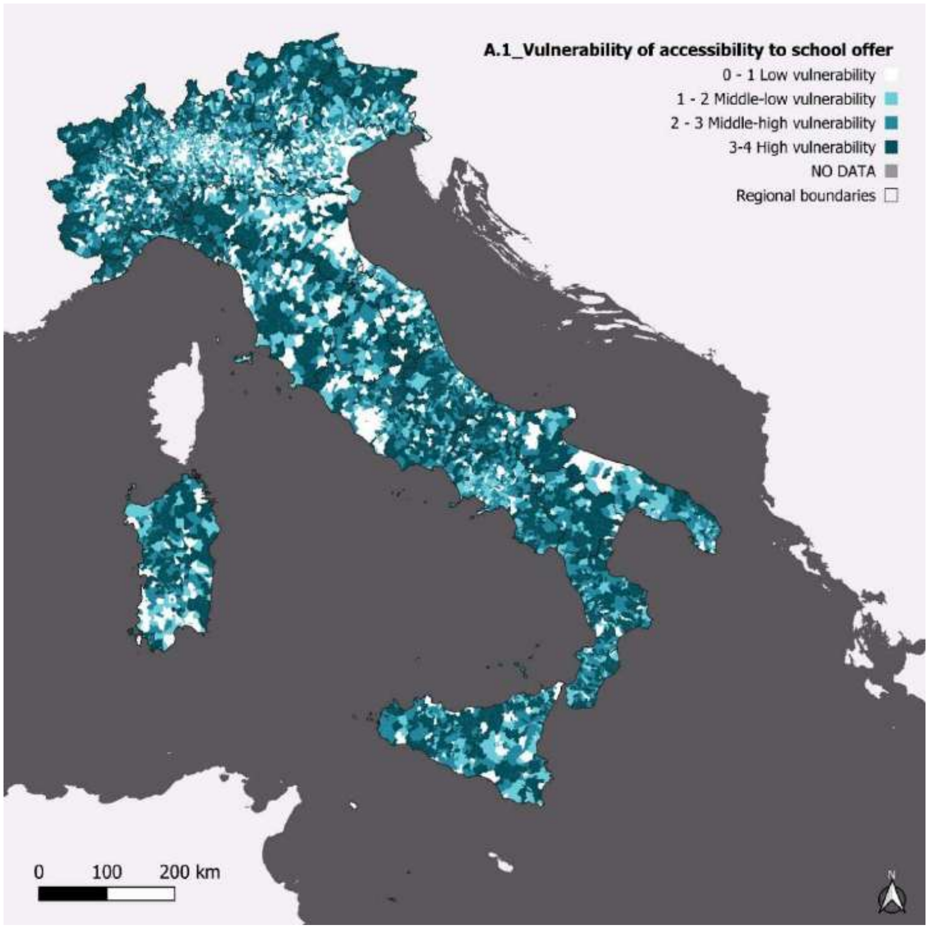

Figure A.1: Vulnerability of accessibility to school offer (6-18 y.) on municipal basis.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.1	Vulnerability of accessibility to school offer	2021	municipality		
A.1.1	Accessibility to primary school (6-10 y.)	2021	municipality	m	ISTAT, MIM
A.1.2	Accessibility to middle school (11-13 y.)	2021	municipality	m	ISTAT, MIM
A.1.3	Accessibility to high school (14-18 y.)	2021	municipality	m	ISTAT, MIM

Table A.1/a: Indicators' metadata and sources

Territorial tipology	A1.1	A1.2	A1.3	**A.1**
1 INNER ITALY	**0.77**	**0.67**	**0.66**	**2.10**
1.1.1 - Inner, remote and sparsely populated area	0.79	0.70	0.72	2.21
1.1.2 - Inner and remote area with medium population density	0.60	0.46	0.25	1.31
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.79	0.69	0.71	2.19
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.60	0.50	0.13	1.23
2 INTERMEDIATE ITALY	**0.64**	**0.54**	**0.52**	**1.70**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.77	0.67	0.70	2.14
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.52	0.43	0.31	1.26
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.67	0.56	0.64	1.87
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	0.49	0.35	0.28	1.12
2.2 - Medium-sized city or non-FUA capital	0.30	0.20	0.02	0.51
2.3 - De facto or de jure metropolitan fringe	0.57	0.46	0.42	1.45
3 METROPOLITAN ITALY	**0.49**	**0.35**	**0.30**	**1.15**
3.1 - De facto metropolitan centre	0.23	0.11	0.02	0.36
3.2.1 - De jure and de facto metropolitan area (not capital)	0.50	0.36	0.32	1.18
3.2.2 - Metropolitan capital	0.29	0.18	0.00	0.46
National value	**0.65**	**0.55**	**0.53**	**1.73**

Table A.1/b: Indicator average for each territorial typology (inner, intermediate and metropolitan Italy).

A.1_ Vulnerability of accessibility to school offer

The indicator expresses the remoteness of schools at different level and grade; it is calculated from 0 to 3 and describes the level of schools proximty (0-low proximity, 3-lhigh proximity) on a municipal basis. It is based on the sum of the following three simple indexes that measure the average distance to the closest schools, divided by order and grade.
The three simple indicators are weighted equally, and the max value is 3: 3-2= High vulnerability, 2-1=medium vulnerability, 0-1= Low vulnerability.

A.1.1_ Accessibility to primary school (6-10 y.)

The index describes the minimum average distance to the nearest primary school on a municipal basis. It considers the distance established by the national ministerial decree (December 18, 1975, point 1.1.3): the optimum maximum distance from home to elementary school was established at 500 m. The index is equal to 0 (optimum distance 500 m) and it increases as the distance increases [Values: 500-1000=0,25; 1000-2000=0,5; 2000-4000=0,75; >4000=1].

A.1.2_ Accessibility to middle school (11-13 y.)

The index describes the minimum average distance to the nearest secondary school on a municipal basis. It considers the distance established by the national ministerial decree (December 18, 1975, point 1.1.3): the optimum maximum distance from home to secondary school was established at 1000 m. The index is equal to 0 (optimum distance 1000 m) and it increases as the distance increases [Values: 1000-2000=0,25; 2000-4000=0,5; 4000-8000=0,75; >8000=1].

A.1.3_ Accessibility to high school (14-18 y.)

The index describes the minimum average distance to the nearest high school on a municipal basis. It considers the distance established by the national ministerial decree (December 18, 1975, point 1.1.3): the optimum maximum distance from home to secondary school was established in minutes, between 20 and 45 minutes. The index is equal to 0 (optimum distance 3000 m) and it increases as the distance increases [Values: <3000=0, <6000=0,25, <9000=0,5, <12000=0,75, >12000=1].

2.2 Map A.2 – Vulnerability of educational landscapes

The second complex indicator makes it possible to assess the vulnerability of 'educational landscapes', understood as systems of conditions that make a public educational, cultural, and sporting education available to citizens. The evidence shows how contextual conditions are fundamental to contrast situations of fragility and inequality (Openpolis, 2019): their territorial dimension and geographical distribution weighs significantly in the different contexts.

The territorial role of institutions and school spaces is, therefore, extremely relevant, particularly where different conditions of vulnerability are combined : economic hardship, lack of services, educational poverty - i.e. 'the deprivation, for children and adolescents, of the opportunity to learn, experience, develop and allow their abilities, talents and aspirations to flourish freely' (Save The Children, 2014). Using the concept of the 'educational landscape', we highlight how, alongside the socio-economic and cultural level of the family of origin, the living context plays a crucial role in determining the educational, recreational and cultural opportunities for school-age population groups. The system of rules and institutions, the distribution of school offerings, as well as the presence and quality of services and facilities, from the home to the neighbourhood (museums, libraries, sports facilities, etc.), are fundamental variables (Celata et al. 2024).

The index A.2 takes into consideration, on a municipal basis, the completeness of the educational offer of the first and second cycle, the endowment of sports and cultural facilities within the schools, the presence of at least one primary school that runs full-time, the presence of at least one secondary school with a musical address, the presence of a public and civic library (Faggiolani 2022). This indicator, correlated with the measures of vulnerability identified by Istat (Istat 2020), which defines an index of social and material vulnerability (IVSM), constitutes a valid support for defining criteria for intervention and targeting 'socio-educational areas' in conditions of greater vulnerability. The IVSM indicator in fact adds significant data on demographic and socio-economic dimensions such as: The incidence of young and adult single-parent families; The incidence of large families; The incidence of low education; Welfare distress; Housing crowding; Young people out of the labour market and training; Economic distress.

Indicator dimensions

Society, Infrastructure

Type of indicator

Status

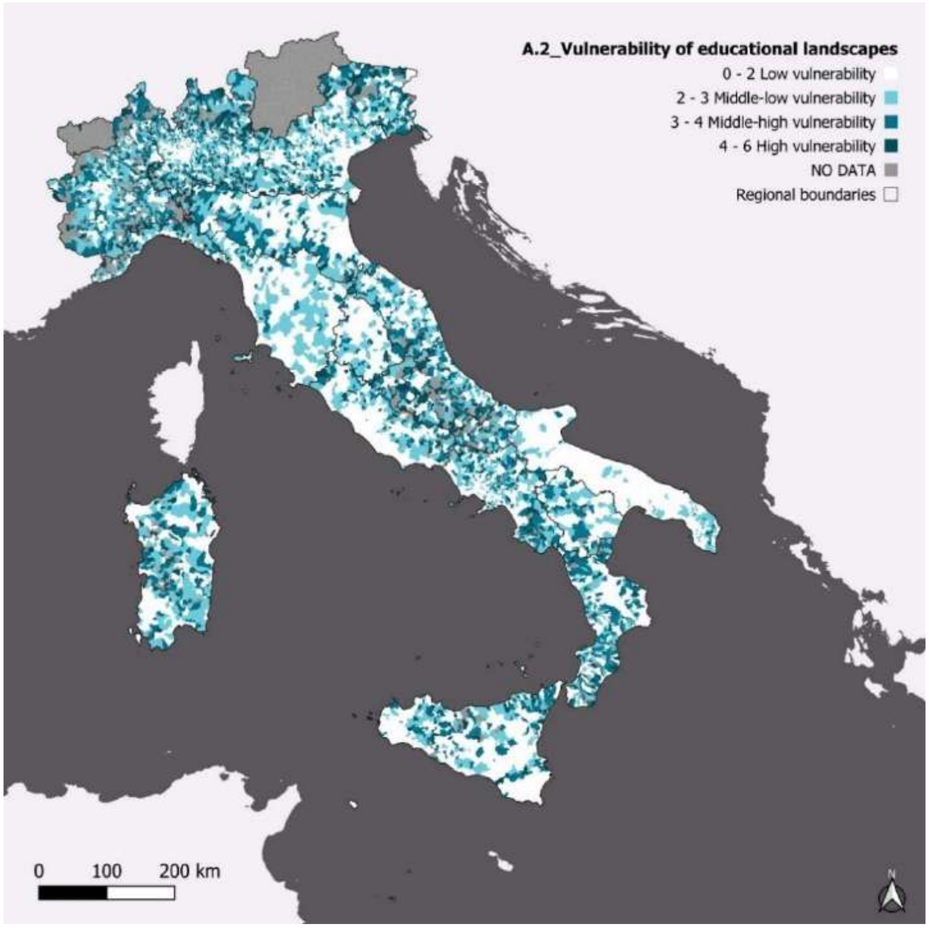

Figure A.2: Vulnerability of educational landscapes on municipal basis.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.2	Vulnerability of educational landscapes	2021	municipality		
A.2.1	Completeness I cycle (6-13 y.)	2021	municipality	%	MIM
A.2.2	Completeness II cycle (14-18 y.)	2021	municipality	%	MIM
A.2.3	School equipment: sport facilities	2021	municipality	%	MIM
A.2.4	School equipment: lecture hall or auditorium	2021	municipality	%	MIM
A.2.5	School equipment: canteen or refectory	2021	municipality	%	MIM
A.2.6	Full time, elementary school (6-10 y.)	2021	municipality	%	MIM
A.2.7	Music track, secondary school (11-13 y.)	2021	municipality	%	MIM
A.2.8	Public and civic library	2021	municipality	%	ISTAT

Table A.2/a: Indicators' metadata and sources.

Territorial tipology	A2.1	A2.2	A2.3	A2.4	A2.5	A2.6	A2.7	A2.8	**A.2**
1 INNER ITALY	0.31	0.86	0.45	0.70	0.35	0.68	0.91	0.34	**2.70**
1.1.1 - Inner, remote and sparsely populated area	0.35	0.92	0.49	0.76	0.35	0.70	0.93	0.36	2.85
1.1.2 - Inner and remote area with medium population density	0.15	0.56	0.20	0.49	0.26	0.57	0.75	0.18	1.88
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.26	0.92	0.54	0.68	0.43	0.65	0.94	0.38	2.84
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.02	0.51	0.16	0.32	0.45	0.61	0.77	0.19	1.78
2 INTERMEDIATE ITALY	0.27	0.86	0.34	0.65	0.25	0.69	0.89	0.26	**2.58**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.36	0.96	0.47	0.78	0.28	0.79	0.94	0.40	2.95
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.23	0.80	0.26	0.58	0.25	0.69	0.86	0.16	2.43
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.32	0.98	0.44	0.77	0.31	0.81	0.95	0.25	3.03
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	0.09	0.72	0.15	0.42	0.18	0.52	0.80	0.08	1.92
2.2 - Medium-sized city or non-FUA capital	0.02	0.00	0.00	0.01	0.01	0.05	0.21	0.00	0.15
2.3 - De facto or de jure metropolitan fringe	0.21	0.86	0.29	0.59	0.24	0.56	0.89	0.20	2.43
3 METROPOLITAN ITALY	0.08	0.74	0.20	0.44	0.24	0.34	0.79	0.14	**1.91**
3.1 - De facto metropolitan centre	0.01	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.10
3.2.1 - De jure and de facto metropolitan area (not capital)	0.09	0.78	0.21	0.47	0.25	0.36	0.83	0.15	2.00
3.2.2 - Metropolitan capital	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
National value	0.26	0.85	0.35	0.64	0.27	0.66	0.89	0.27	**2.54**

Table A.2/b: Indicator average for each territorial typology (inner, intermediate and metropolitan Italy).

A.2_ Vulnerability of educational landscapes

The indicator expresses the level of poverty, lack of diversification and educational supply for each municipality. It is calculated by the sum of the following three simple indicators. The indicators are weighted as follows: A2.1=1; A2.2=1; A2.3=1; A2.4=0,5; A2.5=0,5; A2.6=0,5 max value 1 x 0.5 = 0.5; A2.7=0.5 max value 1 x 0.5 = 0.5; A2.8 = 1 max value 1 x 1 = 1.

The max indicator's value is 6: 6-5 = High vulnerability, 4.75-3 = iddle-high vulnerability, 2.75-1.25 = middle-low vulnerability, 1-0 = low vulnerability).

A.2.1_ Completeness I cycle

The index considers the presence or absence of the schools of the first cycle (primary and middle schools, 6-13 years) on a municipal basis. The indicator is equal to 0.5 in the absence of primary or middle schools and to 1 in the case of the absence of both the degrees of education.

A.2.2_ Completeness II cycle

The index considers the presence or absence of the schools of the second cycle (upper secondary schools, 13-18 years) on a municipal basis. The indicator is equal to 0.33 in the absence of a single educational track (lyceum, technical or vocational offer), to 0.66 in the absence of two tracks and to 1 in the absence of all the tracks.

A.2.3_ School equipment: sport facilities

The index considers the presence or absence of the sport facilities inside the schools of the municipality. The sport facility provisions are important in the promotion of a healthy and active lifestyle and social competences. The indicator is equal to 1 if in the municipality there is at least one school with a gymnasium or a swimming pool.

A.2.4_ School equipment: lecture hall or auditorium

The index considers the presence or absence of a lecture hall or auditorium inside the schools of the municipality. These facilities are important in the promotion of the local cultural activities (events, shows, conferences, etc.). The indicator is equal to 1 if in the municipality there is at least one school with a lecture hall or an auditorium.

A.2.5_ School equipment: canteen or refectory

The index considers the presence or absence of a canteen or refectory inside the schools of the municipality. These facilities are important in the promotion of the full-time educational offer and in the support of working parents and gender equality, as well as in the promotion of healthy nutrition. The indicator is equal to 1 if in the municipality there is at least one school with a canteen or refectory.

A.2.6_ Full-time, primary school

The index considers the presence or absence of the full-time primary school offer in the municipality. Because the full-time offer is mainly concentrated in urban context, it represents a critical issue for the intermediate territories of Italy. The indicator is equal to 0 if there is at least one full-time primary school in the municipality, to 1 if it is absent.

A.2.7_ Music track, middle school

The index considers the presence or absence of the music track in middle school offer in the municipality. The distribution of this educational offer is differentiated between Northern and Southern regions in Italy. The music track promotes the acquisition in pupils of music language and knowledge, integrating technical, practical, theoretical, and cultural aspects through the study of a musical instrument. It also provides the possibility to have full-time activities. In Italy, the music track is present in 1,967 middle schools, on a total number of 7,200 in the whole country: almost the half of them is in the Southern Regions of Calabria, Sicily, Campania, and Apulia.
The indicator is equal to 0 if there is at least one middle school with music track in the municipality, to 1 if it is absent.

A.2.8_ Public and civic libraries

The index considers the presence or absence of public and civic libraries in the municipality. The presence of a public library is important for the promotion of cultural skills and knowledge, as well as for the potential relationships with local schools and their involvement in specific projects. It is a proxy of the 'educational landscape' of a territory.
The indicator is equal to 0 if there is at least one full-time primary school in the municipality, to 1 if it is absent.

2.3 Map A.3 – Vulnerability of school infrastructure's maintenance

The Vulnerability of maintenance of school infrastructure index is a complex indicator that highlights some aspects of maintenance needs at the municipal scale. This indicator comprises three indicators that make it possible to capture the demands of school infrastructure management at its different levels of governance: in Italy Municipalities are in charge for public school building for the I cycle of school (2-5; 6-13 years), and Provinces/Metropolitan Cities and Regions are in charge for the II cycle (14-18 years). These datasets concern the age of the buildings, the presence or absence of seismic/earthquake and energy efficiency certification.
This indicator primarily uses data on the year of construction of school buildings: having the number of school buildings over 50 years old makes it possible to measure the age of the built stock. It is a reliable proxy for maintenance needs: older, less energy-efficient buildings with higher maintenance, renovation, and safety costs. As shown by studies on the national school building heritage (Fondazione Agnelli 2019; Banca d'Italia 2024), the more than 40,000 schools in the country have an advanced average age and are in very different conditions from the point of view of material infrastructure, defining a significant variable for the management and maintenance of this heritage. Secondly, data on the presence or absence of building certifications (seismic and energy certification) is used. The presence or absence of these certifications makes it possible to grasp the vulnerability of building objects to seismic risk and the level of energy efficiency (and consumption): central themes, both for safety and for comfort and sustainability, the absence of which denotes critical levels of educational vulnerability. Furthermore, the data on certifications allows us to grasp the further building adaptation costs that need to be put in place to obtain safe and energy-efficient buildings.

Indicator dimensions

Society, Infrastructure

Type of indicator

Status, Pressure

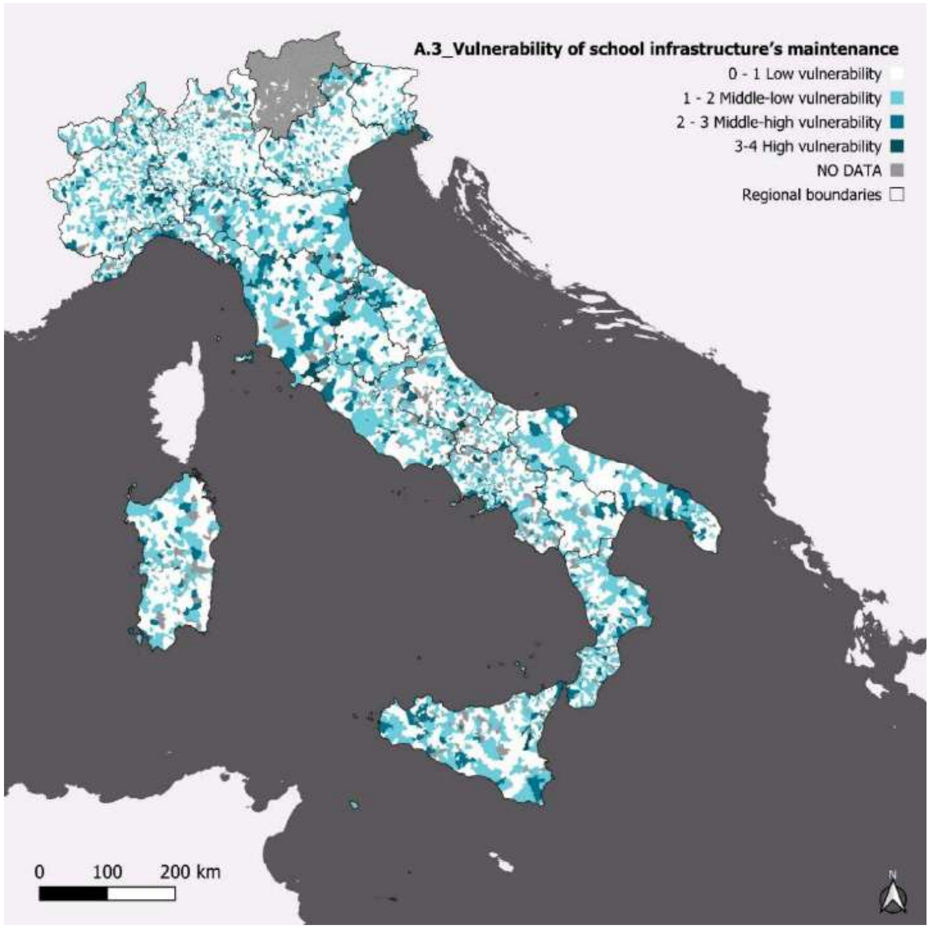

Figure A.3: Vulnerability of school infrastructure's maintenance on municipal basis.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.3	Vulnerability of school infrastructure's maintenance	2021	municipality		
A.3.1	Aging of the school building stock	2021	municipality	%	MIM
A.3.2	Building seismic inadequacy	2021	municipality	%	MIM
A.3.3	Building energy inadequacy	2021	municipality	%	MIM

Table A.3/a: Indicators' metadata and sources.

Territorial tipology	A3.1	A3.2	A3.3	**A.3**
1 INNER ITALY	0.40	0.11	0.10	1.08
1.1.1 - Inner, remote and sparsely populated area	0.39	0.09	0.08	1.01
1.1.2 - Inner and remote area with medium population density	0.43	0.26	0.21	1.50
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.40	0.12	0.11	1.10
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.45	0.23	0.26	1.43
2 INTERMEDIATE ITALY	0.41	0.13	0.12	1.19
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.39	0.09	0.09	1.03
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.42	0.14	0.14	1.26
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.45	0.11	0.09	1.19
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	0.42	0.21	0.20	1.41
2.2 - Medium-sized city or non-FUA capital	0.51	0.41	0.30	1.90
2.3 - De facto or de jure metropolitan fringe	0.41	0.15	0.14	1.23
3 METROPOLITAN ITALY	0.37	0.23	0.22	1.36
3.1 - De facto metropolitan centre	0.45	0.39	0.25	1.73
3.2.1 - De jure and de facto metropolitan area (not capital)	0.36	0.21	0.21	1.33
3.2.2 - Metropolitan capital	0.54	0.61	0.43	2.36
National value	0.41	0.14	0.13	1.19

Table A.3/b: Indicator average for each territorial typology (inner, intermediate and metropolitan Italy).

A.3_Vulnerability of school infrastructure's maintenance

The indicator esxpresses the potential maintenance need and it is obteined by the sum of the three following simple indicators. The simple indicators are weighted as follows: 3.1 =2; A3.2 =1; A3.3 =1. The max indicator's value is 4: 4-3,25 = High vulnerability, 3-2,25 = iddle-high vulnerability, 2-1,25 = middle-low vulnerability, 1-0 = low vulnerability).

A.3.1_ Aging of the school building stock

The index considers the year of school construction: percentage of schools over 50 years old out of the total number of schools in the municipality. Thresholds for old and new schools were identified as a proxy for maintenance needs for municipalities. The indicator is equal to 0 with a low percentage of old schools and equal to 1 with a high percentage of them [values: 0-25% = 0; 25-50% = 0.5; 50-75% = 0.75; 75-100% = 1].

A.3.2_ Building seismic inadequacy

The index considers the number of schools with seismic inadequacy out of the total number of schools in the municipality. Having or not having this certification allows one to grasp the vulnerability of building objects to seismic risk and the level of energy efficiency (and consumption). These are central issues, both for safety and for comfort and sustainability, the absence of which denotes significant levels of educational vulnerability. Thresholds were identified as a proxy for municipalities' maintenance needs. The indicator is equal to 0 with a low percentage of buildings without seismic adequacy certificates and equal to 1 with a high percentage of them [values: 0-25% = 0; 25-50% = 0.5; 50-75% = 0.75; 75-100% = 1].

A.3.3_ Building energy inadequacy

The index considers the number of schools with energy inadequacy out of the total number of schools in the municipality. Having or not having this certification allows one to grasp the vulnerability of building objects to seismic risk and the level of energy efficiency (and consumption). These are central issues, both for safety and for comfort and sustainability, the absence of which denotes significant levels of educational vulnerability. Thresholds were identified as a proxy for municipalities' maintenance needs. The indicator is equal to 0 with a low percentage of buildings without seismic adequacy certificates and equal to 1 with a high percentage of them [values: 0-25% = 0; 25-50% = 0.5; 50-75% = 0.75; 75-100% = 1].

2.4 Map A.4 – Vulnerability of school infrastructure's governance

The Vulnerability of the school infrastructure governance index is a complex indicator that highlights some aspects of governance needs at the municipal scale. This indicator comprises two indicators that make it possible to capture the demands of school infrastructure management at its different levels of governance. These datasets concern the size of the school and the number of pupils per class.

The index considers the size of the school. Since the data on school size expressed in square meters on the ministerial portal for school buildings is partially incomplete and unreliable, the school size figure is calculated from a double perspective. On the one hand, it considers the number of sections (classes) hosted within the school building: the sections each include the number of classes for the whole school: 5 classes for a primary and high school section; 3 classes for a middle school section. This simple indicator makes it possible to assess the concentration and spread of resources concerning the building stock: large and small schools require very different maintenance work and a very different ratio of building expenditure per pupil. On the other hand, the indicator considers the number of pupils according to the minimum national standard for activating classes. These standards are provided nationally with poor spatial criteria, primarily related to orographic and demographic concerns.

This index allows us to understand the role of small schools' (Bartolini et al. 2023) maintenance and governance in the Country: a quantitatively relevant issue for public policies and decision processes on school siting and sizing.

Indicator dimensions

Society, Infrastructure

Type of indicator

Status, pressure

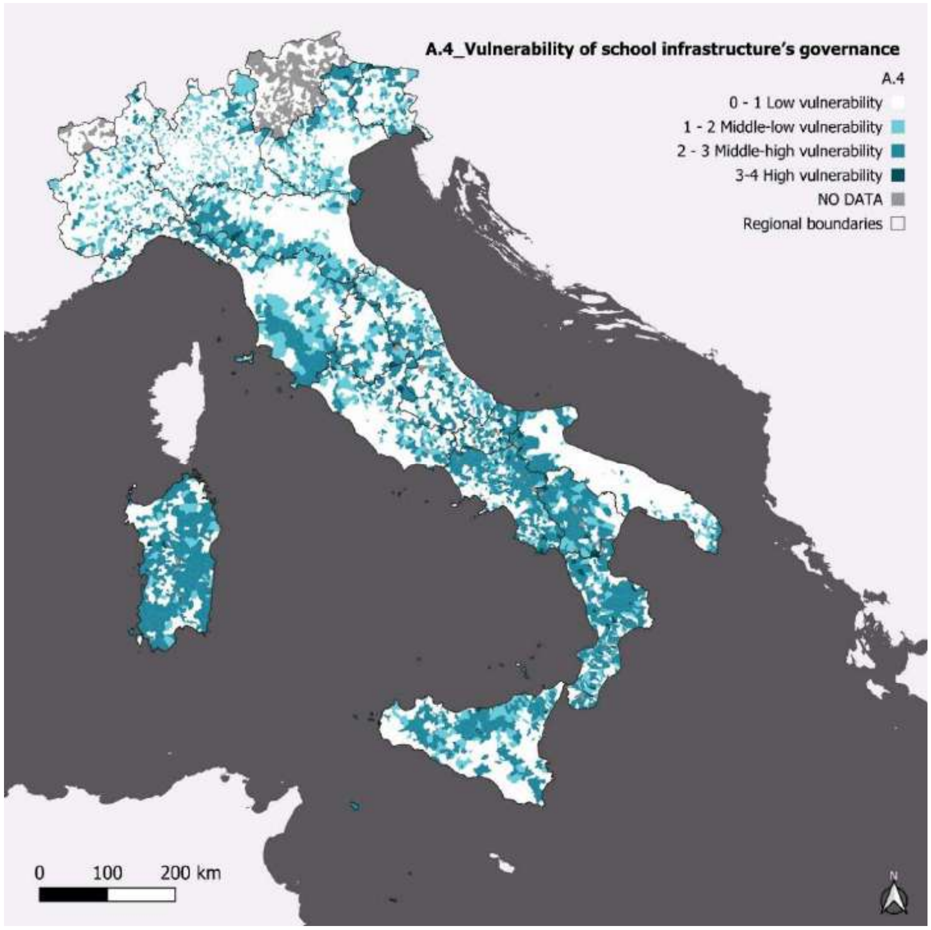

Figure A.4: Vulnerability of school infrastructure's governance on municipal basis.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.4	Vulnerability of school infrastructure's governance	2021	municipality		
A.4.1	School size: number of sections per school	2021	municipality	%	MIM
A.4.2	School size: number of pupils per class	2021	municipality	%	MIM

Table A.4/a: Indicators' metadata and sources.

Territorial tipology	A4.1	A4.2	A.4
1 INNER ITALY	**0.27**	**0.43**	**1.40**
1.1.1 - Inner, remote and sparsely populated area	0.28	0.45	**1.46**
1.1.2 - Inner and remote area with medium population density	0.15	0.20	**0.70**
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.34	0.49	**1.65**
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.19	0.32	**1.03**
2 INTERMEDIATE ITALY	0.19	0.22	**0.83**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.24	0.33	**1.13**
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.13	0.14	**0.54**
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.25	0.23	**0.97**
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	0.11	0.08	**0.39**
2.2 - Medium-sized city or non-FUA capital	0.04	0.03	**0.15**
2.3 - De facto or de jure metropolitan fringe	0.15	0.18	**0.65**
3 METROPOLITAN ITALY	0.09	0.11	**0.41**
3.1 - De facto metropolitan centre	0.00	0.00	**0.00**
3.2.1 - De jure and de facto metropolitan area (not capital)	0.10	0.12	**0.43**
3.2.2 - Metropolitan capital	0.00	0.00	**0.00**
National value	0.20	0.25	**0.89**

Table A.4/b: Indicator average for each territorial typology (inner, intermediate and metropolitan Italy).

A.4_ Vulnerability of school infrastructure's governance

The indicator describes the potential difficulty of maintaining school buildings within a municipality, and it is obtained by the sum of the following two simple indicators.
The simple indicators are weighted as follows: A1.1 = 2; A1.2 =2. T The max indicator's value is 4: 4-3,25 = High vulnerability, 3-2,25 = middle-high vulnerability, 2-1,25 = middle-low vulnerability, 1-0 = low vulnerability).

A.4.1_ School size: number of sections per school

The index considers the average number sections per school on a municipal basis. The indicator equals 1 when the average number of sections is 1 (5 classes for primary schools and high schools;

3 classes for middle schools) or less.

A.4.2_ School size: number of pupils per class

The index considers the average number of pupils per class according to the minimum national standard (15 for primary school, 18 for secondary, and 20 for high school) on a municipal basis. The indicator equals 0 when the average of pupils per class exceeds the threshold; the value is 1 as the average number is below the threshold.

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3. Dossier B – Housing vulnerability

Housing affordability is often connected to issues such as spatial justice and social sustainability. The right to housing is promoted by national and international policies. yet it remains challenging to analyse comprehensively. Examining the issue of housing market accessibility on a territorial scale by combining various types of data allows for the deconstruction of issues and the analysis of some of the main factors contributing to the "Vulnerability of the real estate market and housing estates".

It is important to note that a more vibrant real estate market is not only linked to the increased economic capacity of the resident population but also to an overall improved quality of life. such as the presence of services. job opportunities. and the availability of open spaces. Interpreting the vulnerability of the real estate market thus means also identifying other types of social. economic. technological. and cultural vulnerabilities that influence the choice to invest in one area over another. Therefore. the geography of real estate market vulnerability provides an overall map of revealed preferences. highlighting significant territorial disparities that go beyond economic and quantitative factors.

Moreover. it should be noted that in Italy. the housing market has been generally contracting for many years. and the causes of this phenomenon are highly heterogeneous and varied. including a general aging of the average population. greater economic difficulties. and challenges in accessing mortgages. The housing market is changing significantly. which calls for the necessity of monitoring it through composite and multidimensional indicators.

Four main composite indicators have been selected: (B1) "Housing rental unaffordability index." which interprets the tendency to occupy rental housing based on average income and average rental costs; (B2) "Housing exclusion index." which interprets the possibility of accessing the housing market for residents with different economic capacities; (B3) "Index of real estate abandonment due to lack of digital coverage." which attempts to interpret the tendency for housing abandonment based on internet accessibility; (B4) "Index of tourist pressure on the housing rental market." which highlights the strong link between the tourist appeal of locations and the increase in rental housing costs.

3.1 Map B.1 – Housing rental unaffordability index

Housing vulnerability is related to the physical characteristics of buildings but also to the socio-economic conditions of their occupants (Barreca et al.. 2018). The socio-economic status of households can translate to varying levels of housing vulnerability. For example. low-income households often can only afford housing in areas with inadequate urban infrastructure and public services or in locations more susceptible to natural hazards (Zhu et al.. 2024). Moreover. the COVID-19 pandemic demonstrated that those experiencing severe financial vulnerability might be unable to maintain their standard of living for more than three months without income (Eurofound. 2020).

In scientific literature. rent unaffordability is one of the main components of housing vulnerability. a concept that does not have a single definition: it can refer to both the physical vulnerability of the building stock and the socio-economic vulnerability of people who have difficulties accessing or maintaining housing. Although we do not address them here. we acknowledge the correlation between unemployment. low education levels. and housing vulnerability. Many other studies have highlighted correlations with factors such as ethnicity or age. However. in this work. which covers the entire nation and is analysed statistically at the municipal level (LAU). we use households income as a proxy for other variables. such as those just mentioned.

We decided to revisit an indicator already used at an institutional level to measure the risk of housing unaffordability. In particular. the indicator mapped in this sub-chapter constitutes a review of the approach to the topic proposed by different national and international housing observatories. In its most general definition. the Rental Affordability Index (RAI) aims to capture the rental costs sustained by a household with an average income. The index assumes that a middle-income family can aspire to enter a leasing contract and pay a rent not exceeding 30% of its income.

In the Italian context. a similar indicator has been used by the Regional Observatory of Housing Conditions. established in Puglia with Regional Law no. 20/2005 and included in the network of regional observatories belonging to the National Observatory established by Law 431/98. With a slightly different calculation method. this indicator was also used by the PRIN research on postmetropolitan territories and published in the Web Atlas of Postmetropolitan Territories (www.postmetropoli.it). The indicator we present here. limited to the rental component for residential purposes. relates the average household income (calculated through the income of natural persons) with the average rental fees of "civil homes." The indicator also uses the share of occupied rental homes as a multiplier. This is because according to our focus and approach. 100% home ownership eliminates the risk of rent unaffordability. In brief. the indicator measures the risk of unaffordability of rented houses that could lead to inaccessibility. arrears. or eviction for non-payment in the face of various economic-financial threats.

The map shown in fig. B.1 highlights denser urban areas as particularly vulnerable. but also many tourist areas. especially along some coastal regions and in several mountain locations.

Indicator dimensions

Economy. Society

Type of indicator

Status

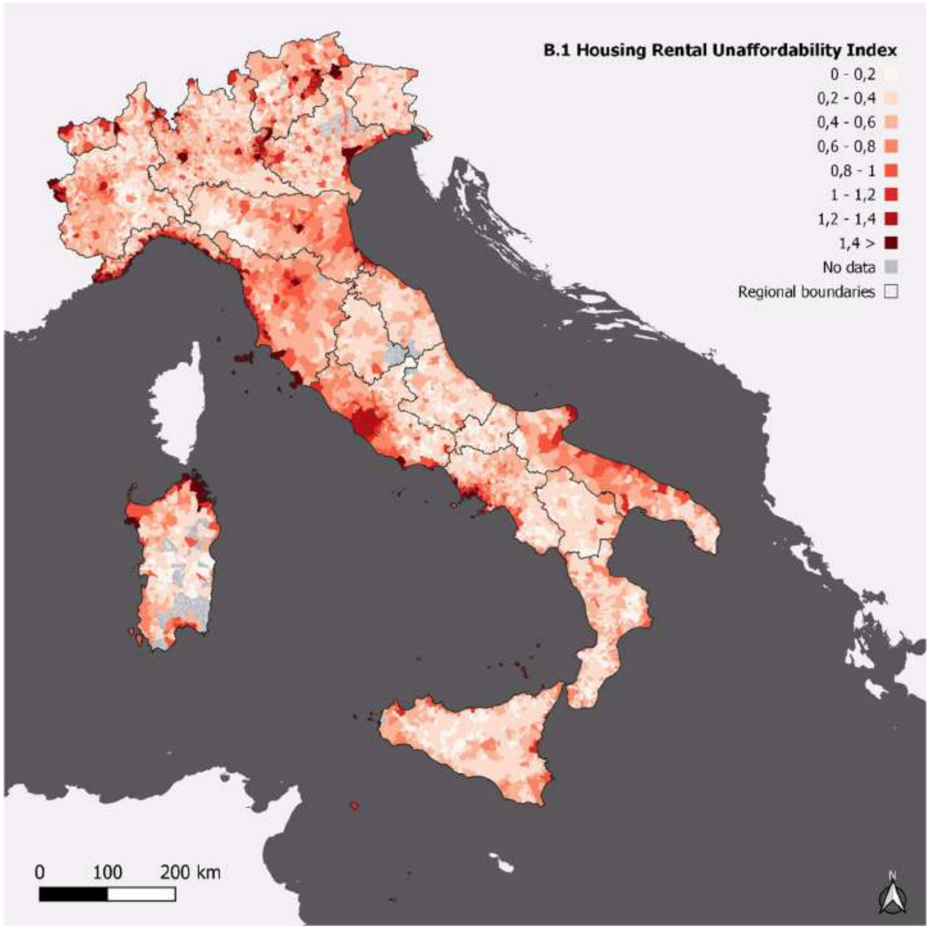

Figure B.1: Housing rental unaffordability index calculated at LAU's level

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	SPATIAL LEVEL OF DETAIL	UNIT OF MEASURE	DATA SOURCE
B.1	Housing rental unaffordability index	2019/2021	Municipality (LAU)	0-100	Authors' elaboration
B.1.1	Average housing rent	2019	Municipality (LAU)	Euro/gross.m^2/month	Authors' elaboration on Agenzia delle Entrate data
B.1.2	Average monthly income per household	2021	Municipality (LAU)	Euro/household/month	Authors' elaboration ond ISTAT and MEF data
B.1.3	Percentage of occupied rental homes	2021	Municipality (LAU)	%	Authors' elaboration on ISTAT data

Table B.1/a: Indicators' metadata and sources

Territorial typology	B.1.1	B.1.2	B.1.3	**B.1**
1 INNER ITALY	**2.94**	**2,031.48**	**8.09**	**0.40**
1.1.1 - Inner. remote and sparsely populated area	2.95	2,061.41	7.61	0.38
1.1.2 - Inner and remote area with medium population density	3.22	2,133.67	11.62	0.52
1.2.1 - Sparsely populated inner area closest to a metropolitan area	2.52	1,832.36	7.95	0.37
1.2.2 – Inner area with medium population density closest to a metropolitan area	3.95	1,815.76	9.35	0.64
2 INTERMEDIATE ITALY	**3.23**	**2,570.49**	**11.71**	**0.43**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	2.70	2,359.5	9.67	0.35
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	3.76	2,813.43	13.91	0.51
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	2.93	2,673.56	11.15	0.37
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	4.00	2,678.38	13.83	0.58
2.2 - Medium-sized city or non-FUA capital	4.84	2,757.43	19.62	0.77
2.3 - De facto or de jure metropolitan fringe	3.53	2,655.75	12.74	0.48
3 METROPOLITAN ITALY	**4.66**	**2,774.65**	**15.80**	**0.69**
3.1 - De facto metropolitan centre	6.43	3,282.16	22.73	0.93
3.2.1 - De jure and de facto metropolitan area (not capital)	4.56	2,764.99	15.48	0.67
3.2.2 - Metropolitan capital	7.16	2,749.05	22.66	1.20

Table B.1/b: LAUs indicator average for each territorial typology. NB: since the most recent data relating to indicator B.1.1 are available for the year 2019. because of the administrative changes that occurred between 2019 and 2021. the calculations reported in the table were made on 7717 municipalities (LAUs) out of a total of 7904.

B.1_ Housing rental unaffordability index

Ratio between average monthly rents for residential buildings in normal condition (€/100gross.m^2/month) and the average monthly taxable income per household (€/household/month). all multiplied by square root of the percentage of occupied rental homes (%). The indicator is equal to 0 (minimum value) in the absence of occupied rental homes; it is equal to 10 (maximum value) in the case in which the average monthly income per household corresponds to the average rent of residential homes. in municipalities with 100% of the homes occupied by rent.

B.1.1_ Average housing rent

Municipal average of minimum and maximum monthly rents for civil homes in normal condition.

B.1.2_ Average monthly income per household

Ratio between the total taxable amount of natural persons and the total number of households residing in the municipality (/12).

B.1.3_ Percentage of rental homes

Ratio between the number of occupied rental homes and the total number of homes in the municipality (x 100).

3.2 Map B.2 - Housing exclusion and precariousness index

The second composite indicator aims to measure housing vulnerability starting from actually existing emergency and housing precarious conditions. One possible consequence of pressure on affordable housing is an increase in people experiencing homelessness or people forced to live in precarious housing. The existence of people in conditions of serious housing exclusion and homelessness is one of the main social problems addressed by the European Union Strategy for Social Protection and Inclusion. According to the European Federation of National Organisations Working with the Homeless (FEANTSA) there are different possible definitions of homelessness across Europe according to different situations and conditions (European Commission, 2016):

- rooflessness (without a shelter of any kind, sleeping rough)
- houselessness (with a place to sleep but temporary in institutions or shelter)
- living in insecure housing (threatened with severe exclusion due to insecure tenancies, eviction, domestic violence)
- living in inadequate housing (in caravans on illegal campsites, in unfit housing, in extreme overcrowding).

Over the past decade, 24 of the 28 EU countries have reported an increase in homelessness. According to existing statistics, several experts have noted significant rises, with the number of homeless people increasing between 16% and 389% over this period (European Commission, 2019). The major causes of this phenomenon are evictions linked to rising levels of housing costs overburden, overindebtedness, impoverishment and lack or insufficient supply of affordable housing. According to European Commission the main weaknesses and gaps that characterise the Italian context are: the endemic scarcity of public resources dedicated to the public housing sector; the limited availability of public dwellings; the too strict eligibility criteria for the minimum income scheme (Ibidem, p. 118).

The composite indicator we propose, based on a specific ISTAT survey, measures the housing exclusion and precarioussness already existing in ordinary conditions, i.e. the incidence of the houseless and roofless population or people living in non-ordinary or informal housing conditions. The survey published by ISTAT in 2022 finally provides visibility and recognition to segments of the population that are typically difficult to trace statistically and often perceived as invisible. According to these data, in Italy there are 96,197 registered homeless individuals: 38% are foreign citizens, with over half originating from the African continent. The 50% of registered homeless are concentrated in six municipalities: Rome (23%), Milan (9%), Naples (7%), Turin (4.6%), Genoa (3%), and Foggia (3.7%).

The map in the figure B.2 can be interpreted also as a proxy of housing unaffordability even though it highlights many cases of housing exclusion connected to specific situations in which the presence of precarious and informal settlements is closely linked to the presence of seasonal workers (especially in the agriculture sectors).

Indicator dimensions

Society

Type of indicator

Status

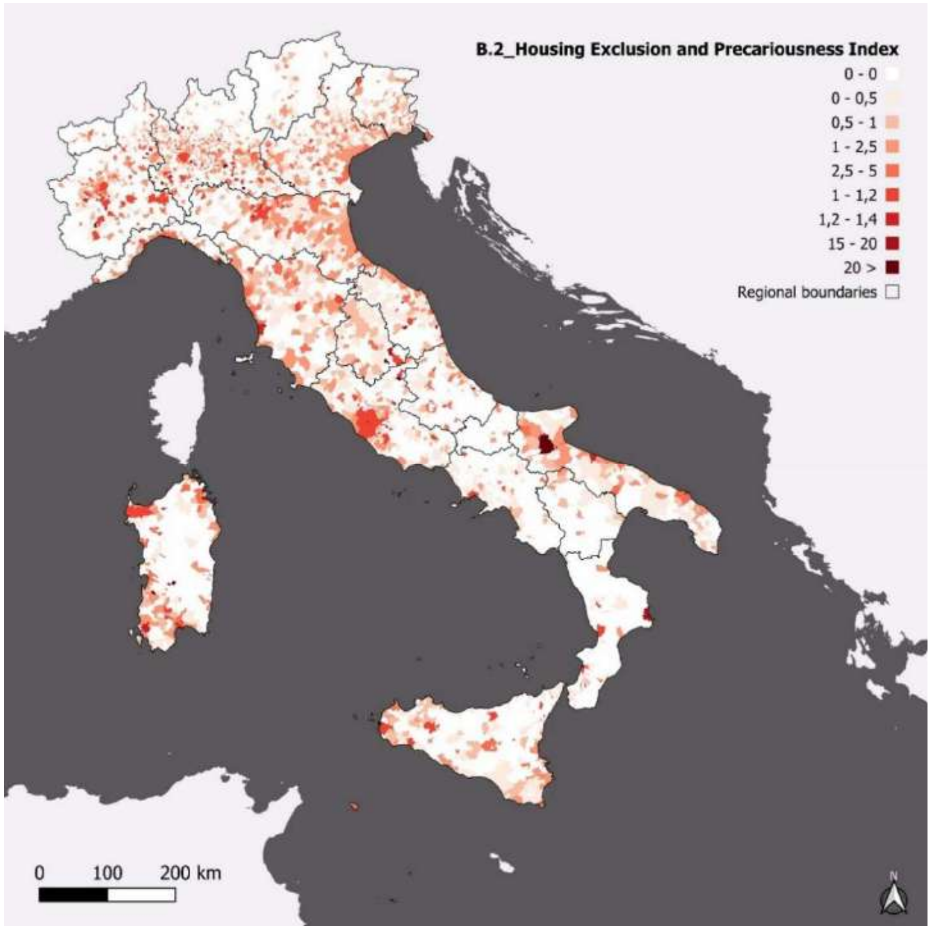

Figure B.2: Housing exclusion and precariousness index calculated at LAU's level

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	SPATIAL LEVEL OF DETAIL	UNIT OF MEASURE	DATA SOURCE
B.2	Housing exclusion and precariousness index	2021	Municipality (LAU)	Num. x 1000 residents	Authors' elaboration
B.2.1	Houseless/roofless people	2021	Municipality (LAU)	Num.	ISTAT
B.2.2	Population living in equipped camps, in tolerated and spontaneous or informal settlements	2021	Municipality (LAU)	Num.	ISTAT

Table B.2/a: Indicators' metadata and sources

Territorial typology	B.2.1	B.2.2	**B.2**	**B.2** (LAUs avg)
1 INNER ITALY	**0**	**754**	**0.24**	**0.16**
1.1.1 - Inner. remote and sparsely populated area	0	254	0.16	0.14
1.1.2 - Inner and remote area with medium population density	0	348	0.37	0.29
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0	61	0.20	0.15
1.2.2 – Inner area with medium population density closest to a metropolitan area	0	91	0.30	0.28
2 INTERMEDIATE ITALY	**7,737**	**35,791**	**1.20**	**0.57**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	171	1,119	0.31	0.27
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	571	3,002	0.61	0.45
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	427	1,721	0.83	0.89
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	2,260	7,653	1.02	0.77
2.2 - Medium-sized city or non-FUA capital	2,537	16,917	2.89	2.68
2.3 - De facto or de jure metropolitan fringe	1,771	5,379	0.96	0.72
3 METROPOLITAN ITALY	**8,033**	**59,652**	**3.47**	**0.83**
3.1 - De facto metropolitan centre	2,082	2,867	2.48	2.46
3.2.1 - De jure and de facto metropolitan area (not capital)	1,767	6,318	0.98	0.71
3.2.2 - Metropolitan capital	4,184	50,467	5.92	3.98

Table B.2/b: Indicator value for each territorial typology.

B.2_ Housing exclusion and precariousness index

Total number of houseless people, roofless people and people living in equipped camps, tolerated and spontaneous or informal settlements per 1000 total inhabitants.

B.2.1_ Houseless/roofless people

Number of houseless people who have established their domicile in the Municipality and roofless people who have no domicile, registered in the registry at a fictitious address or at a real address belonging to an association or in any case used by the Municipality for registration.

B.2.2_ Population living in equipped camps, in tolerated and spontaneous or informal settlements

Number of people living in equipped camps, in tolerated and spontaneous or informal settlements.

3.3 Map B.3 - Index of real estate abandonment due to lack of digital coverage

The investigation into the relationship between the digital divide and the abandonment of real estate assets aims to highlight the vulnerability of areas characterised by poor digital coverage and the resulting dynamics of local community decrease and depopulation. The digital divide is a complex issue involving various factors, from digital literacy to cybersecurity. In this case, the focus is on the dimension related to access to technology and the type of connectivity used to abandon real estate assets. Broadband access is a key factor for the socio-economic development of territories at all scales, enabling the evolution of contemporary telecommunications into general-purpose technologies (Cardona et al., 2013; Majumdar, 2008). With specific attention to territory-related dynamics, the uneven distribution of high-speed broadband can affect economic disparities and growth opportunities, particularly in rural and underserved communities (Lucendo-Monedero et al., 2019). Limiting access to health, cultural, and educational resources and negatively affecting the quality of life and community development incrementally contributes to depopulation. This is closely linked to the abandonment of real estate assets, constituting a significant disadvantage for rural communities and highlighting the need for further structural investments (Ferrandis et al., 2021). High-speed digital expansion is closely correlated with the real economic growth of territories, the persistence of the urban-rural digital divide, and regional differences and disparities. It plays a potential role as a change factor to be considered in rural development policies and, in general, in policies aimed at reducing existing territorial inequalities (de Clercq et al., 2023). The map, based on simple municipal-level indicators of average download speed and the percentage of unoccupied housing assets, subsequently aggregated into a composite indicator, is essential for understanding the status of vulnerable areas and territories (Cerreta & Poli, 2017). It represents a geographic divide that combines unequal access to digital infrastructure with the abandonment of real estate assets related to peripheral territorial contexts.

The evaluation and respective analysis of the index is helpful in detecting a range of damages linked to real estate depreciation, as properties located in areas with poor internet coverage tend to be less desirable due to the lack or scarcity of related services. This results in a reduction in their market value, difficulties in selling or renting, and limitations on economic opportunities for owners. At the same time, areas with inadequate digital infrastructure are subject to lower productive and economic investments, creating a vicious cycle of underinvestment and underutilisation of housing. The index analysis allows for detecting a series of socio-economic shocks related to excluding entire communities from the opportunities offered by digitalisation, such as access to online education, telecommuting, and essential digital services. The lack or scarcity of these services can trigger migratory dynamics towards digitally well-infrastructured areas, leading to the abandonment of real estate and depopulation of less serviced areas. The abandonment of real estate in areas affected by the digital divide correlates with several threats, starting with significant barriers to an area's economic and social development. This has long-term effects on regional growth and prosperity and significant impacts on urban planning related to redevelopment and renovation interventions to attract new residents and businesses. In conclusion, the index thus developed measures a specific territorial vulnerability and serves as a useful tool to guide more informed decisions and proactive strategies against real estate and territorial abandonment.

Indicator dimensions

Economy, Society

Type of indicator

Status

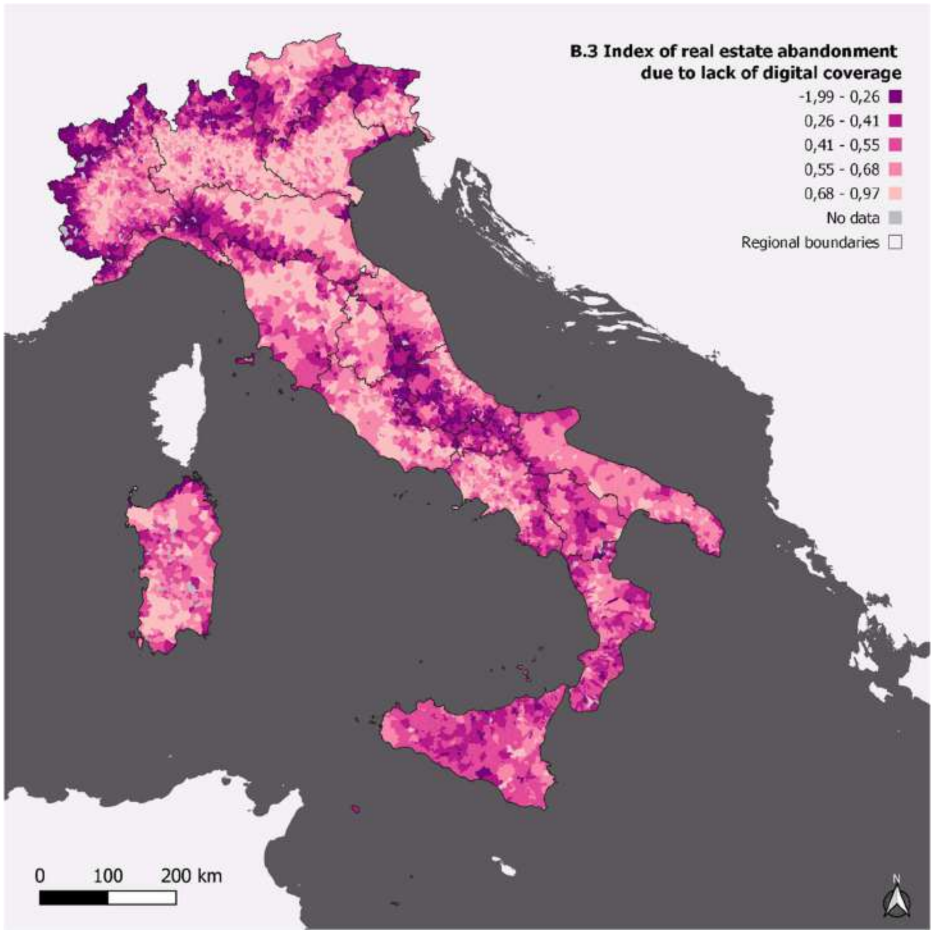

Figure B.3: Index of real estate abandonment due to lack of digital coverage

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
B.3	Index of real estate abandonment due to lack of digital coverage	2021	municipality	normalised 0-1	Author's elaboration
B.3.1	Average download speed	2023	municipality	kbps	Authors' elaboration on Ookla
B.3.2	Percentage of unoccupied dwellings	2021	municipality	%	Authors' elaboration on ISTAT

Table B.3/a: Indicators' metadata and sources.

Territorial typology	B.3.1	B.3.2	**B.3**
1 INNER ITALY	**75,364.92**	**56.06**	**0.37**
1.1.1 - Inner, remote and sparsely populated area	76,690.32	57.67	0.36
1.1.2 - Inner and remote area with medium population density	73,453.65	42.73	0.50
1.2.1 - Sparsely populated inner area closest to a metropolitan area	69,203.51	60.10	0.34
1.2.2 – Inner area with medium population density closest to a metropolitan area	74,829.38	36.98	0.55
2 INTERMEDIATE ITALY	**81,191.16**	**35.16**	**0.56**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	72,767.65	46.83	0.46
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	79,035.42	27.76	0.63
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	89,490.60	28.99	0.60
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	85,501.92	24.34	0.65
2.2 - Medium-sized city or non-FUA capital	138,489.23	20.77	0.62
2.3 - De facto or de jure metropolitan fringe	85,554.02	30.15	0.60
3 METROPOLITAN ITALY	**110,304.94**	**20.71**	**0.65**
3.1 - De facto metropolitan centre	206,558.57	13.30	0.57
3.2.1 - De jure and de facto metropolitan area (not capital)	105,341.26	20.96	0.66
3.2.2 - Metropolitan capital	226,842.52	16.66	0.53

Table B.3/b: Municipality average download speed (year 2023), and percentage of municipal unoccupied dwellings (year 2021).

B.3_ Real estate abandonment due to lack of digital coverage

The index expresses the relationship between the area of real estate without adequate digital coverage and the total area of real estate at risk of abandonment. The mapping operation reveals a scenario where vulnerability, marked by the most intense colours, is distributed across Italy's peripheral and inner areas, highlighting the existing divide and confirming the close relationship between digital coverage and migratory phenomena of expulsion from rural and peripheral territories.

Data normalisation through the MIN-MAX rule (Cerreta et Poli, 2017) has allowed two differing indicators - respectively referred to as B.3.1 and B.3.2 in Table B.3/b - to be compared and, thus, combined into a composite indicator by using the geometric aggregation to avoid full compensation among the variables.

According to each single indicator's direction, indicator values have been maximised or minimised, and the final index was derived by following these steps:

- Maximising the average download speed (B.3.1) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance;
- Minimising the percentage of unoccupied housing stock (B.3.2) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

The composite indicator is calculated by multiplying the single normalised indicators B.3.1 and B.3.2 according to the formula B.3 = (1-xn) *(0+yn),

Where:
Xn represents the normalised value per municipality of average download speed ranging from 0-1;
Yn is the normalised value per municipality of unoccupied dwellings ranging from 0-1.
B.3 is the normalised value ranging from -1 to 1. The inclusion of -1 within this range emphasises and reveals flaws that would have remained unnoticed if the normalisation had been confined to a range of 0 to 1. This method guarantees that certain weaknesses, which may have been hidden while using a 0 to 1 normalisation, are revealed. Therefore, compared to less complex indicators, a result of -1 signifies the utmost level of vulnerability.

B.3.1_ Average download speed

The individual indicator B.3.1 (status indicator, unit of measurement in kbps), pertaining to the average download speed in Italian municipalities, is derived from empirical data collected through the Speedtest by Ookla application (Ookla, last accessed on 05/08/2024). This data presents a scenario where large cities do not face difficulties; conversely, in the nation's peripheral and inner areas, the divide is significant.

B.3.2_ Percentage of unoccupied dwellings

The individual indicator B.3.2 (status indicator, unit of measurement in percentage) represents the ratio of unoccupied dwellings to the total number of dwellings in each Italian municipality (ISTAT, last accessed on 05/08/2024). The mapping reveals a scenario where cities and urban areas are minimally affected by this phenomenon, in stark contrast to the peripheral and inner areas of the country.

3.4 Map B.4 - Tourist pressure on the housing rental market index

The relationship between tourist density and rental prices is examined to highlight the vulnerability of areas affected by the economic, social, and environmental impacts due to rising rental costs or the unavailability of housing caused by their conversion into tourist accommodations. These factors contribute to socio-economic disparities among the population, viewing the real estate market as an indicator of urban sustainable development and a source of information for risk assessment (Antipin et al., 2023).

The effect of increased tourist pressure is more complex than the rise in housing prices due to higher demand. It also exerts pressure on infrastructure, increases congestion and pollution, and lengthens service wait times—all factors capitalised into housing prices (Biagi et al., 2016). The intensification of tourism generates a series of negative sociocultural and environmental impacts (Ahmad et al., 2020), affecting economic vulnerability and income inequalities (Cahn & Than, 2020), and diminishing the ability of local residents to afford housing. This also negatively impacts employment fluctuations, difficulties in maintaining economic status, and income instability in areas subject to seasonal tourist fluctuations (Mikulić et al., 2021). The result is a dynamic of displacement, which forces low and middle-income populations to move to less desirable or inadequate areas. This leads to the alteration and decline of the social and cultural fabric of the community, and the deterioration of the quality of life for permanent residents, who must deal with issues such as increased commuting, traffic congestion, and reduced public spaces. Consequently, these areas become increasingly homogeneous and exclusively oriented towards the needs of visitors.

The map, developed using simple and composite municipal-level indicators, such as the average rental rate of ordinary residences and municipal tourist density, subsequently aggregated into a composite indicator essential for understanding the status of vulnerable areas and territories (Cerreta & Poli, 2017), provides a representation of a territorial divide that reflects the growing socio-economic divide and has direct and immediate consequences on the quality of life of communities.

The developed index serves as a useful tool in identifying territorial damages, including the potential reduction and loss of availability of affordable housing for low- and middle-income residents, forcing them to move to less desirable or inadequate areas due to rising prices. This in turn triggers a dynamic of exacerbating inequalities and socio-economic divides within communities, between those who can afford to stay and those who are compelled to leave. The expulsion of residents from neighbourhoods experiencing rental and property price increases can lead to the disintegration of established communities, eroding the social and cultural fabric that makes these areas unique.

Exclusion in turn generates socio-economic shocks, linked to the rapid transformation of a neighborhood and residents' inability to cope with and sustain the cost of living. It also causes cultural shocks due to the alteration of community identities, leading to the loss of authenticity and attractiveness of the area in the name of tourism homogenisation. These changes generate significant shifts in the perception and use of urban space, making the context more vulnerable. Speculative price increases and the resulting instability of the real estate market can lead to a housing bubble, with potential economic shocks affecting homeowners and investors.

The analysis of the index's vulnerability reveals a series of social, economic, cultural, and environmental threats. The homogenisation of neighborhoods with a predominance of high-income residents due to rising rents can threaten the cultural, economic, and social diversity that often characterises urban areas. The phenomenon of residential displacement also leads to increased commuting, raising transportation times and costs, and contributing to congestion and pollution. The result is a social vulnerability closely linked to displaced families who also face reduced access to essential services such as education, healthcare, and social assistance, which are fundamental to long-term well-being.

Urban transformation processes related to tourism, often incentivised by real estate investments, have profound and complex implications for cities and their inhabitants. The influx of new residents with higher purchasing power leads to an increase in property prices and rents, making it increasingly difficult for long-standing residents to maintain their homes. This alters the demographic composition of neighbourhoods, leading to a loss of cultural identity and social cohesion, and the emergence of tensions between residents and tourists due to the impacts these have on residents' daily lives, such as the rising cost of living, traffic congestion, overcrowded public transportation, and pressure on local services. Moreover, the massive presence of tourists can alter the social fabric of neighbourhoods, leading to the closure of traditional shops and their replacement with businesses catering exclusively to visitors. These dynamics create fertile ground for social tensions: residents may perceive tourists as a threat to their lifestyle and community, while tourists may feel unwelcome or misunderstood.

In conclusion, the developed index proves crucial not only in assessing territorial vulnerabilities but also as a useful tool in guiding inclusive housing policies and urban and tourism development strategies. These aim to create a balance that allows for economic development without sacrificing social cohesion and the cultural identity of local communities. Through an integrated approach, it becomes possible to mitigate negative effects, ensuring livable and welcoming territories for all.

Indicator dimensions

Environment, Economy, and Society

Type of indicator

Pressure

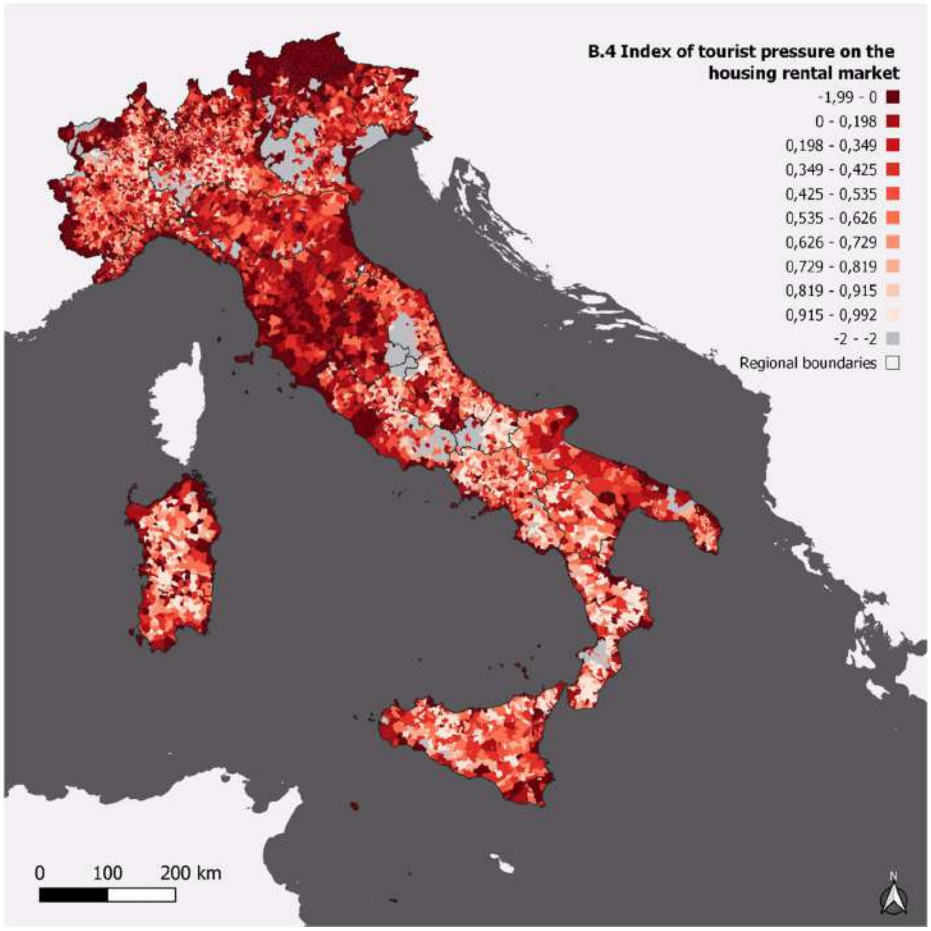

Figure B.4: Index of tourist pressure on the housing rental market.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
B.4	Index of tourist pressure on the housing rental	2020	municipality	normalised 0-1	Author's elaboration
B.4.1	Average rental rate of residential properties (standard)	2020	municipality	Euro/mt^2 x month	Authors' elaboration on Agenzia delle Entrate
B.4.2	Municipal tourist density	2022	municipality	0-5	ISTAT

Table B.4/a: Indicators' metadata and sources.

Territorial typology	B.4.1	B.4.2	**B.4**
1 INNER ITALY	**3.16**	**2.45**	**0.48**
1.1.1 - Inner, remote and sparsely populated area	3.18	2.48	0.47
1.1.2 - Inner and remote area with medium population density	3.48	2.86	0.40
1.2.1 - Sparsely populated inner area closest to a metropolitan area	2.65	1.86	0.60
1.2.2 – Inner area with medium population density closest to a metropolitan area	4.16	3.23	0.33
2 INTERMEDIATE ITALY	**3.47**	**2.31**	**0.48**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	2.92	2.29	0.50
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	3.94	2.51	0.44
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	3.14	1.75	0.58
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	4.30	2.86	0.38
2.2 - Medium-sized city or non-FUA capital	5.48	4.23	0.13
2.3 - De facto or de jure metropolitan fringe	3.71	2.132	0.52
3 METROPOLITAN ITALY	**4.95**	**2.62**	**0.41**
3.1 - De facto metropolitan centre	6.79	4.82	0.03
3.2.1 - De jure and de facto metropolitan area (not capital)	4.80	2.52	0.43
3.2.2 - Metropolitan capital	9.13	4.86	0.48

Table B.4/b: Average rental rate of residential properties (standard), (year 2020) and Municipal tourist density, (year 2022).

B.4_Index of tourist pressure on the housing rental market

The index represents the ratio between the number of nights tourists spend (presences) in municipal accommodation facilities (hotels or other types) per square kilometer of the municipality, and the average rental rate of ordinary residences. The mapping operation reveals a scenario where vulnerability, marked by the most intense colors, is predominantly distributed in cities and tourist destinations, both in the mountains and along the coasts, particularly in certain areas of Tuscany and Trentino Alto Adige.

Data normalisation through the MIN-MAX rule (OECD, 2008) has allowed two differing indicators - respectively referred to as B.4.1 and B.4.2 in Table 8 - to be compared and, thus, combined into a composite indicator by using the geometric aggregation to avoid full compensation among the variables.

According to each single indicator's direction, indicator values have been maximised or minimised, and the final index was derived by following these steps:

- Maximising the average download speed (B.4.1) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance;
- Minimising the percentage of unoccupied housing stock (B.4.2) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

The composite indicator is calculated by multiplying the single normalised indicators B.4.1 and B.4.2 according to the formula B.4 = (1-xn)*(0+yn),
Where:
Xn represents the normalised value per municipality of average download speed ranging from 0-1;
Yn is the normalised value per municipality of unoccupied dwellings ranging from 0-1.
B.4 is the normalised value ranging from -1 to 1. The inclusion of -1 within this range emphasises and reveals flaws that would have remained unnoticed if the normalisation had been confined to a range of 0 to 1. This method guarantees that certain weaknesses, which may have been hidden while using a 0 to 1 normalisation, are revealed. Therefore, compared to less complex indicators, a result of -1 signifies the utmost level of vulnerability.

B.4.1_Average rental rate of residential properties (standard)

The individual indicator B.4.1 (state indicator, unit of measurement in €/mt^2 x month) represents an average value on a municipal basis calculated from the data of the Real Estate Market Observatory of the Italian Ministry of Economy and Finance's Revenue Agency (Agenzia delle Entrate, 2020). The indicator is calculated as a percentage change in the average rental price of civil dwellings over the period from the second half of 2010 to the second half of 2020. The calculation of the average municipal value is obtained from the arithmetic mean between the minimum and the maximum value recorded in all the bands, central and peripheral, of the same municipality. The map reveals not only the divide between cities and surrounding areas but also the disparity between Northern and Southern Italy, including the major islands. Rental rates are significantly lower in the southern regions, particularly in Calabria, Basilicata, Sicily, and Sardinia.

B.4.2_Municipal tourist density

The composite indicator B.4.2 (pression indicator, normalised between {0, 5}), provided by Istat (ISTAT, 2022) measures the "tourism density" of territories. Defined by the aggregation of several simple indices, these measure the presence of tourism infrastructure endowments, the presence of tourist flows, the incidence at the local level of productive activities and employment levels in tourism-oriented sectors of economic activity. The map presents a rather heterogeneous picture, where tourist distribution is primarily concentrated in cities, along the coasts, and in the mountainous areas popular for winter tourism. The regions most affected by tourist density appear to be Tuscany and Trentino Alto Adige.

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4 Dossier C - Vulnerability of agro-forestry capital

Vulnerability is considered the opposite of sustainability, implying a state of "fatal losses" or "disaster risk" (Eakin & Luers, 2006). It can be analysed as the "risk of degradation of abiotic components of the environment," such as air, water, and soil (Kumar, 2024).

The vulnerability of agro-forestry capital can be assessed by evaluating the "risk of degradation" of the benefits it provides as an ecosystem: resilience to climate change, biodiversity conservation, carbon sequestration, soil erosion reduction, and the preservation of traditional agro-silvo-pastoral practices (Afreen et al., 2010). The associated indicators can be described through a state condition, referring to the status of the specific component, and a pressure condition, referring to the forces or factors exerting influence on the agro-forestry component, causing potential changes or degradation.

The topic is analysed across three assets: biodiversity, urbanisation, and investments. The theme of biodiversity relates to wildfires, agro-forestry surface area, and the protected areas of "Natura 2000 sites": Sites of Community Importance (SCIs), Special Protection Areas (SPAs), and Special Areas of Conservation (SACs). The theme of urbanisation is investigated as a pressure on the agricultural component, and land use maps over different time intervals are examined to monitor the erosion of agricultural land.

Investments refer to policies of the National Recovery and Resilience Plan (NRRP), which select and combine measures that address the vulnerability of agro-forestry heritage.

Composite pressure indicators are derived from the combination of state indicators using Geographic Information Systems (GIS) tools, enabling the construction of Spatial Decision Support Systems (SDSS) for subsequent analyses and implementations.

4.1 Map C.1 - Index of ecological transition of agricultural assets

Global urbanisation is one of our time's most significant and transformative phenomena, with profound and extensive implications on a planetary scale. With a rapidly growing urban population estimated to reach 68% by 2050, cities are becoming the epicentre of economic, social, and cultural activity. However, this growth also poses significant challenges for sustainability. Urban expansion entails pollution, biodiversity loss, consumption of land and non-renewable resources, and increased greenhouse gas emissions. Simultaneously, it provides unique opportunities to innovate and implement sustainable solutions to enhance quality of life and reduce environmental impact. The transition towards integrated sustainability necessitates a multidisciplinary and collaborative approach combining urban planning, green technologies, and inclusive policies to construct resilient, livable cities that harmonise with the environment.

The Ecological Transition of Agricultural Assets index measures agricultural production assets' vulnerability to embrace the transition towards sustainable and circular agriculture. The index C.1, is constructed by correlating the investments (in euro) I2.1 (Logistics development for the agri-food, fishery and aquaculture, forestry, floriculture and nursery sectors), I2.2 (Agrisolar park), I2.3 (Modernisation of agricultural machinery), I3.2(Green communities), I3. 3 (Culture and Awareness on Environmental Issues and Challenges) related to the winning projects of NRRP Mission 2 "Green Revolution and Ecological Transition", for the theme of Measure 2 Component 1 (M2C1) "Sustainable Agriculture and Circular Economy" and the total municipal agricultural Surface (TAS) determinate by ISTAT data on 2020.

The dimensions intercepted by the index are the environment and the economy. In detail, the index also aims to investigate certain damages, shocks, and threats that may arise in the transition towards sustainable agriculture. The Italian context faces the challenges posed by the 2030 Agenda Goals, while one of the main threats is the difficulty in adapting existing agricultural practices to more sustainable methods. This challenge is significant for traditional farms or those with limited resources, which may find integrating new technologies and methodologies complex, primarily due to the inability to invest, creating a barrier to adopting sustainable practices. Furthermore, farmers, communities, and consumers may resist change because the benefits of the transition are not immediately visible and may involve very high initial costs.

Additionally, another factor that makes the transition to sustainable agricultural practices even more vulnerable is the potential short-term loss of productivity due to temporary adaptation to both the new techniques implemented and the adaptability of agricultural ecosystems, which may experience a reduction in crop genetic diversity. Emphasising certain more sustainable crop varieties can limit genetic diversity, making crops more vulnerable to diseases and environmental changes. Moreover, modifying agricultural practices can negatively impact the traditional agricultural landscape in some areas, altering local biodiversity and potentially affecting cultural identity. The transition towards sustainable agriculture can also provoke economic, environmental, and political shocks. On the one hand, economically, farms that do not manage to adapt quickly or that face market difficulties due to higher prices of sustainable products may risk bankruptcy. On the other hand, looking at environmental aspects, if the transition is not managed correctly, it could cause shocks such as increased use of water resources for certain sustainable practices or disruption of local ecosystems. Therefore, assessing this sector's

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vulnerability from the government incentives perspective helps identify municipalities that cannot transition to sustainable practices.
The index's representation shows, through a gradient ranging from -1 (high vulnerability) to 1 (low vulnerability), municipalities' vulnerability to moving towards sustainable agriculture due to a lack of or insufficient funding to help small, medium, and large farms move towards ecological agriculture. The mapping operation shows which vulnerability, characterised by the value -1 with a more intense colour (dark blue), highlights a condition of municipalities that currently have a large portion of land area in agricultural use but have not received or have failed to receive incentives to make the agricultural sector more sustainable in ecological and environmental terms. Very few Italian municipalities have almost zero vulnerability [value 1] (colour tending towards white).
The geography that emerges describes two conditions. On the one hand, there are those municipalities that have not received any funding despite having a high percentage of total agricultural land at the municipal level (for example, municipalities in the northern part of Veneto bordering Trentino Alto Adige, in Basilicata, in the province of Arezzo, and, more notably, municipalities in Sardinia and Sicily). The remaining portion, approximately 40% (3206 out of the 7904 municipalities analysed), is in a condition of lesser vulnerability. This represents a context in which the utilised agricultural area at the municipal level has received sufficient funding to promote agricultural development and transition towards ecological farming.

Indicator dimensions

Environment and Economy

Type of indicator

Pression

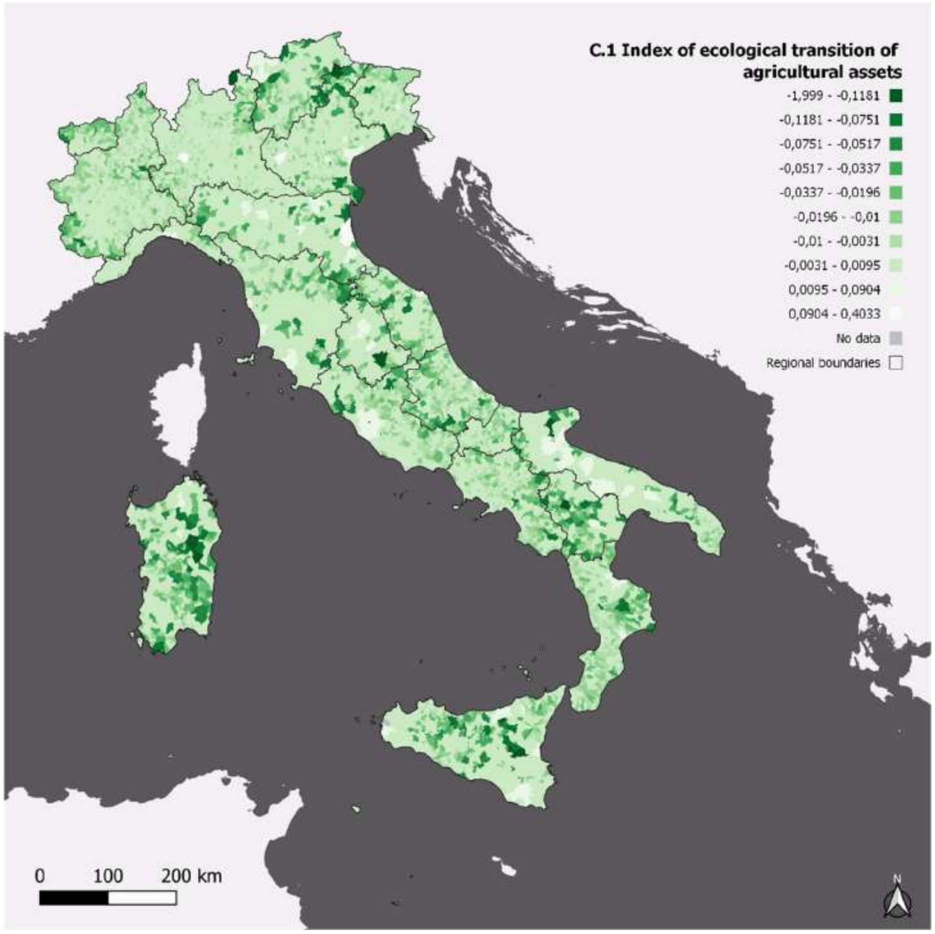

Figure C.1: Index of ecological transition of agricultural assets.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.1	Index of ecological transition of agricultural assets	2020	municipality	Euro/Mt^2 (normalised 0-1)	Author's elaboration
C.1.1	Territorial investment in Sustainable Agriculture and Circular Economy's Measure M2C1 - I2.1, I2.2, I2.3, I3.2, I3.3	2023	municipality	euro	Author's elaboration on OpenCup and OpenPNRR (PNRR Project)
C.1.2	Total Agricultural Surface (TAS)	2020	municipality	Mq	Author's elaboration on ISTAT

Table C.1/a: Informations related to metadata used in the construction of the index C.1.

Territorial typology	C.1.1	C.1.2	**C.1**
1 INNER ITALY	**246,411,930**	**356,638,556**	**-0.010**
1.1.1 - Inner, remote and sparsely populated area	149,349,414	255,885,050	-0.011
1.1.2 - Inner and remote area with medium population density	14,920,392	47,248,063	-0.008
1.2.1 - Sparsely populated inner area closest to a metropolitan area	72,595,594	38,391,612	-0.009
1.2.2 – Inner area with medium population density closest to a metropolitan area	9,546,530	15,113,831	- 0.011
2 INTERMEDIATE ITALY	**1,006,539,788**	**1,143,841,030**	**-0.004**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	321,982,501	364,132,783	-0.006
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	121,346,202	133,617,121	-0.003
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	142,480,475	176,935,234	-0.003
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	181,439,108	217,724,772	-0.004
2.2 - Medium-sized city or non-FUA capital	124,080,576	108,140,590	-0.003
2.3 - De facto or de jure metropolitan fringe	115,210,926	143,290,530	0.000
3 METROPOLITAN ITALY	**107,235,843**	**107,926,990**	**-0.002**
3.1 - De facto metropolitan centre	21,581,724	14,077,999	0.007
3.2.1 - De jure and de facto metropolitan area (not capital)	37,847,787	62,512,283	-0.003
3.2.2 - Metropolitan capital	47,806,332	31,336,708	0.03

Table C.1/b: Territorial investment (in euro) in Sustainable Agriculture and Circular Economy 's Measure M2C1 - I2.1, I2.2, I2.3, I3.2, I3.3 and Total Agricultural Surface (TAS).

C.1_Index of ecological transition of agricultural assets

The index is calculated as the ratio between the investments (in euros) I2.1 (Logistics development for the agri-food, fishery and aquaculture, forestry, floriculture and nursery sectors), I2.2 (Agrisolar park), I2.3 (Modernisation of agricultural machinery), I3.2(Green communities), I3. 3 (Culture and Awareness on Environmental Issues and Challenges) related to the winning projects of PNRR Mission 2 "Green Revolution and Ecological Transition", for the theme of Measure 2 Component 1 (M2C1) "Sustainable Agriculture and Circular Economy" and the total municipal agricultural area. Since the indicator values have a different unit of measurement, it is essential to normalise the data. Data normalisation through the MIN-MAX rule (Cerreta et Poli, 2017) has allowed two differing indicators - respectively referred to as C.1.1 and C.1.2 in C.1/b - to be compared and, thus, combined into a composite indicator by using the geometric aggregation to avoid full compensation among the variables.
According to each single indicator's direction, indicator values have been maximised or

minimised, and the final index was derived by following these steps:

- Maximising the Territorial investment in Sustainable Agriculture and Circular Economy's Measure M2C1 - I2.1, I2.2, I2.3, I3.2, I3.3 (C.1.1) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance;
- Minimising the total agricultural surface (C.1.2) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

The composite indicator is calculated by multiplying the single normalised indicators C.2.1 and C.2.2 according to the formula $C.2 = (1-x_n)(0+y_n)$, where:

- X_n represents the normalised value per Territorial investment in Sustainable Agriculture and Circular Economy's Measure M2C1 - I2.1, I2.2, I2.3, I3.2, I3.3 ranging from 0-1;
- Y_n is the normalised value per Total agricultural surface ranging from 0-1.

The index C.1 is the normalised value ranging from -1 to 1. Including -1 within this range emphasises and reveals flaws that would have remained unnoticed if the normalisation had been confined to a range of 0 to 1. This method guarantees that specific weaknesses, which may have been hidden while using a 0 to 1 normalisation, are revealed. Therefore, compared to less complex indicators, -1 signifies the utmost level of vulnerability. When $X_n=0$ and $Y_n>0$, C.1 will have values [-1,0] than even when Y_n is high.

C.1.1_Indicator of Territorial Investment in Sustainable Agriculture and Circular Economy 's Measure M2C1 - I2.1, I2.2, I2.3, I3.2, I3.3

The indicator is constructed by summing up the amounts in euros related to the winning projects of the PNRR's Mission 2, "Green Revolution and Ecological Transition", for the theme of Measure 2 Component 1 (M2C1) "Sustainable Agriculture and Circular Economy" concerning investments I2.1, I2.2, I2.3, I3.2, I3.3 on land area. Subsequently, the indicator was maximised, through the MIN-MAX rule (Cerreta et Poli, 2017), within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

C.1.2_Indicator of Total Agricultural Surface (TAS)

The indicator was calculated by associating, for each municipality, the total agricultural area on the ISTAT survey of the 7th General Census of Agriculture for the agricultural year 2019/2020 with the observation unit referring to the farm, as defined in Reg. (EU) 2018/1091 of the European Parliament and of the Council (ISTAT, 2020). Subsequently, the indicator was minimised, through the MIN-MAX rule (Cerreta et Poli, 2017), within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

4.2 Map C.2 - Sustainable agricultural index for water resources

The global urbanisation process of recent times has made it crucial to sustainability goals within urban regions, promoting strategies to create more sustainable cities, using effective techniques and evaluating progress towards sustainable urban growth (Newman & Jennings, 2008; Wu, 2010). In this context, it becomes crucial to identify those tools that enable cities to aim for a process aimed at achieving their sustainability. The theme of sustainable development in the economic, social and environmental dimensions is at the heart of the United Nations Agenda 2030 (Ginson, 2011; Singh et al., 2012) and among the various Sustainable Development Goals, many can be linked to the different areas of development that will match the missions provided by the National Recovery and Resilience Plan (NRRP), a governance and policy tool that addresses the different themes of the ecological transition and the statistical indicators associated with it, as well as the evaluations on the effectiveness of the programming implemented by the NRRP to pursue it in practice. Given the evolution of the concept of sustainability, the emergence of new statistical data (Rotondo et al., 2022) lays the basis for analysing the Italian contexts and their progress towards sustainability themes by constructing indicators that fully reflect the economic characteristics of environmental issues. Ecological sustainability, hydraulic hazard management strategies, and investment allocation policies are increasingly important in climate change and current environmental challenges. Hydraulic hazards, which include extreme events such as floods and droughts, pose significant threats to agriculture, affecting food production, water security, and the economic stability of cities. Floods, salinisation of the soil and restrictions on access to agricultural areas pose significant risks that can undermine farm production and the resilience of communities.

The Sustainable Agricultural Index for Water Resources aims to measure the vulnerability of the agroforestry heritage to the harmful effects and damage generated by hydrogeological hazards. The index C.2, is constructed by correlating the investments (in euro) I2.1 (Simplification and acceleration of procedures for the implementation of interventions against hydrogeological disaster), I3.3 (Renaturation of the Po area), I4.1 (Investments in primary water infrastructure for water security), I4.2 (Reduction of leaks in water distribution networks, including digitisation and monitoring of networks), I4.3 (Investments in the resilience of the irrigation agro-system for better management of water resources) envisaged by the NRRP for Mission 2, "Green Revolution and ecological Transition" for the theme "Protection of Territory and Water Resource" (measure 2, component 4 – M2C4) and the Copernicus agricultural area (from the code 211 to 244) affected by the hydraulic hazard (ISPRA).

The dimensions intercepted by the index are the environment and the economy. The index's representation shows, through a gradient ranging from -1 (high vulnerability) to 1 (low vulnerability), the municipalities that are more vulnerable in economic terms than the municipal agricultural land affected by flooding events (hydraulic hazard).

The latter constitutes one of the main threats to agriculture, as they alter the quality of the soil (either through its erosion or as a result of sediment deposits from strangulation or the resulting phenomenon) and make the land less fertile and more difficult to cultivate in the future, leading to massive economic losses and affecting not only farmers' incomes but also the entire food supply chain, resulting in a potential increase in food prices and a decrease in food security at the local and regional levels. In particular, small agricultural communities are vulnerable because they do not have the necessary resources for recovery and prevention, making them more susceptible to extreme events in the future.

Furthermore, saltwater penetration can increase soil salinity during high tide events or floods in coastal areas or near saltwater sources, further aggravating the vulnerability in regions where freshwater resources are already scarce. In addition to crop loss, hydraulic events can cause long-term environmental degradation. Soil erosion, the loss of natural habitats, and the alteration of hydrological cycles are negative impacts that affect ecosystems, reducing biodiversity and undermining the territory's capacity to support agriculture and other human activities.

Another issue is the damage such events can cause to major agricultural infrastructures (roads, irrigation, and drainage systems) by limiting agricultural production's recovery and recovery capacity. Reconstruction and repair require considerable time and resources, aggravating communities' economic difficulties.

The mapping operation shows in which vulnerability, characterised by the value -1 with a more intense colour (dark blue), highlights a condition in Italy in which about 70% of the municipalities that currently have agricultural land affected by hydraulic hazards have not received or have not been successful in making useful investments to protect the territory and to compensate for the damage or threats generated by hydraulic hazards. Very few Italian municipalities have almost no vulnerability [value 1] (colour tending towards white). The latter reflects two conditions in Italy. On the one hand, some municipalities have not received investments but, at the same time, do not have an agricultural surface area affected by hydraulic hazard, or they are municipalities that have received investments commensurate with the municipal, agricultural surface area affected by the hydraulic hazard.

Indicator dimensions

Environment and Economy

Type of indicator

Pressure

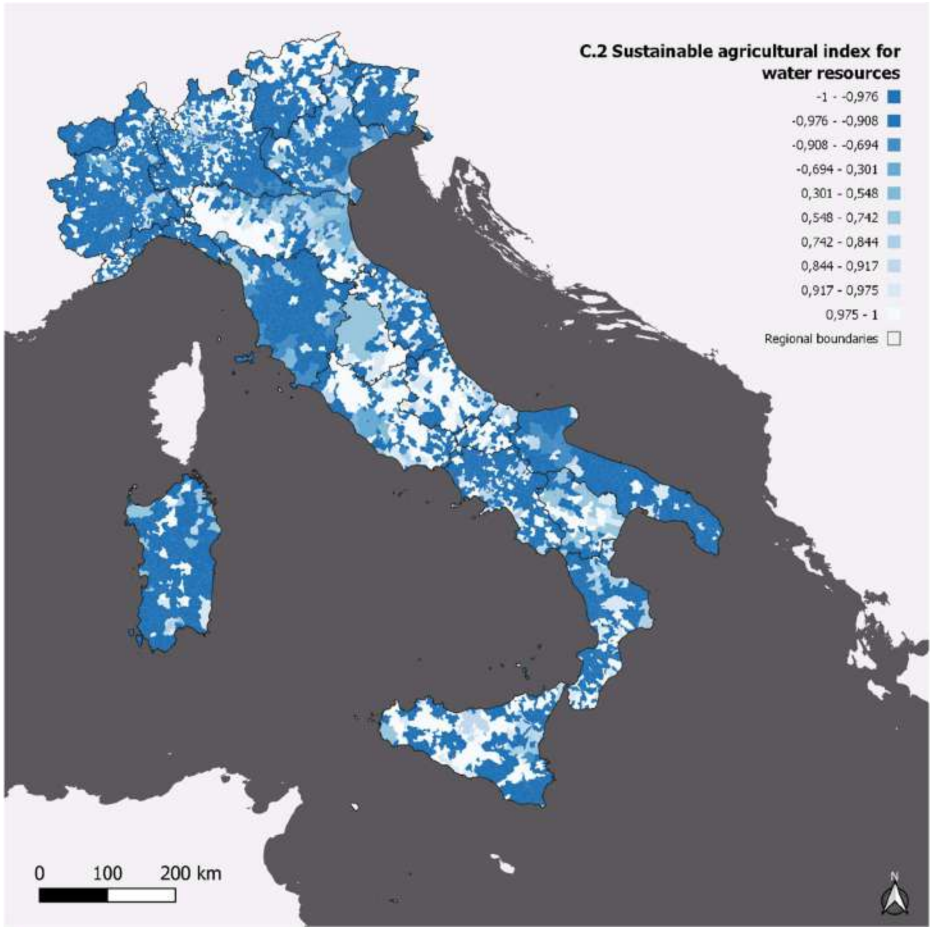

Figure C.2: Sustainable agricultural index for water resources.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.2	Sustainable agro-forestry index for water resources	2020	municipality	Euro/Mt² (normalised 0-1)	Authors' elaboration
C.2.1	Territorial investment for Territory and Water Resource Protection's measures M2C4 - I2.1, I.3.3, I4.1, I4.2, I4.3	2020-2023	municipality	Euro	Authors' elaboration on OpenCup and OpenPNRR (PNRR Project)
C.2.2	Hydraulic hazard in agricultural contexts	2020	municipality	Mt²	Authors' elaboration on ISPRA Copernicus (Corine Land Cover - CCL)

Table C.2/a: Informations related to metadata used in the construction of the index C.2.

Territorial typology	C.2.1	C.2.2	**C.2**
1 INNER ITALY	**2,784,537,961**	**1,626,574,325**	**-0.156**
1.1.1 - Inner, remote and sparsely populated area	1,829,687,895	1,046,776,175	-0.180
1.1.2 - Inner and remote area with medium population density	640,776,558	360,675,008.6	-0.369
1.2.1 - Sparsely populated inner area closest to a metropolitan area	218,601,340	127,327,674.4	0.100
1.2.2 – Inner area with medium population density closest to a metropolitan area	95,472,168	91,795,466.84	0.009
2 INTERMEDIATE ITALY	**18,616,628,965**	**26,571,845,722**	**-0.350**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	3,323,079,547	2,815,835,143	-0.293
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	2,566,264,898	1,467,689,607	-0.317
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	1,280,943,906	8,201,091,334	-0.572
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	3,032,312,328	7,103,695,552	-0.361
2.2 - Medium-sized city or non-FUA capital	560,143,053	2,728,030,038	-0.061
2.3 - De facto or de jure metropolitan fringe	7,853,885,233	4,255,504,048	-0.300
3 METROPOLITAN ITALY	**4,446,777,680**	**2,890,029,816**	**-0.254**
3.1 - De facto metropolitan centre	204,452,530	535,078,058.9	0.260
3.2.1 - De jure and de facto metropolitan area (not capital)	3,951,135,837	2,030,797,865	-0.271
3.2.2 - Metropolitan capital	291,189,313	324,153,892.5	0.015

Table C.2/b: Territorial investment for Territory and Water Resource Protection measures M2C4 - I2.1, I.3.3, I4.1, I4.2, I4.3 and Hydraulic hazard in agricultural contexts.

C.2_Sustainable agro-forestry index for water resources

The C.2 index was obtained by comparing the total amounts of NRPP investments - retrieved from the OpenCup and Open NRPP open data - and the agricultural area with hydraulic hazard.
Since the indicator values have a different unit of measurement, it is essential to normalise the data. Data normalisation through the MIN-MAX rule (Cerreta et Poli, 2017) has allowed two differing indicators - respectively referred to as C.2.1 and C.2.2 in Table C.2/b - to be compared and, thus, combined into a composite indicator by using the geometric aggregation to avoid total compensation among the variables.
According to each single indicator's direction, indicator values have been maximised or minimised, and the final index was derived by following these steps:

- Maximising the Territorial investment for Territory and Water Resource Protection's measures M2C4 - I2.1, I.3.3, I4.1, I4.2, I4.3 (C.2.1) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance;

- Minimising the Hydraulic hazard in agricultural contexts (C.2.2) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

The composite indicator is calculated by multiplying the single normalised indicators C.2.1 and C.2.2 according to the formula $C.2 = (1\text{-}x_n)(0+y_n)$,
Where:

- X_n represents the normalised value per Territorial investment for Territory and Water Resource Protection's measures M2C4 - I2.1, I.3.3, I4.1, I4.2, I4.3 ranging from 0-1;
- Y_n is the normalised value per Hydraulic hazard in agricultural contexts ranging from 0-1

C.2 is the normalised value ranging from -1 to 1. Including -1 within this range emphasises and reveals flaws that would have remained unnoticed if the normalisation had been confined to a range of 0 to 1. This method guarantees that certain weaknesses, which may have been hidden while using a 0 to 1 normalisation, are revealed. Therefore, compared to less complex indicators, -1 signifies the utmost level of vulnerability. In particular, when $X_n=0$ and $Y_n>0$, C.2 will have values [-1,0] than even when Y_n is high.

C.2.1_Indicator of territorial investment for Territory and Water Resource Protection's measures M2C4 - I2.1, I.3.3, I4.1, I4.2, I4.3

The indicator is constructed by summing up, for each municipality, the investment amounts of the winning projects for the theme of Measure 2 Component 4 (M2C4) "Protection of Land and Water Resources" of the NRPP. Subsequently, the indicator was maximised, through the MIN-MAX rule (Cerreta & Poli, 2017), within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

C.2.2_Indicator of Hydraulic hazard in agro-forestry contexts

The indicator captures the municipal, agricultural area affected by low flood hazard (P1). This was constructed by intersecting the agricultural surface area at the municipal level with the Corine Land Cover codes of Copernicus (from 211 to 244) and the hydraulic hazard provided by ISPRA. Subsequently, the indicator was minimised, through the MIN-MAX rule (Cerreta & Poli, 2017), within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

4.3 Map C.3 - Index of agro-forestry biodiversity loss due to fires

The index of agro-forestry biodiversity loss due to fires describes the impact of fires on biodiversity in protected areas, determined by the reduction of agro-forestry cover. As a consequence of climate change, wildfires are becoming an increasingly significant environmental issue, affecting agro-forestry resources in all their multiple functions with substantial economic and ecological damage (Lavecchia & Pietramellara, 2012). On average, fires affect 107,000 hectares of land annually, representing one of the main risk factors for the services provided by forests (Ascoli et al., 2022). In addition to direct causes such as drought and global warming, soil erosion and the weakening of forest ecosystems due to pollution make agro-forestry resources more susceptible to the risk of fires. Strongly associated with extreme weather conditions (Ruffault et al., 2018), the damage increases further when protected areas are affected, which are delicate balances: biodiversity reserves where already vulnerable ecosystems and species are present.

Protected areas are more exposed to the risk of fire. In fact, 41% of the burnt area in Europe in 2022 was within the boundaries of Natura 2000 sites, and in 2021 in Italy, over 25,000 hectares of protected areas were affected by fires, equal to a quarter of all protected areas burned in the rest of the European Union (San-Miguel-Ayanz et al., 2023). Soil degradation also makes natural regeneration more difficult and jeopardises future agricultural production. Besides the destruction of habitats and the death of plant and animal species, the damage also affects the agro-forestry landscape heritage and the ability of ecosystems to regenerate, reducing ecological resilience and increasing the likelihood of other threats such as diseases and pests.

The index considers biodiversity exposure as the portion of territory where the land use classification corresponds to categories of natural vegetation (Mastachi-Loza et al., 2024). These have been interpreted as agro-forestry land, extracted from the CORINE Land Cover by Copernicus with codes from 211 to 324, and associated with protected areas of "Natura 2000 sites": Sites of Community Importance (SCIs), Special Protection Areas (SPAs), Special Areas of Conservation (SACs).

The dimensions intercepted by the index are the environment and the landscape. The damage associated with this vulnerability includes the loss of vegetative cover, agro-forestry productivity, and the landscape values of natural and rural areas. The shocks affect ecosystem alteration, habitat loss, ecological niches, as well as microclimatic changes and carbon storage due to the loss of vegetative cover. The landscape dimension is also associated with the impact on local communities, who depend on agro-forestry resources, with repercussions on tourism and the aesthetic-recreational value of the landscape. The threats concern the reduction of ecosystem resilience and increased vulnerability to future fires and other environmental threats. In particular, the potential for harmful events related to these threats affects the regeneration capacity of native vegetation, their exposure to diseases and pests, opportunities for invasive species to colonise burned areas, and the increased risk of erosion and landslides following the loss of vegetative cover.

Indicator dimensions

Environment and Landscape

Type of indicator

Pressure

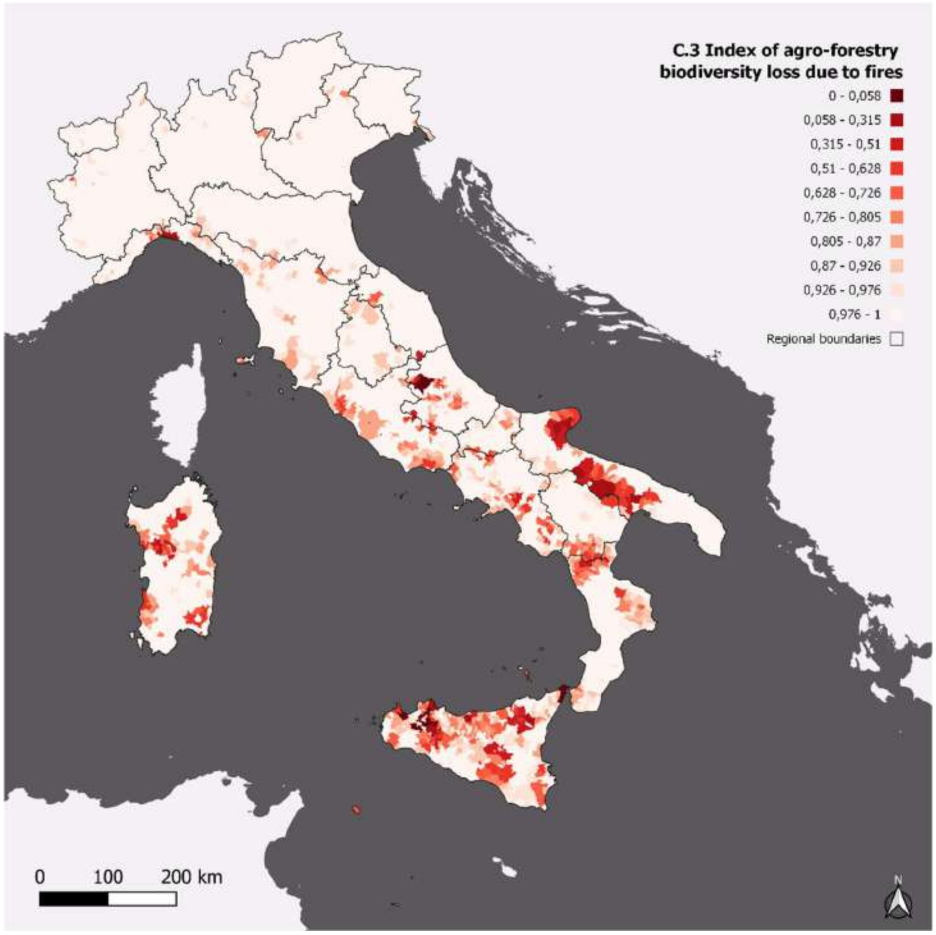

Figure C.3: Index of agro-forestry biodiversity loss due to fires.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.3	Index of agro-forestry biodiversity loss due to fires	2000 - 2021	municipality	% (normalised 0-1)	Author's elaboration
C.3.1	Indicator of Surface area affected by fires from 2000 to 2023	2000 - 2023	municipality	Mt^2	Author's elaboration on European Environment Agency / Sinanet
C.3.2	Indicator of Agro-forestry surface area in protected areas	2000 - 2021	municipality	Mt^2	Author's elaboration on Copernicus

Table C.3/a: Informations related to metadata used in the construction of the index C.3.

Territorial typology	C.3.1	C.3.2	**C.3**
1 INNER ITALY	**139,311,171.7**	**4,316,905.21**	**0.982**
1.1.1 – Inner, remote and sparsely populated area	109,423,574.3	3,355,542.03	0.982
1.1.2 – Inner and remote area with medium population density	10,125,841.51	350,425.88	0.990
1.2.1 – Sparsely populated inner area closest to a metropolitan area	17,351,376.11	537,515.97	0.979
1.2.2 – Inner area with medium population density closest to a metropolitan area	2,410,379.77	73,421.33	0.985
2 INTERMEDIATE ITALY	**576,111,021.2**	**19,697,423.73**	**0.980**
2.1.1.1 – Sparsely populated mountain/inland hill urban-rural continuum	227,088,092.4	7,572,574.66	0.979
2.1.1.2 – Mountain/inland hill urban-rural continuum with medium population density	83,883,311.29	2,862,665.99	0.982
2.1.2.1 – Sparsely populated coastal and/or lowland urban-rural continuum	108,465,064.4	3,701,426.79	0.979
2.1.2.2 – Coastal and/or plain urban-rural continuum with medium population density	67,008,024.43	2,717,766.81	0.980
2.2 – Medium-sized city or non-FUA capital	11,570,330.32	373,201.90	0.964
2.3 – De facto or de jure metropolitan fringe	78,096,198.43	2,469,787.58	0.985
3 METROPOLITAN ITALY	**41,929,783.69**	**1,477,488.89**	**0.988**
3.1 – De facto metropolitan centre	2,891,385.77	47,127.06	0.958
3.2.1 – De jure and de facto metropolitan area (not capital)	38,074,585.21	1,426,792.59	0.988
3.2.2 – Metropolitan capital	963,812.70	3,569.24	1

Table C.3/b: Surface area affected by fires (age 2000-2023) and Agro-forestry surface area in protected areas (age 2023)

C.3_ Index of agro-forestry biodiversity loss due to fires

Ratio between the protected agro-forestry surface area in protected areas and the protected agro-forestry surface area affected by fires.

Since the indicator values have a different unit of measurement, it is essential to normalise the data. Data normalisation through the MIN-MAX rule (Cerreta & Poli, 2017) has allowed two differing indicators - respectively referred to as C.3.1 and C.3.2 in Table C.3/b to be compared and, thus, combined into a composite indicator by using the geometric aggregation to avoid full compensation among the variables.

According to each single indicator's direction, indicator values have been maximised or minimised, and the final index was derived by following these steps:

- Maximising the Territorial investment in Sustainable Agriculture and Circular Economy's Measure M2C1 - I2.1, I2.2, I2.3, I3.2, I3.3 (C.3.1) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance;

- Minimising the total agricultural surface (C.3.2) within the range {0;1}, where 0 corresponds to the worst performance and 1 to the best performance.

The composite indicator is calculated by multiplying the single normalised indicators C.3.1 and C.3.2 according to the formula $C.3= (1-x_n)(0+y_n)$, where:

- X_n represents the normalised value per Territorial investment in Sustainable Agriculture and Circular Economy's Measure M2C1 - I2.1, I2.2, I2.3, I3.2, I3.3 ranging from 0-1;
- Y_n is the normalised value per Total agricultural surface ranging from 0-1.

The index C.3 is the normalised value ranging from -1 to 1. Including -1 within this range emphasises and reveals flaws that would have remained unnoticed if the normalisation had been confined to a range of 0 to 1. This method guarantees that specific weaknesses, which may have been hidden while using a 0 to 1 normalisation, are revealed. Therefore, compared to less complex indicators, -1 signifies the utmost level of vulnerability. In particular, when $X_n=0$ and $Y_n>0$, C.3 will have values [-1,0] than even when Y_n is high.

C.3.1_ Indicator of Surface area affected by fires from 2000 to 2023

This data measures the extent of the areas directly affected by fires.

C.3.2_ Indicator of Agro-forestry surface area in protected areas

Total protected agro-forestry surface area: Sites of Community Importance (SCIs), Special Protection Areas (SPAs), Special Areas of Conservation (SACs).

4.4 Map C.4 - Index of agricultural surface erosion due to urbanisation processes

The vulnerability examined by the agricultural land surface erosion index due to urbanisation processes investigates and checks the anthropisation processes of the territory related to urban expansion dynamics in agricultural contexts. The loss of agricultural land is a trend that continues regularly. In fact, even in the latest national monitoring by SNPA, it is confirmed that soil consumption dynamics have primarily affected agricultural areas, with reference to arable land, where over 40% of the changes have been concentrated (Munafò, 2023). Urbanisation processes negatively affect agricultural activities (Agostini, 2014). The increase in urbanisation makes it even more essential to protect non-urbanised areas, which produce useful services for the ecosystem, such as pollution reduction, microclimate regulation, carbon sequestration and oxygen production (La Rosa and Privitera, 2013).

The dimensions intercepted by the index concern the economy, the environment, and the landscape. Attention to the economic dimension highlights the soil's vital role in agricultural production. However, the soil is crucial for the long-term environmental sustainability of an area (Pagnotta et al., 2014). To preserve the environmental functions of the soil, it is essential to optimise the relationship between urban and agricultural areas, maintaining an adequate balance (Setälä et al., 2014). This topic opens up the multifunctional approach of agriculture as a producer of public goods and positive externalities for the environment (De Nuccio & Monteduro, 2020; Magnaghi, 2010; Henke et al., 2008), integrating the productive aims of rural development with the sustainable management of resources, the safeguarding of the environment, and the agricultural landscape.

The decrease in agricultural land surface is not limited solely to the theme of production on the economic level but has repercussions on environmental challenges, considering the cultural and intra/intergenerational aspects typically linked to sustainable processes (Ronconi, 2014). The related damages concern the loss of soil productivity and vegetative cover, changes in water flows, reduction of food security, and the compromise of the cultural landscape as an expression. The shocks, definable as immediate impacts, are attributable to the compromise of the agricultural production system, land-use conflicts, and exposure to extreme weather events. The territory is thus more vulnerable to threats of loss of agricultural heritage, increase in land costs, and fragmentation of the agricultural landscape. In particular, the latter generates a reduction in ecological connectivity, territorial resilience, the capacity of habitats to provide ecosystem services, increases the isolation of species and their ability to access resources, affecting the quality and value of the landscape (as defined by Article 131 of the Cultural Heritage and Landscape Code) and the costs of agricultural activity (Munafò, 2023).

The vulnerability was investigated using the CORINE Land Cover of Copernicus-Land Monitoring Services to produce a spatial index that allows the investigation of urban expansion dynamics in the continuation of the research. The CORINE Land Cover categories used for urbanised areas are as follows: continuous urban fabric (111), discontinuous urban fabric (112), industrial or commercial units (121), road and rail networks and associated land (122), port areas (123), airports (124), mineral extraction sites (131), dump sites (132), construction sites (133), and sport and leisure facilities (142). The CORINE Land Cover categories used for agricultural land are as follows: non-irrigated arable land (211), permanently irrigated land (212), rice fields (213), vineyards (221), fruit trees and berry plantations (222), olive groves (223), pastures (231), annual crops associated with permanent crops (241), complex cultivation patterns (242), land principally occupied by agriculture with significant areas of natural vegetation (243), and agro-forestry areas (244).

Indicator dimensions

Economy, Environment and Landscape

Type of indicator

Pressure

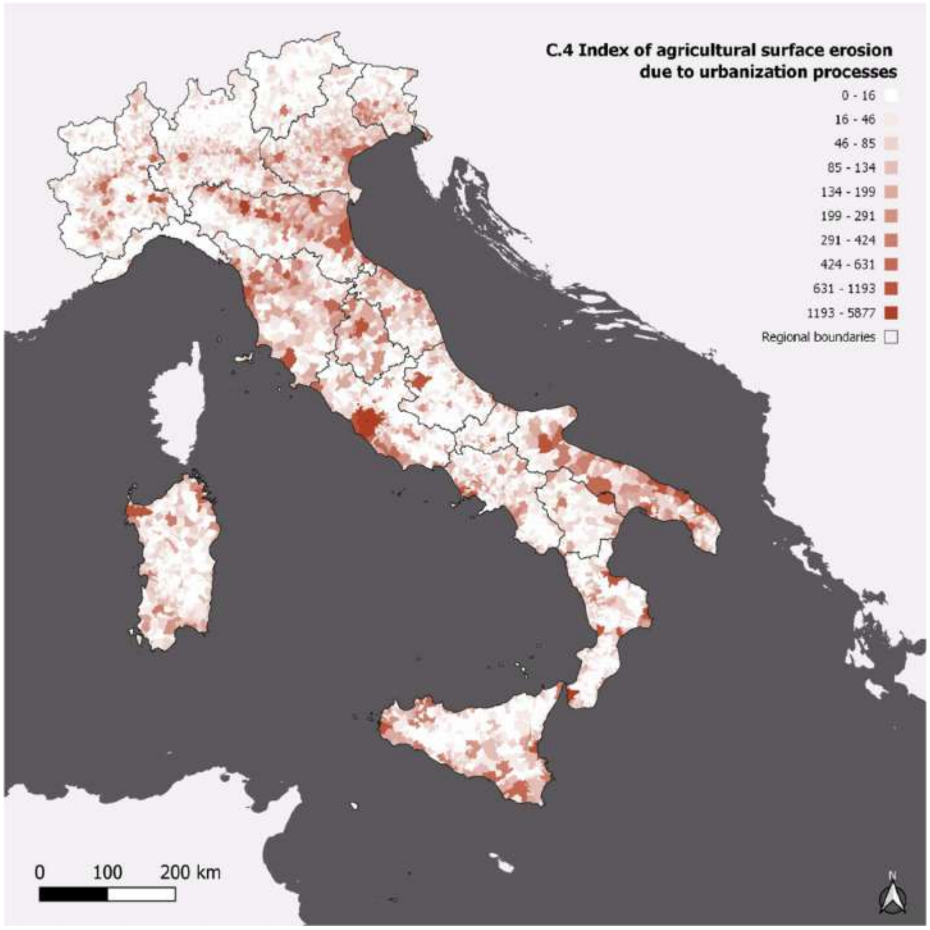

Figure C.4: Index of agro-forestry biodiversity loss due to fires.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.4	Index of agricultural surface erosion due to urbanisation processes	1990 - 2018	Municipality (land use)	Ha	Author's elaboration
C.4.1	Surface area covered by agricultural areas	1990	Municipality (land use)	Ha	Author's elaboration on Copernicus - Land Monitoring Service
C.4.2	Surface area covered by urbanised areas	2018	Municipality (land use)	Ha	Author's elaboration on Copernicus - Land Monitoring Service

Table C.4/a: Informations related to metadata used in the construction of the index C.4.

Index of agricultural surface erosion due to urbanisation processes	C.4.1	C.4.2	**C.4**
1 INNER ITALY	**2,529,632**	**108,186**	**39.66%**
1.1.1 - Inner, remote and sparsely populated area	1,634,424	59,608	31.09%
1.1.2 - Inner and remote area with medium population density	450,544	32,139	118.70%
1.2.1 - Sparsely populated inner area closest to a metropolitan area	312,624	9,249	21.97%
1.2.2 – Inner area with medium population density closest to a metropolitan area	132,040	7,190	99.96%
2 INTERMEDIATE ITALY	**12,066,673**	**1,170,769**	**100.78%**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	3,191,450	149,783	40.31%
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	1,378,261	196,640	100.48%
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	2,102,646	120,203	79.85%
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	2,664,651	323,286	220.29%
2.2 - Medium-sized city or non-FUA capital	1,097,317	169,363	822.83%
2.3 - De facto or de jure metropolitan fringe	1,632,348	211,494	101.40%
3 METROPOLITAN ITALY	**1,182,685**	**356,585**	**236.16%**
3.1 - De facto metropolitan centre	131,090	46,721	1,606.79%
3.2.1 - De jure and de facto metropolitan area (not capital)	900,448	183,245	159.30%
3.2.2 - Metropolitan capital	151,147	126,619	2,140.09%

Table C.4/b: Surface area affected by fires (age 2000-2023) and Agro-forestry surface area in protected areas (age 2023)

C.4_Index of agricultural surface erosion due to urbanisation processes

Intersection of agricultural land cover since 1990 with urbanised area as of 2018.

C.4.1_Surface area covered by agricultural areas

The indicator measures the total agricultural surface area in each municipality as recorded in 1990 by Corine Land Cover

C.4.2_Surface area covered by urbanised areas

The indicator measures the total agricultural surface area in each municipality as recorded in 2018 by Corine Land Cover.

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5. Dossier D - Vulnerability from natural phenomena (landslide and earthquake)

This contribution aims to define GRINS indicators related to the occurrence of natural phenomena, specified at the national scale, necessary for the creation of interactive maps depicting local vulnerability.
The effects resulting from a disturbance (natural or anthropogenic event) can be expressed through the quantification of risk, *R*, as per Equation (DPC, 2018):

$$R = P \cdot V \cdot E \tag{0.1}$$

The individual risk components are explained as follows:

- *P* represents hazard: the probability that a phenomenon of a certain intensity will occur within a specific period of time and in a given area.
- *V* signifies vulnerability: the susceptibility of an element (such as people, buildings, infrastructure, economic activities, or natural systems) to sustain damage as a result of the stresses induced by an event of a certain intensity.
- *E* denotes exposure or exposed value: the number of units (or "value") of each at-risk element present in a given area, such as human lives or settlements.

Given that one of the objectives of this project is the production of interactive maps at a local scale, it is important to focus on the characteristics of these maps. The attributes "interactive" and "local" require that these maps be generated from disaggregated data so that they can be queried at multiple scales and provide aggregated results according to user needs. In this regard, it is interesting to note that maps of hazard and exposure to natural events are available for the entire national territory with different resolutions as described below:

- landslides (slope instability), variable extent polygons;
https://idrogeo.isprambiente.it/app/page/open-data
- earthquake (seismic hazard), cell size 400 m x 400 m;
https://data.mendeley.com/datasets/jywfbwxmzs/1
- buildings (volume and height), cell size 90 m x 90 m;
https://download.geoservice.dlr.de/WSF3D/files/global/

The following chapters describe the maps of indicators derived from landslide hazard and seismic hazard.

5.1 Map D.1 – Indicator of exposed buildings to landslide hazard at municipal scale

The term landslide refers to a movement of rock, earth, or debris along a slope (Brown et al., 1992; Cruden & Varnes, 1996). A series of predisposing and triggering factors can be recognized for landslide events. Predisposing factors are intrinsic characteristics of the study area, such as surface morphology or the physic-mechanical properties of the geological materials underlying the area. Triggering factors, on the other hand, are natural or anthropogenic disturbances (*e.g.*, rainfall, road cutting) that disrupt slope equilibrium and initiate irreversible movement. Analysing these factors can help characterize landslide hazard quantitatively or qualitatively, depending on the level of detail with which the factors can be quantified. Typically, the larger the study area, the lower the level of detail. The Italian Institute for Environmental Protection and Research (ISPRA) produced the report on hydrogeological instability in Italy (Trigila et al., 2021) which presents new national landslide and flood hazard maps based on data provided by the River Basin Authorities (Autorità di Bacino Distrettuali in Italian). Different methods can be applied at varying levels of detail and integrated to define landslide hazard. For example, a 1:10,000 scale detail level may involve classifying landslides in the inventory as very high, high, or moderate hazard based on movement type and activity status, while a 1:25,000 scale detail level may assess susceptibility in remaining non-landslide areas based on geomorphological and lithological criteria.

ISPRA releases the new national landslide hazard maps following data standardization from River Basin Authorities. The hazard maps classify the territory into five landslide hazard zones (from P0 to P4) based on representative parameters of potential landslide movement: velocity, geometric severity (*e.g.*, depth of landslide body in case of slides), activity status, and probable frequency. For further details on analysis methods, refer to the ISPRA report (Trigila et al., 2021).

ISPRA also proposes indicators resulting from the overlay of the landslide hazard layer and the exposure layer. In particular, the following aspects need to be considered:

1) only polygons classified as hazard levels P3 and P4 in the ISPRA mapping are selected;
2) ISTAT census sections from the 2011 census are included. Within each section, a uniform distribution of the number of buildings is assumed. However, this methodology provides a good estimate of the exposure layer only if the building stocks are evenly distributed within the census section;
3) the vulnerability of the exposed element is assumed to be 1. Therefore, any element within a P3 or P4 risk area is considered to experience total loss.

Therefore, based on the ISPRA procedure, new indicators have been determined by overlaying the same landslide hazard information layer (*i.e.*, ISPRA mapping) with an exposure layer associating the building volume considering a 90 m x 90 m grid (Esch et al., 2022). This exposure layer is freely available from EOC GEOSERVICE at the following web address https://download.geoservice.dlr.de/WSF3D/files/global/.

Specifically, the indicator shown in Figure D.1 highlight the effect of hazard on risk. Moreover, these indicators can be particularly useful for ranking risk among municipalities at a regional level.

Tables D.1/a shows the indicators' metadata and sources. Tables D.1/b shows the minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of the Municipal Landslide Hazard Structure Ratio named D.1. The type of indicator is well reflected by the classification of the territory. In fact, the highest values of the maximum and the 84th percentile of D.1 distribution are found in Inner Italy and Italy in the middle, which are characterised by the highest landslide hazard.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

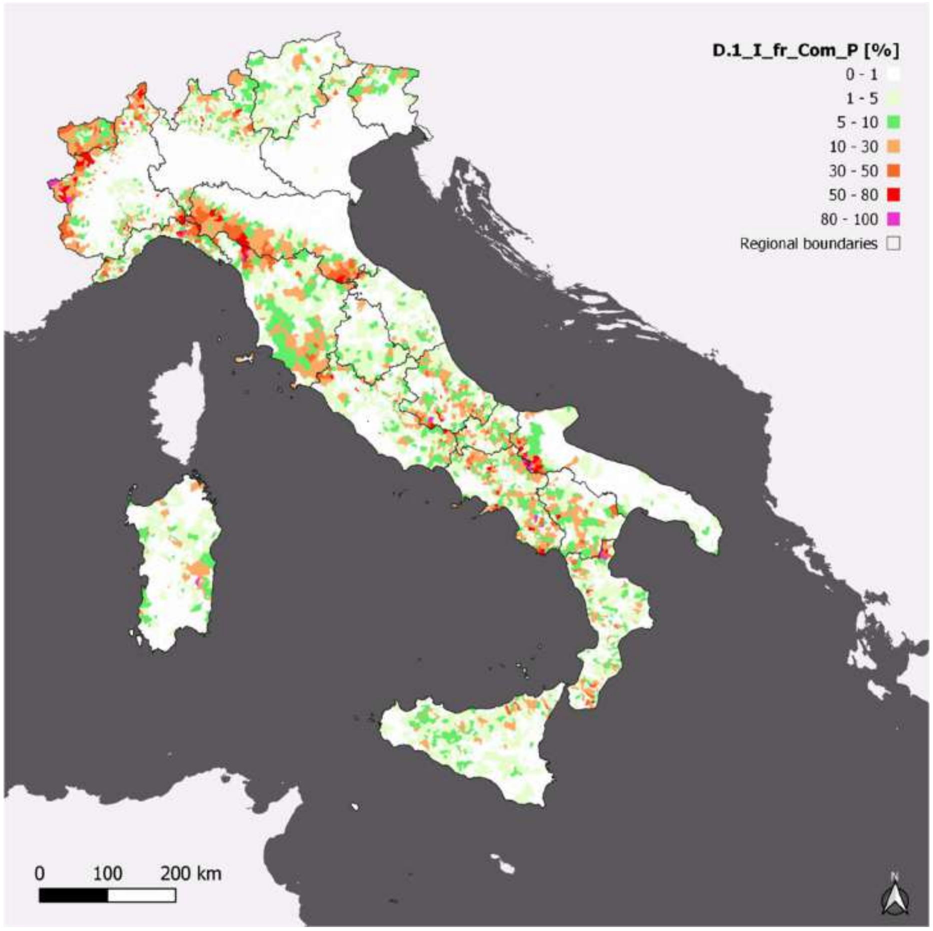

Figure D.1: Map of the indicator D.1.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.1	Indicator of exposed buildings to landslide hazard at municipal scale	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D1.1	Municipality buildings volume within landslide polygons classified as P3 and P4 in terms of landslide hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D1.2	Structure volume within a municipality	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.1/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.20	3.10	18.27	100.00
1.1.1 - Inner, remote and sparsely populated area	0.00	0.20	3.30	19.13	100.00
1.1.2 - Inner and remote area with medium population density	0.00	0.10	1.50	5.27	47.50
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.20	4.90	26.38	99.90
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.36	2.10	9.66	34.80
2 INTERMEDIATE ITALY	0.00	0.00	0.30	6.50	97.80
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	2.30	11.70	97.80
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.30	4.16	69.90
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	1.30	87.50
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.00	1.20	82.50
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	0.20	1.82	6.70
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	4.20	81.40
3 METROPOLITAN ITALY	0.00	0.00	0.00	3.26	90.20
3.1 - De facto metropolitan centre	0.00	0.00	0.00	0.00	1.10
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	3.73	90.20
3.2.2 - Metropolitan capital	0.00	0.01	0.15	0.69	2.50

Table D.1/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of the indicator named D.1.

D.1_Indicator of exposed buildings to landslide hazard at municipal scale

Based on the ISPRA procedure, new indicators have been determined by overlaying the same landslide hazard information layer (*i.e.*, ISPRA mapping) with an exposure layer associating the building volume considering a 90 m x 90 m grid (Esch et al., 2022). This exposure layer is freely available from EOC GEOSERVICE at the following web address https://download.geoservice.dlr.de/WSF3D/files/global/.

The indicator D1 highlights the effect of hazard on risk. The indicators D1 is determined by the following Equations:

$$\mathrm{D.1} = \frac{V_{Com\_P3+P4}}{V_{Com}} \cdot 100 \qquad (0.2)$$

Here, V_{Com_P3+P4} represents the volume of structures within landslide polygons classified as P3 and P4 in terms of landslide hazard in a municipality and V_{Com} is the total volume of structures within the same municipality. Figure D.1 shows the map of the D.1 indicator.

D.1.1_Municipality buildings volume within landslide polygons classified as P3 and P4 in terms of landslide hazard

The indicator D.1.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the landslide hazard information layer (*i.e.*, ISPRA mapping) and with an exposure layer associating the buildings volume considering a 90 m x 90 m grid (Esch et al., 2022). D.1.1 is also named Ds.1 for the sake of brevity.

D.1.2_Structure volume within a municipality

The indicator D.1.2 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with an exposure layer associating the buildings volume with a 90 m x 90 m grid (Esch et al., 2022). D.1.2 is also named Ds.2 for the sake of brevity.

5.2 Map D.2 - Ratio between municipal and regional exposed buildings to landslide hazard

The term landslide refers to a movement of rock, earth, or debris along a slope (Brown et al., 1992; Cruden & Varnes, 1996). A series of predisposing and triggering factors can be recognized for landslide events. Predisposing factors are intrinsic characteristics of the study area, such as surface morphology or the physic-mechanical properties of the geological materials underlying the area. Triggering factors, on the other hand, are natural or anthropogenic disturbances (*e.g.*, rainfall, road cutting) that disrupt slope equilibrium and initiate irreversible movement. Analysing these factors can help characterize landslide hazard quantitatively or qualitatively, depending on the level of detail with which the factors can be quantified. Typically, the larger the study area, the lower the level of detail. The Italian Institute for Environmental Protection and Research (ISPRA) produced the report on hydrogeological instability in Italy (Trigila et al., 2021) which presents new national landslide and flood hazard maps based on data provided by the River Basin Authorities (Autorità di Bacino Distrettuali in Italian). Different methods can be applied at varying levels of detail and integrated to define landslide hazard. For example, a 1:10,000 scale detail level may involve classifying landslides in the inventory as very high, high, or moderate hazard based on movement type and activity status, while a 1:25,000 scale detail level may assess susceptibility in remaining non-landslide areas based on geomorphological and lithological criteria.

ISPRA releases the new national landslide hazard maps following data standardization from River Basin Authorities. The hazard maps classify the territory into five landslide hazard zones (from P0 to P4) based on representative parameters of potential landslide movement: velocity, geometric severity (*e.g.*, depth of landslide body in case of slides), activity status, and probable frequency. For further details on analysis methods, refer to the ISPRA report (Trigila et al., 2021).
ISPRA also proposes indicators resulting from the overlay of the landslide hazard layer and the exposure layer. In particular, the following aspects need to be considered:

1) only polygons classified as hazard levels P3 and P4 in the ISPRA mapping are selected;
2) ISTAT census sections from the 2011 census are included. Within each section, a uniform distribution of the number of buildings is assumed. However, this methodology provides a good estimate of the exposure layer only if the building stocks are evenly distributed within the census section;
3) the vulnerability of the exposed element is assumed to be 1. Therefore, any element within a P3 or P4 risk area is considered to experience total loss.

Therefore, based on the ISPRA procedure, new indicators have been determined by overlaying the same landslide hazard information layer (*i.e.*, ISPRA mapping) with an exposure layer associating the building volume considering a 90 m x 90 m grid (Esch et al., 2022). This exposure layer is freely available from EOC GEOSERVICE at the following web address https://download.geoservice.dlr.de/WSF3D/files/global/.

Specifically, the indicator shown in Figure D.2 highlight the effect of exposure on risk. Moreover, these indicators can be particularly useful for ranking risk among municipalities at a regional level. Tables D.2/a shows the indicators' metadata and sources. Tables D.2/b shows the minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of the Municipal to Regional Landslide Hazard Structure Ratio named D.2. The type of indicator is well reflected by the classification of the territory. In fact, densely populated areas such as Metropolitan Italy are characterised by the highest values of the maximum and the 84th percentile of the D.2 distribution.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

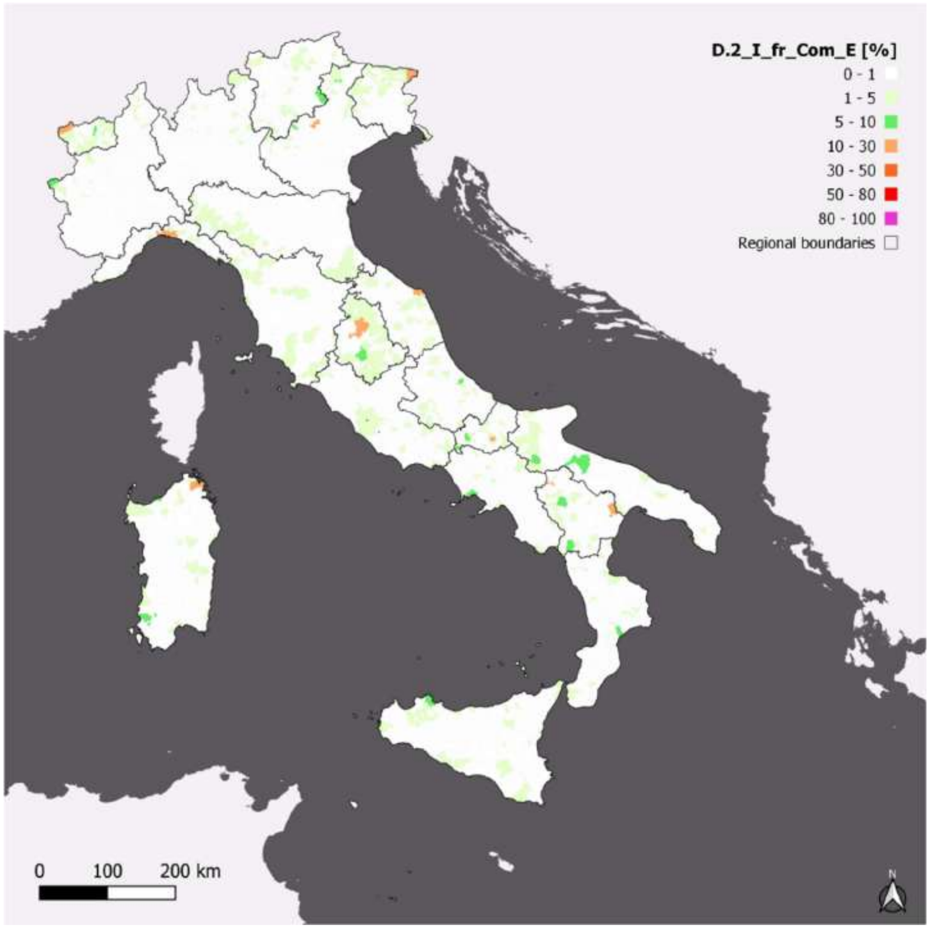

Figure D.2: Map of the indicator D.2.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.2	Ratio between municipal and regional exposed buildings to landslide hazard	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
Ds.1	Municipality buildings volume within landslide polygons classified as P3 and P4 in terms of landslide hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.2/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.10	0.60	5.10
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.10	0.50	5.10
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.20	0.90	2.20
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	0.10	0.40	3.30
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.08	0.20	0.50	1.40
2 INTERMEDIATE ITALY	0.00	0.00	0.00	0.30	16.10
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.10	0.50	14.30
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	0.50	10.90
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	0.10	5.20
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.00	0.30	15.80
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	0.40	2.76	16.10
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	0.20	7.40
3 METROPOLITAN ITALY	0.00	0.00	0.00	0.30	22.80
3.1 - De facto metropolitan centre	0.00	0.00	0.00	0.00	13.40
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	0.30	2.90
3.2.2 - Metropolitan capital	0.00	0.20	0.95	5.50	22.80

Table D.2/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution the indicator named D.2.

D.2_Ratio between municipal and regional exposed buildings to landslide hazard

Based on the ISPRA procedure, new indicators have been determined by overlaying the same landslide hazard information layer (*i.e.*, ISPRA mapping) with an exposure layer associating the building volume considering a 90 m x 90 m grid (Esch et al., 2022). This exposure layer is freely available from EOC GEOSERVICE at the following web address https://download.geoservice.dlr.de/WSF3D/files/global/.

The indicator D2 emphasizes the exposure effect on risk. The indicators D2 is determined by the following Equations:

$$\mathrm{D.2} = \frac{V_{Com\_P3+P4}}{V_{Reg\_P3+P4}} \cdot 100 \qquad (0.3)$$

Here, V_{Com_P3+P4} represents the volume of structures within landslide polygons classified as P3 and P4 in terms of landslide hazard in a municipality and V_{Reg_P3+P4} is the volume of structures within landslide polygons classified as P3 and P4 in terms of landslide hazard in the region where the municipality belongs. Figure D.2 shows the map of the D.2 indicator.

D.2.1_Municipality buildings volume within landslide polygons classified as P3 and P4 in terms of landslide hazard

The indicator D.2.1 has been determined by overlaying the ISTAT municipality layer for 2021 (https://www.istat.it/it/archivio/222527) with the landslide hazard information layer (i.e., ISPRA mapping) and with an exposure layer associating the buildings volume considering a 90 m x 90 m grid (Esch et al., 2022). D.2.1 is also named Ds.1 for the sake of brevity.

5.3 Map D.3 - Indicator of exposed low-rise buildings to seismic hazard at municipal scale

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range $T1 - T2$, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range $T1 - T2$ can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the $T1 - T2$ period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, H (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to H is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \qquad (0.4)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.3 highlights the effect of hazard on risk with reference to low-heigth structures. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.3/a lists the Indicators' metadata and sources. Table D.3/b shows the minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator D.3. The type of indicator is well reflected by the classification of the territory. In fact, the highest values of the maximum and the 84th percentile of D.3 distribution are generally found in Inner Italy and Italy in the middle, which are characterised by the highest seismic hazard.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

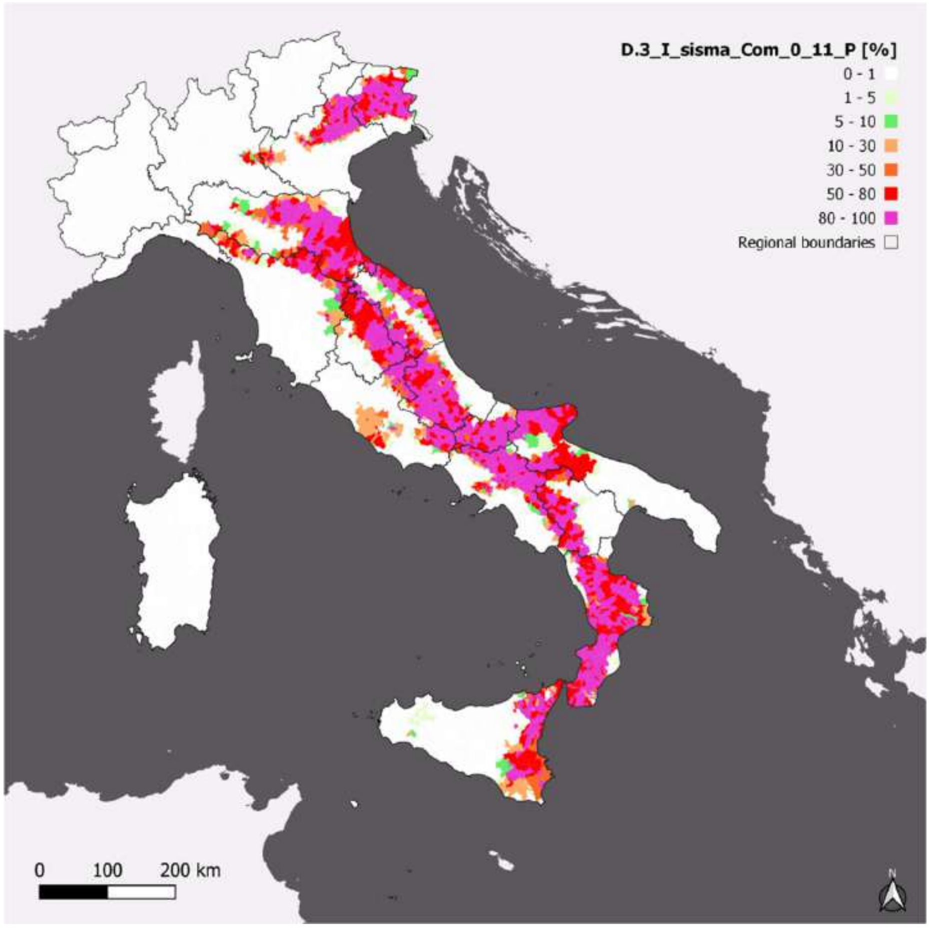

Figure D.3: Map of the indicator D.3.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.3	Indicator of exposed low-rise buildings to seismic hazard at municipal scale	2011	municipality	%	Authors' elaboration on EOC Geoservise, Mendeley data, ISTAT data
D.3.1	Structure volume within a municipality	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.3.2	Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.3/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	79.27	100.00
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	81.70	100.00
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	6.91	89.84
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	0.00	79.49	99.56
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	0.00	76.77	96.67
2 INTERMEDIATE ITALY	0.00	0.00	0.00	80.49	100.00
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	88.23	100.00
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	69.13	100.00
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	12.54	100.00
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.00	77.25	100.00
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	0.00	55.73	82.77
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	62.55	100.00
3 METROPOLITAN ITALY	0.00	0.00	0.00	23.13	98.55
3.1 - De facto metropolitan centre	0.00	0.00	0.10	51.52	69.74
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	18.75	98.55
3.2.2 - Metropolitan capital	0.00	0.00	0.00	38.14	57.86

Table D.3/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator named D.3.

D.3_ Indicator of exposed low-rise buildings to seismic hazard at municipal scale

In this study, the D.3 indicator is presented. This indicator has been determined through the following Equation:

$$\mathrm{D3} = \frac{V_{Com\_0-11\_P3+P4}}{V_{Com}} \cdot 100 \qquad (0.5)$$

where $V_{Com\_0-11\_P3+P4}$ is the volume of buildings with heights falling within the intervals 0-11 m and within polygons classified as P3 and P4 with respect to seismic hazard in a municipality and V_{Com} is the total volume of structures in the same municipality.

The maps of the indicator D.3 is shown in Figure D.3. The subscripts 0-11 refers to the height class considered, i.e.]0, 11[m.

D.3.1_Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.3.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 0-11 m high have been selected. D.3.1 is also named Ds.3 for the sake of brevity.

D.3.2_Structure volume within a municipality

The indicator D.3.2 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with an exposure layer associating the buildings volume with a 90 m x 90 m grid (Esch et al., 2022). D.3.2 is also named Ds.2 for the sake of brevity.

5.4 Map D.4 - Indicator of exposed medium-rise buildings to seismic hazard at municipal scale

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range *T1* – *T2*, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range *T1* – *T2* can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the *T1* – *T2* period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, *H* (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to *H* is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \qquad (0.6)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.4 highlights the effect of hazard on risk with reference to medium-heigth structures. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.4/a lists the Indicators' metadata and sources. Table D.4/b shows the minimum, 16^{th} percentile, 50^{th} percentile, 84^{th} percentile and maximum values of the distribution of indicator D.4. The type of indicator is well reflected by the classification of the territory. In fact, the highest values of the maximum and the 84^{th} percentile of D.4 distribution are generally found in Inner Italy and Italy in the middle, which are characterised by the highest seismic hazard.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

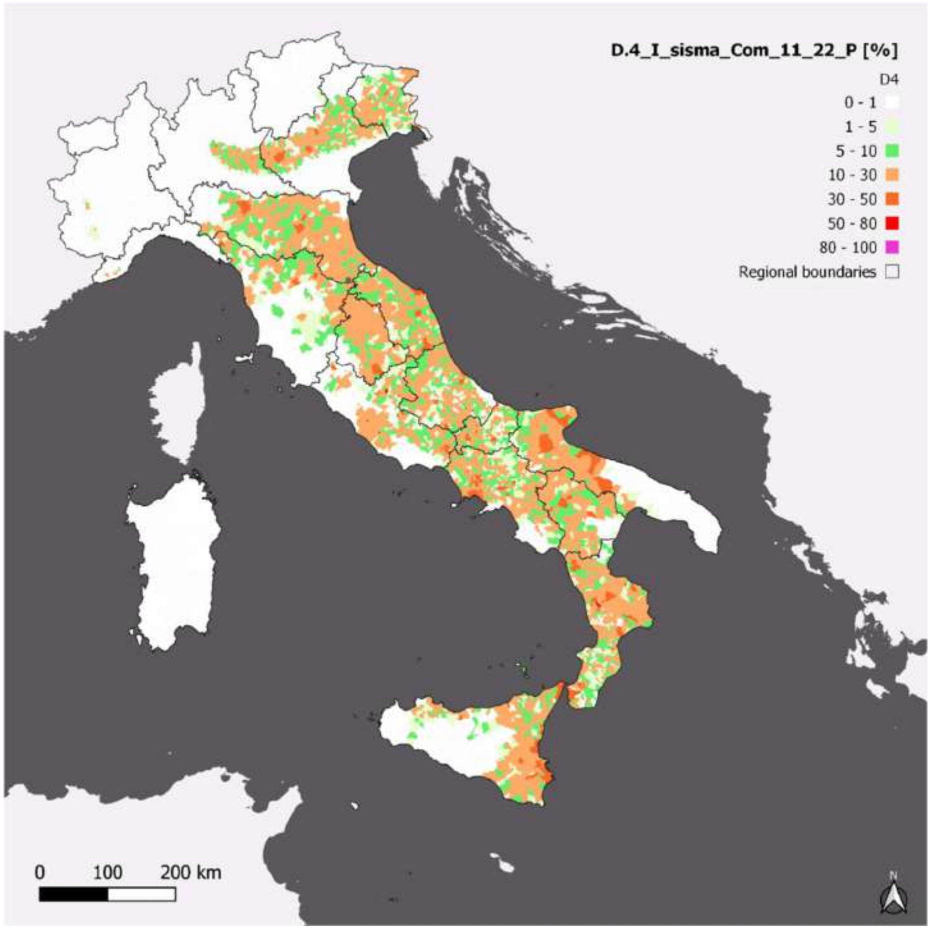

Figure D.4: Map of the indicator D.4.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.4	Indicator of exposed medium-rise buildings to seismic hazard at municipal scale	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.4.1	Structure volume within a municipality	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.4.2	Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.4/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	12.34	54.12
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	10.80	54.12
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	15.88	37.56
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	1.95	15.03	40.82
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	7.97	18.44	32.00
2 INTERMEDIATE ITALY	0.00	0.00	0.00	12.38	61.46
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	11.52	61.46
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	14.27	41.83
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	8.40	29.49
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	2.91	15.95	47.68
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	19.66	32.40	50.83
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	12.03	41.46
3 METROPOLITAN ITALY	0.00	0.00	0.00	16.79	66.02
3.1 - De facto metropolitan centre	0.00	0.00	22.66	26.68	31.65
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	15.45	66.02
3.2.2 - Metropolitan capital	0.00	0.00	19.50	37.37	43.78

Table D.4/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of the indicator named D.4.

D.4_ Indicator of exposed medium-rise buildings to seismic hazard at municipal scale

In this study, the D.4 indicator is presented. This indicator has been determined through the following Equation:

$$\mathrm{D.4} = \frac{V_{Com\_11-22\_P3+P4}}{V_{Com}} \cdot 100 \qquad (0.7)$$

where $V_{Com\_11-22\_P3+P4}$ is the volume of buildings with heights falling within the intervals 1-22 m and within polygons classified as P3 and P4 with respect to seismic hazard in a municipality and V_{Com} is the total volume of structures in the same municipality.

The maps of the indicator D.4 is shown in Figure D.4. The subscripts 11-22 refers to the height class considered, i.e.]11, 22[m.

D.4.1_ Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.4.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structures 11-22 m high have been selected. D.4.1 is also named Ds.4 for the sake of brevity.

D.4.2_ Structure volume within a municipality

The indicator D.4.2 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with an exposure layer associating the buildings volume with a 90 m x 90 m grid (Esch et al., 2022). D.4.2 is also named Ds.2 for the sake of brevity.

5.5 Map D.5 - Indicator of exposed high-rise buildings to seismic hazard at municipal scale

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range $T1 - T2$, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range $T1 - T2$ can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the $T1 - T2$ period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, H (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to H is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \qquad (0.8)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.5 highlights the effect of hazard on risk with reference to high-heigth structures. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.5/a lists the Indicators' metadata and sources. Table D.5/b shows the minimum, 16^{th} percentile, 50^{th} percentile, 84^{th} percentile and maximum values of the distribution of indicator D.5. The type of indicator is well reflected by the classification of the territory. In fact, the highest values of the maximum and the 84^{th} percentile of D.5 distribution are generally found in Inner Italy and Italy in the middle, which are characterised by the highest seismic hazard.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

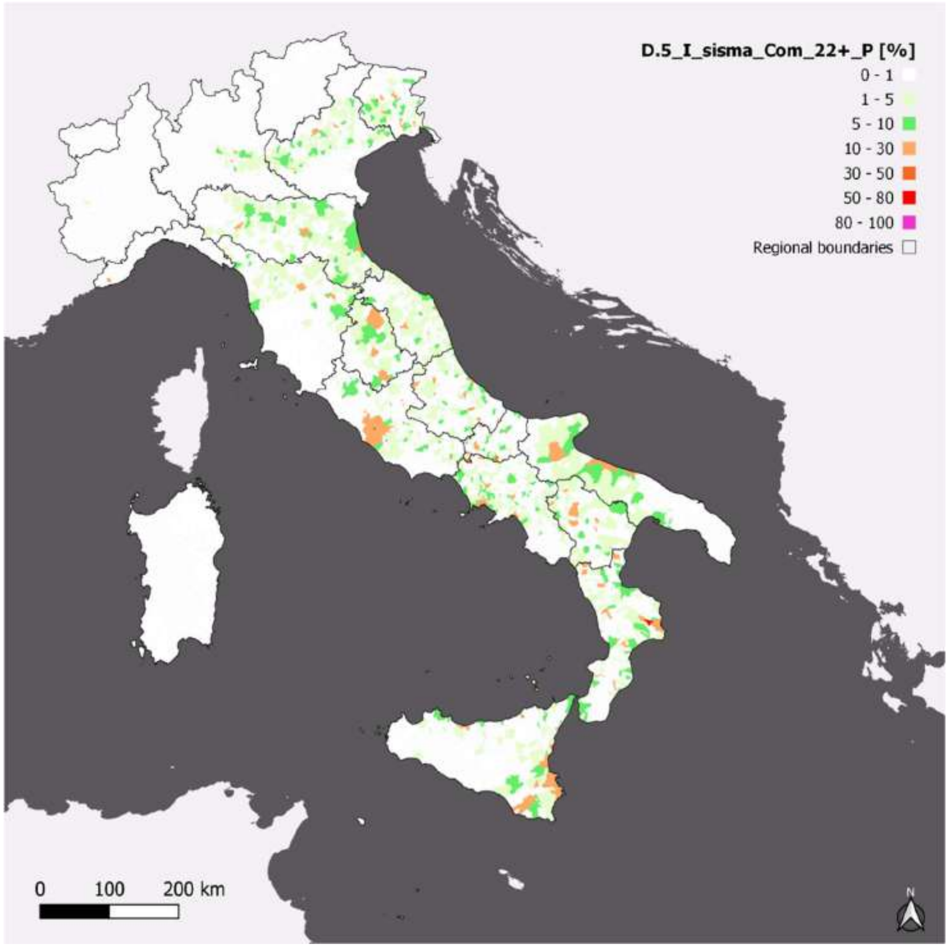

Figure D.5: Map of the indicator D.5.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.5	Municipal Seismic Hazard High-Heigth Structure Ratio	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.5.1	Structure volume within a municipality	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.5.2	Municipality volume of buildings high more than 22 m within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.5/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	0.00	62.67
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	0.00	62.67
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	1.63	6.28
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	0.00	0.00	10.52
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	0.00	1.60	7.22
2 INTERMEDIATE ITALY	0.00	0.00	0.00	0.76	64.92
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	0.00	64.92
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	0.92	25.11
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	0.00	22.42
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.00	2.22	20.90
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	3.35	10.29	25.64
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	0.84	26.77
3 METROPOLITAN ITALY	0.00	0.00	0.00	1.80	28.59
3.1 - De facto metropolitan centre	0.00	0.00	6.32	8.00	9.04
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	1.40	28.59
3.2.2 - Metropolitan capital	0.00	0.00	7.50	19.87	24.59

Table D.5/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of the indicator named D.5.

D.5_Indicator of exposed high-rise buildings to seismic hazard at municipal scale

In this study, the D.5 indicator is presented. This indicator has been determined through the following Equation:

$$\text{D.5} = \frac{V_{Com\_22+\_P3+P4}}{V_{Com}} \cdot 100 \qquad (0.9)$$

where $V_{Com\_22+\_P3+P4}$ is the volume of buildings higher than 22 m abd falling within polygons classified as P3 and P4 with respect to seismic hazard in a municipality for the considered height class and V_{Com} is the total volume of structures in the same municipality.
The maps of the indicator D.5 is shown in Figure D.5. The subscripts 22+ refers to the height class considered, i.e. [22, ∞[m.

D.5.1_Municipality volume of buildings 22 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.5.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 11-22 m high have been selected. D.5.1 is also named Ds.5 for the sake of brevity.

D.5.2_Structure volume within a municipality

The indicator D.5.2 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with an exposure layer associating the buildings volume with a 90 m x 90 m grid (Esch et al., 2022). D.5.2 is also named Ds.2 for the sake of brevity.

5.6 Map D.6 - Indicator of exposed buildings to seismic hazard at municipal scale

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range $T1 - T2$, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range $T1 - T2$ can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the $T1 - T2$ period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, H (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to H is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \qquad (0.10)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.6 highlights the effect of hazard on risk with reference to all height classes. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.6/a lists the Indicators' metadata and sources. Table D.6/b shows the minimum, 16^{th} percentile, 50^{th} percentile, 84^{th} percentile and maximum values of the distribution of indicator D.6. The type of indicator is well reflected by the classification of the territory. In fact, the highest values of the maximum and the 84^{th} percentile of D.4 distribution are generally found in Inner Italy and Italy in the middle, which are characterised by the highest seismic hazard.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

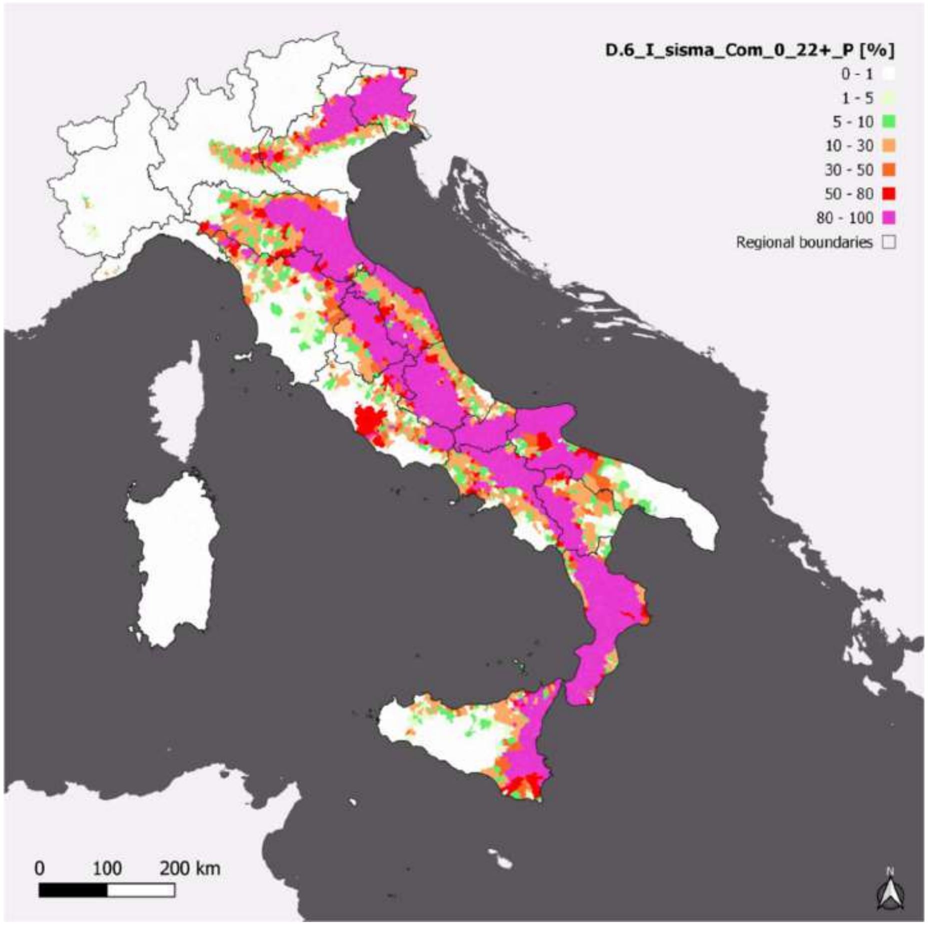

Figure D.6: Map of the indicator D.6.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.6	Indicator of exposed buildings to seismic hazard at municipal scale	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.6.1	Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.6.2	Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.6.3	Municipality volume of buildings high more than 22 m within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.6.4	Structure volume within a municipality	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.6/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	99.98	100.00
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	100.00	100.00
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	27.86	100.00
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	4.14	99.94	100.00
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	12.55	98.15	100.00
2 INTERMEDIATE ITALY	0.00	0.00	0.00	100.00	100.00
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	100.00	100.00
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	95.36	100.00
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	27.27	100.00
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	3.90	98.72	100.00
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	32.29	97.96	100.00
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	83.33	100.00
3 METROPOLITAN ITALY	0.00	0.00	0.00	56.36	100.00
3.1 - De facto metropolitan centre	0.00	0.00	31.17	83.11	100.00
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	48.16	100.00
3.2.2 - Metropolitan capital	0.00	0.00	38.05	93.33	98.04

Table D.6/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator named D.6.

D.6_ Indicator of exposed buildings to seismic hazard at municipal scale

In this study, the D.6 indicator is presented. This indicator has been determined through the following Equation:

$$D.6 = \frac{V_{Com\_0-22+\_P3+P4}}{V_{Com}} \cdot 100 \qquad (0.11)$$

where $V_{Com\_0\text{-}22+\_P3+P4}$ is the volume of buildings falling within within polygons classified as P3 and P4 with respect to seismic hazard in a municipality for each height class and V_{Com} is the total volume of structures in the same municipality.

The maps of the indicator D.6 is shown in Figure D.6. The subscripts 0-22+ refers to the height class considered, i.e. all heights.

D.6.1_Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 0-11 m high have been selected. D.6.1 is also named Ds.3 for the sake of brevity.

D.6.2_Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.2 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 11-22 m high have been selected. D.6.2 is also named Ds.4 for the sake of brevity.

D.6.3_Municipality volume of buildings 22+ m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.3 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structures higher than 22 m have been selected. D.6.3 is also named Ds.5 for the sake of brevity.

D.6.4_Structure volume within a municipality

The indicator D.6.4 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with an exposure layer associating the buildings volume with a 90 m x 90 m grid (Esch et al., 2022). D.6.4 is also named Ds.2 for the sake of brevity.

5.7 Map D.7 - Ratio between municipal and regional exposed low-rise buildings to seismic hazard

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range $T1 - T2$, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range $T1 - T2$ can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the $T1 - T2$ period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, H (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to H is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \qquad (0.12)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.7 highlights the effect of exposure on risk with reference to medium-heigth structures. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.7/a lists the Indicators' metadata and sources. Table D.7/b shows the minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator D.7. The type of indicator is well reflected by the classification of the territory. In fact, densely populated areas such as Metropolitan Italy are characterised by the highest values of the maximum and the 84th percentile of the D.7 distribution.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

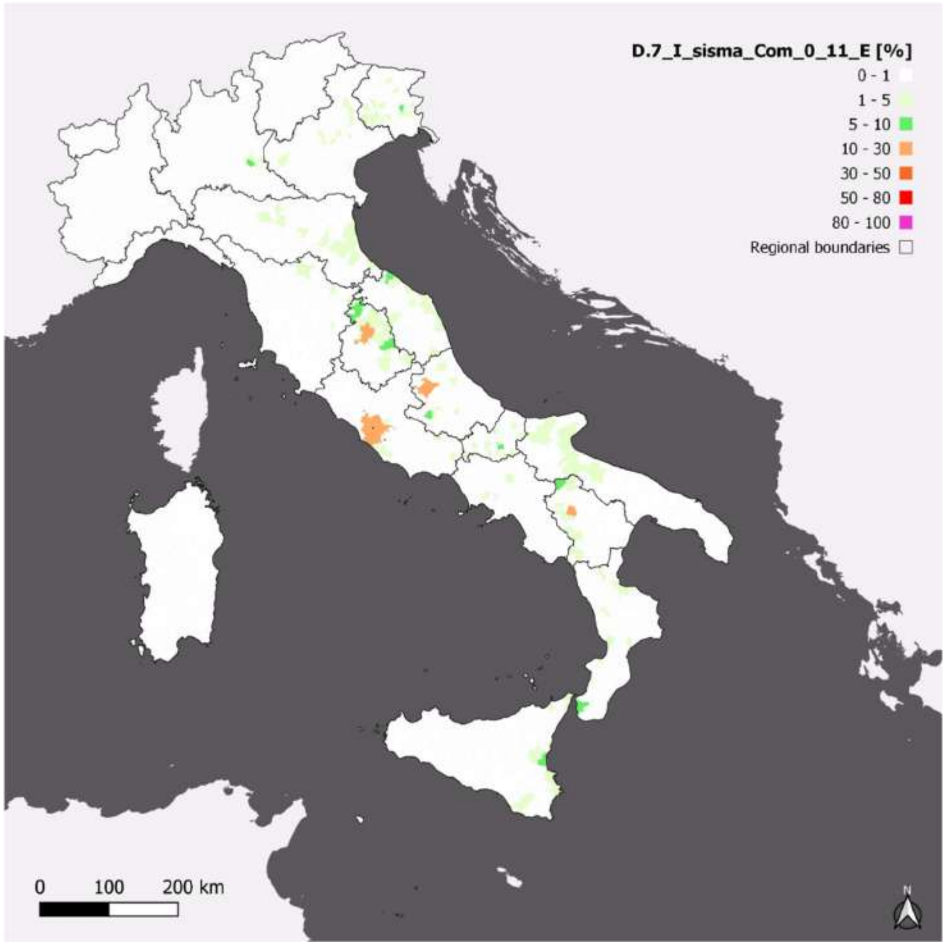

Figure D.7: Map of the indicator D.7 ($I_{sisma\_Com\_0\text{-}11\_E}$).

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.7	Municipal to Regional Seismic Hazard Low-Heigth Structure Ratio	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.7.1	Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.7.2	Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.7.3	Municipality volume of buildings high more than 22 m within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.7/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	0.06	7.31
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	0.06	3.83
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	0.03	7.31
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	0.00	0.03	0.74
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	0.00	0.18	0.58
2 INTERMEDIATE ITALY	0.00	0.00	0.00	0.13	11.81
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	0.13	2.10
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	0.17	6.94
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	0.02	1.26
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.00	0.40	8.30
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	0.00	2.53	11.81
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	0.04	3.70
3 METROPOLITAN ITALY	0.00	0.00	0.00	0.13	14.42
3.1 - De facto metropolitan centre	0.00	0.00	0.05	3.36	14.42
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	0.07	2.74
3.2.2 - Metropolitan capital	0.00	0.00	0.00	5.38	12.76

Table D.7/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator named D.7.

D.7_ Ratio between municipal and regional exposed low-rise buildings to seismic hazard

In this study, the D.7 indicator is presented. This indicator has been determined through the following Equation:

$$\mathrm{D.7} = \frac{V_{Com\_0-11\_P3+P4}}{V_{Reg\_P3+P4}} \cdot 100 \qquad (0.13)$$

where $V_{Com\_0-11\_P3+P4}$ is the volume of buildings with heights falling within the intervals 0-11 m and within polygons classified as P3 and P4 with respect to seismic hazard in a municipality and V_{Reg_P3+P4} is the volume of structures within areas classified as P3 and P4 in terms of seismic hazard in the region where the municipality belongs.

The maps of the indicator D.7 is shown in Figure D.7. The subscripts 0-11 refers to the height class considered, i.e.]0, 11[m.

D.7.1_Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 0-11 m high have been selected. D.7.1 is also named Ds.3 for the sake of brevity.

D.7.2_Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.2 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 11-22 m high have been selected. D.7.2 is also named Ds.4 for the sake of brevity.

D.7.3_Municipality volume of buildings 22+ m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.3 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structures higher than 22 m have been selected. D.7.3 is also named Ds.5 for the sake of brevity.

5.8 Map D.8 - Ratio between municipal and regional exposed medium-rise buildings to seismic hazard

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range *T*1 – *T*2, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range *T*1 – *T*2 can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the *T*1 – *T*2 period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, *H* (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to *H* is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \quad (0.14)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.8 highlights the effect of exposure on risk with reference to medium-heigth structures. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.8/a lists the Indicators' metadata and sources. Table D.8/b shows the minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator D.8. In fact, densely populated areas such as Metropolitan Italy are characterised by the highest values of the maximum and the 84th percentile of the D.8 distribution.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

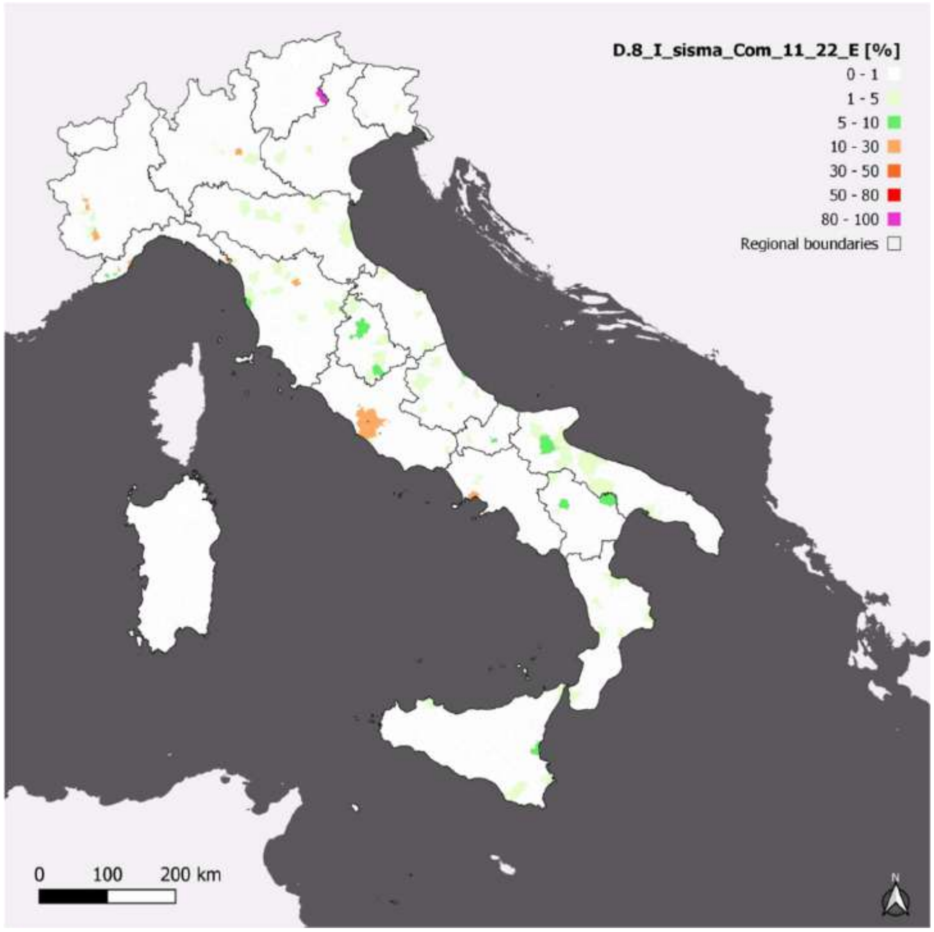

Figure D.8: Map of the indicator D.8.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.8	Ratio between municipal and regional exposed medium-rise buildings to seismic hazard	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.8.1	Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.8.2	Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.8.3	Municipality volume of buildings high more than 22 m within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.8/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	0.02	2.89
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	0.02	0.69
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	0.13	2.89
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	0.00	0.01	0.07
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	0.02	0.08	0.46
2 INTERMEDIATE ITALY	0.00	0.00	0.00	0.06	100.00
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	0.02	100.00
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	0.09	1.85
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	0.03	9.42
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.02	0.18	17.91
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	0.77	2.71	25.42
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	0.05	22.85
3 METROPOLITAN ITALY	0.00	0.00	0.00	0.08	23.66
3.1 - De facto metropolitan centre	0.00	0.00	1.25	4.58	11.44
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	0.06	1.68
3.2.2 - Metropolitan capital	0.00	0.00	2.69	11.09	23.66

Table D.8/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of the indicator D.8.

D.8_Ratio between municipal and regional exposed medium-rise buildings to seismic hazard

In this study, the D.8 indicator is presented. This indicator has been determined through the following Equation:

$$D.8 = \frac{V_{Com\_11-22\_P3+P4}}{V_{Reg\_P3+P4}} \cdot 100 \qquad (0.15)$$

where $V_{Com\_11-22\_P3+P4}$ is the volume of buildings with heights falling within the intervals 11-22 m and within polygons classified as P3 and P4 with respect to seismic hazard in a municipality and V_{Reg_P3+P4} is the volume of structures within areas classified as P3 and P4 in terms of seismic hazard in the region where the municipality belongs.

The maps of the indicator D.8 is shown in Figure D.8. The subscripts 11-22 refers to the height class considered, i.e. [11, 22[m.

D.8.1_Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 0-11 m high have been selected. D.8.1 is also named Ds.3 for the sake of brevity.

D.8.2_Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.2 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 11-22 m high have been selected. D.8.2 is also named Ds.4 for the sake of brevity.

D.8.3_Municipality volume of buildings 22+ m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.3 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structures higher than 22 m have been selected. D.8.3 is also named Ds.5 for the sake of brevity.

5.9 Map D.9 - Ratio between municipal and regional exposed high-rise buildings to seismic hazard

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range *T*1 – *T*2, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range *T*1 – *T*2 can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the *T*1 – *T*2 period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, *H* (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to *H* is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \qquad (0.16)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.9 highlights the effect of exposure on risk with reference to medium-heigth structures. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.9/a lists the Indicators' metadata and sources. Table D.9/b shows the minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator D.9. The type of indicator is well reflected by the classification of the territory. In fact, densely populated areas such as Metropolitan Italy are characterised by the highest values of the maximum and the 84th percentile of the D.9 distribution.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

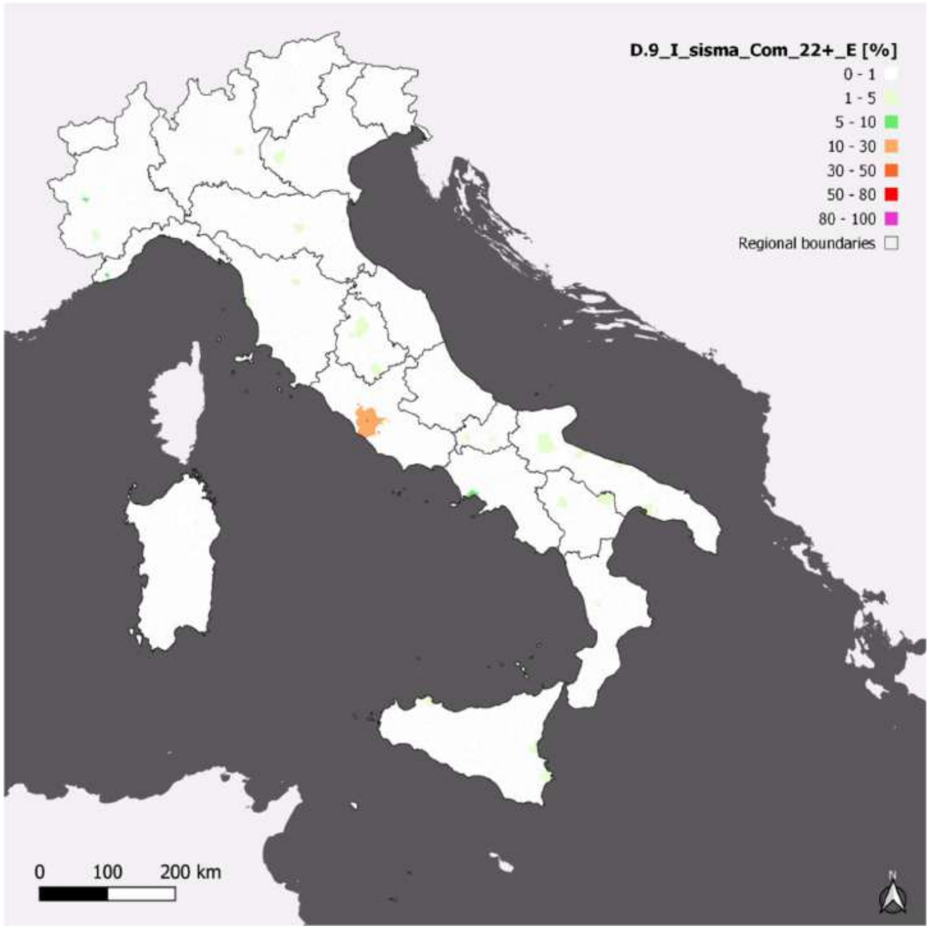

Figure D.9: Map of the indicator D.9.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.9	Ratio between municipal and regional exposed high-rise buildings to seismic hazard	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.9.1	Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.9.2	Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.9.3	Municipality volume of buildings high more than 22 m within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.9/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	0.00	0.49
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	0.00	0.17
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	0.01	0.49
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	0.00	0.00	0.03
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	0.00	0.01	0.12
2 INTERMEDIATE ITALY	0.00	0.00	0.00	0.00	6.15
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	0.00	5.66
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	0.01	0.78
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	0.00	0.43
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.00	0.02	2.46
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	0.19	0.85	4.41
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	0.00	6.15
3 METROPOLITAN ITALY	0.00	0.00	0.00	0.01	19.63
3.1 - De facto metropolitan centre	0.00	0.00	0.40	2.03	3.55
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	0.01	0.65
3.2.2 - Metropolitan capital	0.00	0.00	0.96	4.62	19.63

Table D.9/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator named D.9.

D.9_Ratio between municipal and regional exposed high-rise buildings to seismic hazard

In this study, the D.9 indicator is presented. This indicator has been determined through the following Equation:

$$D.9 = \frac{V_{Com\_22+\_P3+P4}}{V_{Reg\_P3+P4}} \cdot 100 \qquad (0.17)$$

where $V_{Com\_22+\_P3+P4}$ is the volume of buildings with heights higher than 22 m and within polygons classified as P3 and P4 with respect to seismic hazard in a municipality and V_{Reg_P3+P4} is the volume of structures within areas classified as P3 and P4 in terms of seismic hazard in the region where the municipality belongs.

The maps of the indicator D.9 is shown in Figure D.9. The subscripts 22+ refers to the height class considered, i.e. [22, ∞[m.

D.9.1_Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.1 has been determined by overlaying the ISTAT municipality layer for 2021 (https://www.istat.it/it/archivio/222527) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 0-11 m high have been selected. D.9.1 is also named Ds.3 for the sake of brevity.

D.9.2_Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.2 has been determined by overlaying the ISTAT municipality layer for 2021 (https://www.istat.it/it/archivio/222527) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 11-22 m high have been selected. D.9.2 is also named Ds.4 for the sake of brevity.

D.9.3_Municipality volume of buildings 22+ m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.6.3 has been determined by overlaying the ISTAT municipality layer for 2021 (https://www.istat.it/it/archivio/222527) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structures higher than 22 m have been selected. D.9.3 is also named Ds.5 for the sake of brevity.

5.10 Map D.10 - Ratio between municipal and regional exposed buildings to seismic hazard

The determination of seismic risk using a simplified procedure in a GIS environment is based on overlaying informative layers related to seismic hazard and building characteristics defined by height and volume. Specifically, seismic hazard is defined by the mean spectral acceleration over a certain period range *T*1 – *T*2, named H_{SM}. It has been demonstrated that the parameter H_{SM} calculated within the spectral period range *T*1 – *T*2 can be correlated with the degree of damage (Grunthal, 1998) associated with structures characterized by their natural oscillation period, T_0, within the same range (Mori et al., 2019) and depending on their vulnerability (Lagomarsino and Giovinazzi 2006).

Consistently with the approach used for landslide risk, indicators resulting from the overlay of the seismic hazard layer (INGV, 2022; Montaldo & Meletti, 2007) modified by Falcone et al. (2020) and the exposure layer associating building volumes to a grid of cells measuring 90 m x 90 m (Esch et al., 2022) have been determined. However, it is essential to note that the exposure layer required a filtering operation to select only cells (*i.e.*, volumes) that can be associated with a T_0 value within the *T*1 – *T*2 period interval of interest. Since an informative layer at national scale of natural oscillation periods of structures is not available but a layer representing building heights with reference to a grid of 90 m x 90 m cells (Esch et al., 2022) is available, the correlation of T_0 as a function of height, *H* (expressed in m), described by Equation (0.4) (Falcone et al., 2020; ItBC, 2018) was selected to use the height layer. The informative layer relevant to *H* is freely available from EOC GEOSERVICE at the following web address: https://download.geoservice.dlr.de/WSF3D/files/global/. Based on this correlation, for the three periods intervals of 0.1 – 0.5 s, 0.4 – 0.8 s, and 0.7 – 1.1 s (Gruppo di Lavoro MS, 2008), the following height intervals were considered:]0, 11[m, [11, 22[m e [22, ∞[m.

$$T_0 = 0.075 \cdot H^{3/4} \qquad (0.18)$$

New indicators have been determined by overlaying the seismic hazard information layer (Falcone et al., 2020) with an exposure layer associating building volume and height with a 90 m x 90 m grid (Esch et al., 2022).

Specifically, the indicator shown in Figure D.10 highlights the effect of exposure on risk with reference to structures disregarding the height. Moreover, this indicator can be particularly useful for ranking risk among municipalities at a regional level. Table D.10/a lists the Indicators' metadata and sources. Table D.10/b shows the minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator D.10. The type of indicator is well reflected by the classification of the territory. In fact, densely populated areas such as Metropolitan Italy are characterised by the highest values of the maximum and the 84th percentile of the D.10 distribution.

Indicator dimensions

Environment, Economy, Society

Type of indicator

Risk

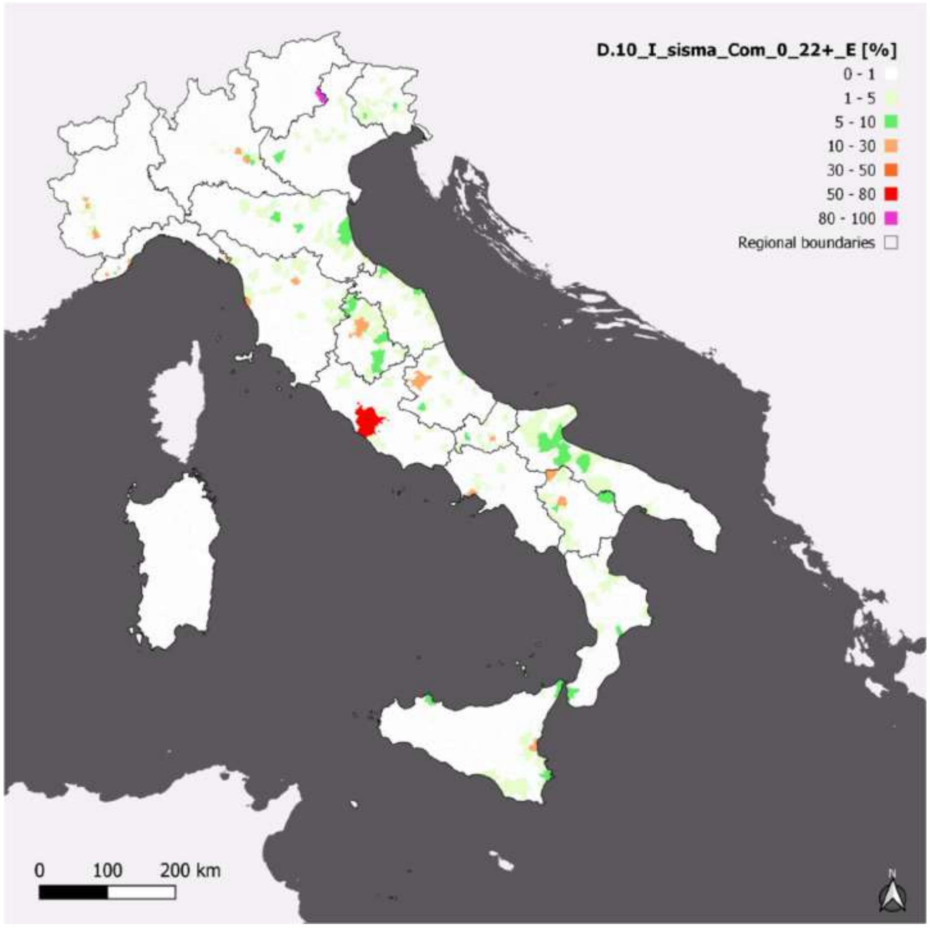

Figure D.10: Map of the indicator D.10.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.10	Ratio between municipal and regional exposed buildings to seismic hazard	2011	municipality	%	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.10.1	Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.10.2	Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data
D.10.3	Municipality volume of buildings high more than 22 m within areas classified as P3 and P4 according to seismic hazard	2011	municipality	m^3	Authors' elaboration on EOC Geoservise data, Mendeley data, ISTAT data

Table D.10/a: Indicators' metadata and sources.

Territorial typology	min	16th	50th	84th	max
1 INNER ITALY	0.00	0.00	0.00	0.09	10.69
1.1.1 - Inner, remote and sparsely populated area	0.00	0.00	0.00	0.08	4.61
1.1.2 - Inner and remote area with medium population density	0.00	0.00	0.00	0.35	10.69
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.00	0.00	0.00	0.04	0.79
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.00	0.00	0.04	0.29	0.71
2 INTERMEDIATE ITALY	0.00	0.00	0.00	0.24	100.00
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.00	0.00	0.00	0.15	100.00
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.00	0.00	0.00	0.27	8.59
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.00	0.00	0.00	0.11	9.42
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium pop. density	0.00	0.00	0.03	0.67	17.91
2.2 - Medium-sized city or non-FUA capital	0.00	0.00	1.46	6.24	29.83
2.3 - De facto or de jure metropolitan fringe	0.00	0.00	0.00	0.17	28.99
3 METROPOLITAN ITALY	0.00	0.00	0.00	0.31	56.05
3.1 - De facto metropolitan centre	0.00	0.00	3.41	10.99	21.82
3.2.1 - De jure and de facto metropolitan area (not capital)	0.00	0.00	0.00	0.25	4.30
3.2.2 - Metropolitan capital	0.00	0.00	6.15	17.95	56.05

Table D.10/b: List of minimum, 16th percentile, 50th percentile, 84th percentile and maximum values of the distribution of indicator named D.10.

D.10_Ratio between municipal and regional exposed buildings to seismic hazard

In this study, the D.10 indicator is presented. This indicator has been determined through the following Equation:

$$\mathrm{D.10} = \frac{V_{Com\_0-22+\_P3+P4}}{V_{Reg\_P3+P4}} \cdot 100 \qquad (0.19)$$

where $V_{Com\_0-22+\_P3+P4}$ is the volume of buildings within polygons classified as P3 and P4 with respect to seismic hazard in a municipality and V_{Reg_P3+P4} is the volume of structures within areas classified as P3 and P4 in terms of seismic hazard in the region where the municipality belongs.

The maps of the indicator D.10 is shown in Figure D.10. The subscripts 0-22+ refers to the height class considered, i.e. $]0, \infty[$m.

D.10.1_Municipality volume of buildings 0-11 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.10.1 has been determined by overlaying the ISTAT municipality layer for 2021 (*https://www.istat.it/it/archivio/222527*) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 0-11 m high have been selected. D.10.1 is also named Ds.3 for the sake of brevity.

D.10.2_Municipality volume of buildings 11-22 m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.10.2 has been determined by overlaying the ISTAT municipality layer for 2021 (https://www.istat.it/it/archivio/222527) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structure 11-22 m high have been selected. D.10.2 is also named Ds.4 for the sake of brevity.

D.10.3_Municipality volume of buildings 22+ m high within areas classified as P3 and P4 according to seismic hazard

The indicator D.10.3 has been determined by overlaying the ISTAT municipality layer for 2021 (https://www.istat.it/it/archivio/222527) with the seismic hazard information layer (Falcone et al., 2020) and with an exposure layer associating structure volume with a 90 m x 90 m grid (Esch et al., 2022). Structures higher than 22 m have been selected. D.10.3 is also named Ds.5 for the sake of brevity.

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6. Dossier E - Vulnerability of the transport network

The Italian railway network, intended as the rail transportation infrastructure serving the entire Peninsula, is subject to hydrogeological risks. In this context, hydrogeological vulnerability of the Italian railway network is conceptualized as the risk of service disruptions of the lines and, consequently, the loss of network functionality (Berche et al., 2009; Berdica, 2002; Bergantino et al., 2024; Mattsson & Jenelius, 2015; Reggiani et al., 2015) due to hydrogeological disruption. Landslides and floods are the events that have been identified as possible hydrogeological disruptions. The likelihood of such events has been increasing in recent years, and the degree of spatial exposure at the Italian level has been defined in detail (ISPRA, 2020).

At the methodological level, the indicators that have been defined to characterize the rail vulnerability to hydrogeological disruptions by province are two topological indicators of change in network connectivity as a result of the removal of critical rail lines. The following indexes and were used to identify the critical lines to be removed due to landslides and floods, respectively::

$$CF_i = PF_i^2 \times E_i$$

$$CA_i = PA_i^2 \times E_i$$

where PF_i is the vulnerability to landslides at the OD line level at the provincial level, PA_i is the vulnerability to floods at the OD line level at the provincial level and E_i is the exposure to risk.
Vulnerability to landslides and floods is operationalized as the expected probability of the event. In the case of landslides, six levels are defined, from 0 to 5, from no risk to very high probability. In the case of floods, the High Probability Hazard (HPH) scenario is considered, in which areas are classified by a dummy variable 0/1 on the basis of being characterized or not by a high probability of flooding with return times between 20 and 50 years. The geometric intersection between the rail lines and the spatial exposure (for both landslide and flood risk, the national hazard mosaics produced by ISPRA are used) defines at the provincial OD level the vulnerability to hydrogeological hazard. To specify risk exposure, potential demand is used, operationalized as the average between local unit employees at origin and destination. The methodological process is repeated on two rail network scenarios to construct the two topological indices. The first network consists only of main (high-capacity) lines while the second network consists of both main and regional lines. For each of the two scenarios, six subscenarios are created:

- Removal of the most landslide critical line to the north,
- Removal of the most flood critical line to the north,
- Removal of the most landslide critical line to the center,
- Removal of the most flood critical line to the center,
- Removal of the most landslide critical line in the south,
- Removal of the most flood critical line in the south.

The identified connectivity index of the network is the *route efficiency*:

$$MNRE_i = \sum_{1}^{n} \left(\frac{d_0(i,j)}{d_1(i,j)}\right)/n$$

$$SNRE_i = \sum_{1}^{n} \left(\frac{d_0(i,j)}{d_1(i,j)}\right)/n$$

Where the route efficiency RE_i, both on main network MN and on main and secondary network SN, is the average of all route efficiencies $\frac{d_0(i,j)}{d_1(i,j)}$ of province i towards all other provinces j which is measured by comparing the shortest path d between two nodes i and j before and after the service interruption on the disrupted line (Morelli and Cuhna, 2021). The parameter η varies between 0 and 1, a value of 1 indicates that the line experienced no interference and maintaines its full efficiency in connecting the nodes. A value less than 1 indicates that the interruption of the service increased the distance between nodes.

The vulnerability assessment of the Italian railway network was conducted considering the hydrogeological and socio-economic characteristics of the territory, together with the topological peculiarities of the network itself. Using simple indicators based on the analysis of landslide and flood hazard maps (source ISPRA) and the analysis of the distribution of employees, aggregated by province (source ISTAT), critical railway lines were identified, both for the high-capacity network and for the main and secondary lines network.

The lines most critical to flood risk in the high-capacity network, and therefore removed in the respective scenarios, are:
1) Treviso - Padua (north)
2) Rome - Terni (central)
3) Salerno - Vibo Valentia (south).

The lines most critical to landslide risk in the high-carrier network, and therefore removed in the respective scenarios, are:
1) La Spezia - Genoa (north)
2) Florence - Arezzo (central)
3) Salerno - Naples (south)

The lines most critical to landslide risk in the main and secondary lines network, and therefore removed in the respective scenarios, are:
4) Lecco - Bergamo (north)
5) Rome - Terni (center)
6) Potenza - Salerno (south)

The lines most critical to flood risk in the main and secondary lines network, and therefore removed in the respective scenarios, are:
4) La Spezia - Genoa (north)
5) Florence - Arezzo (central)
6) Potenza - Salerno (south)

6.1 Map E.1 - Route efficiency of the high-capacity network (MNRE)

The MNRE indicator, and its related maps, spatially shows how the connectivity of each province changes relative to all others as a result of hydrogeological disruptions such as landslides and floods in the high-capacity rail network. After identifying the most critical line in the north, center, and south with respect to landslides and floods, six scenarios were constructed (see previous section) in which the Italian rail network is systematically modified by removing the critical line of the high-capacity network of the reference scenario. For example, in the landslide scenario in northern Italy, the network is modified by removing the Genoa - La Spezia link. The MNRE shows how the average route efficiency between one province and all others, operationalized through the average shortest path length, changes as a result of removing the critical line. In the maps, the darker areas will therefore identify the provinces that suffered the most in terms of efficiency reduction, thus indicating that the average shortest path length increased more than the other provinces following the line closure.

Indicator dimensions

Transport infrastructure

Type of indicator

Status

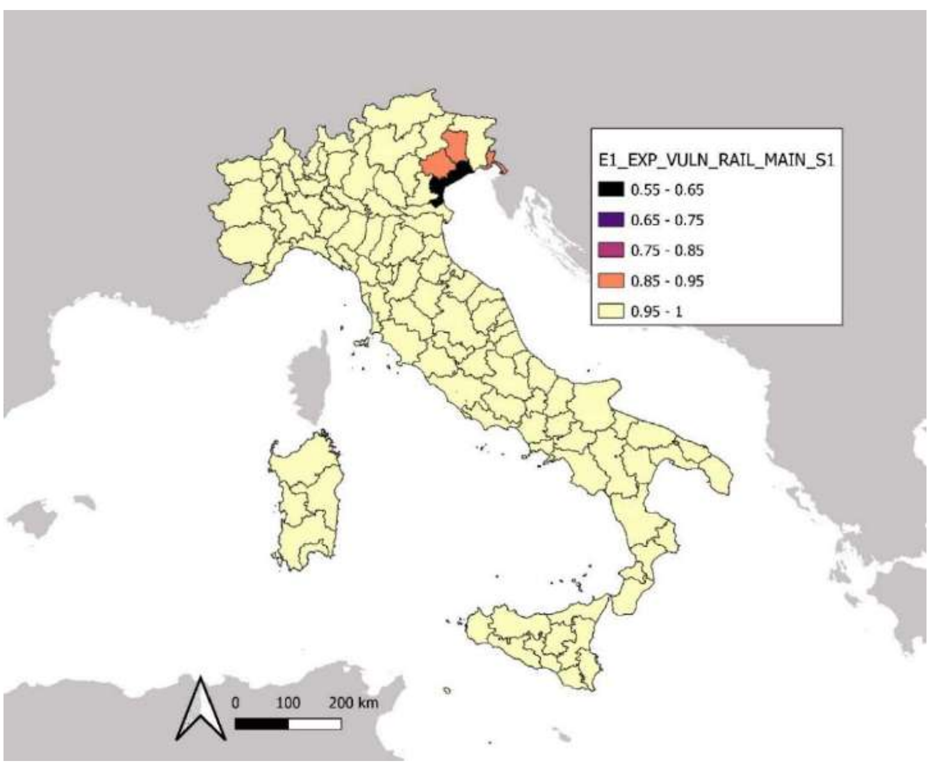

Figure E.1_(S1): Change in MNRE in the Treviso-Padua flood scenario

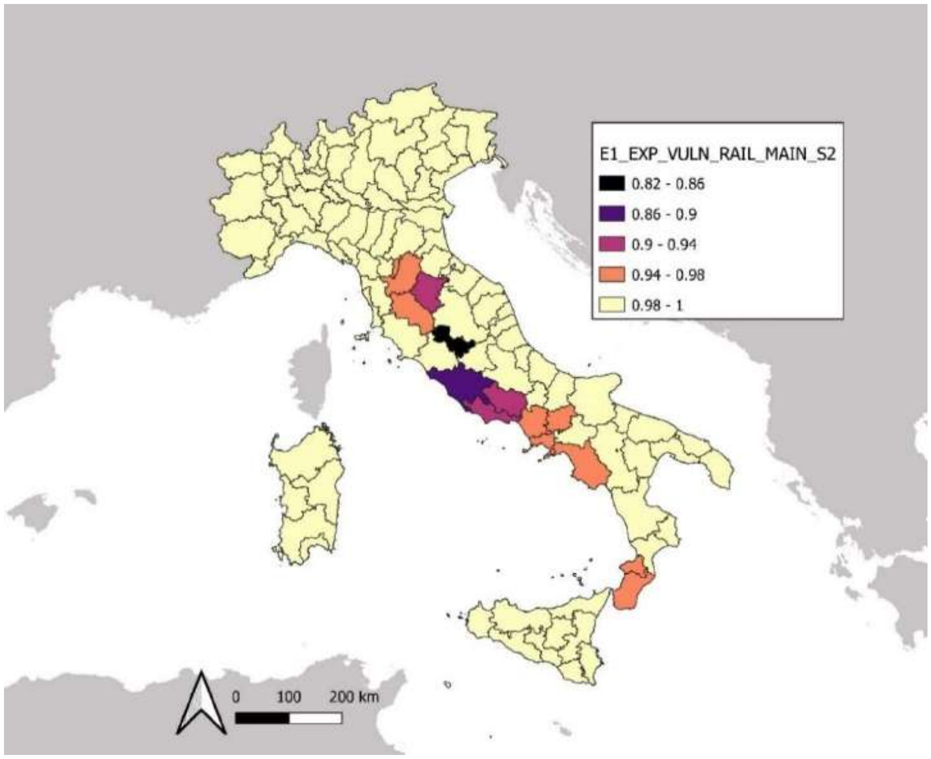

Figure E.1_(S2): Change in MNRE in the Rome-Terni flood scenario

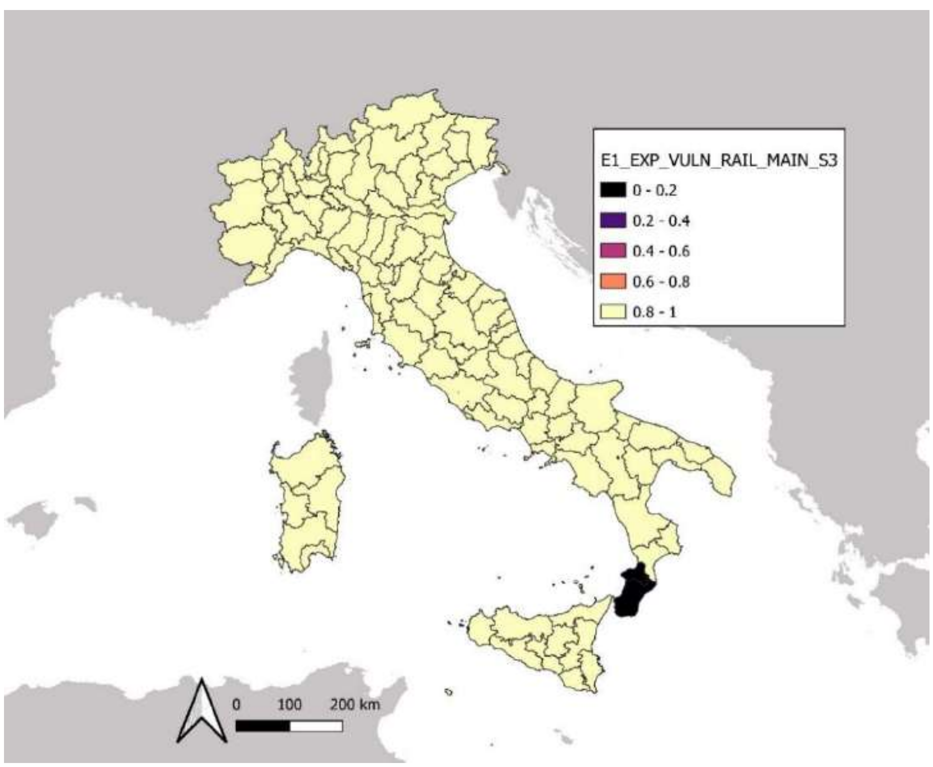

Figure E.1_(S3): Change in MNRE in the Salerno-Vibo Valentia flood scenario

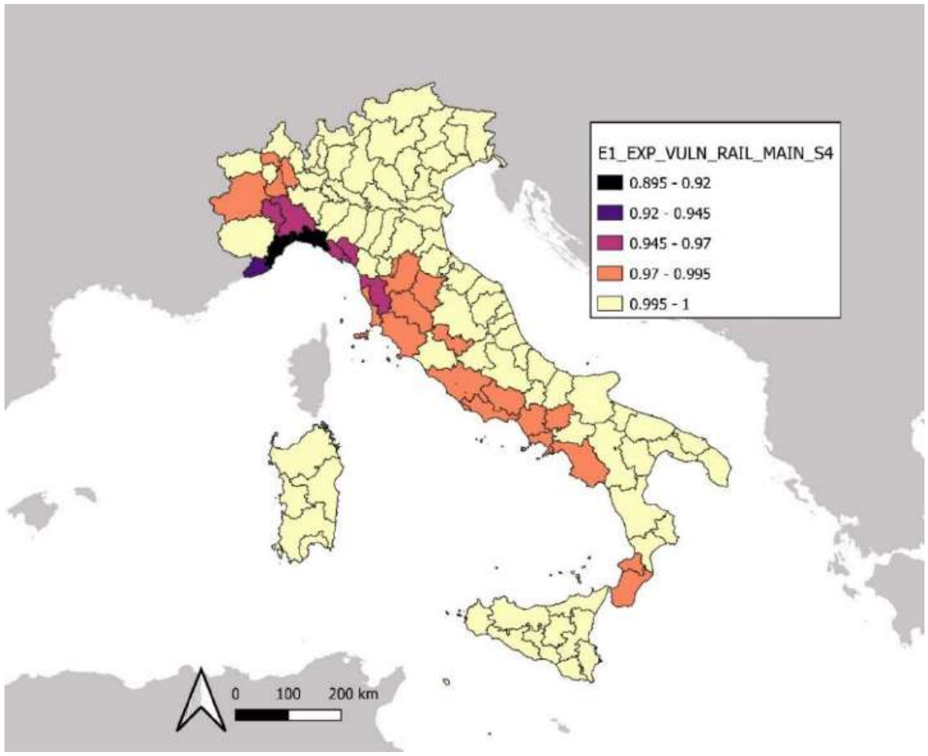

Figure E 1_(S4): Change in MNRE in the Genua-La Spezia landslide scenario

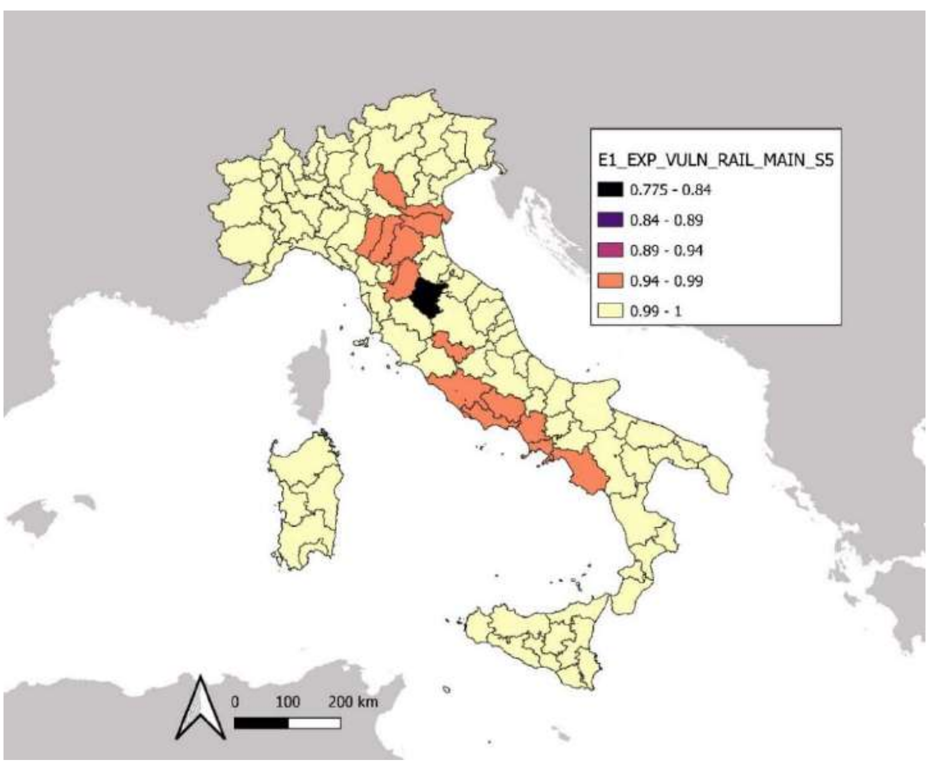

Figure E 1_(S5): Change in MNRE in the Florence-Arezzo landslide scenario

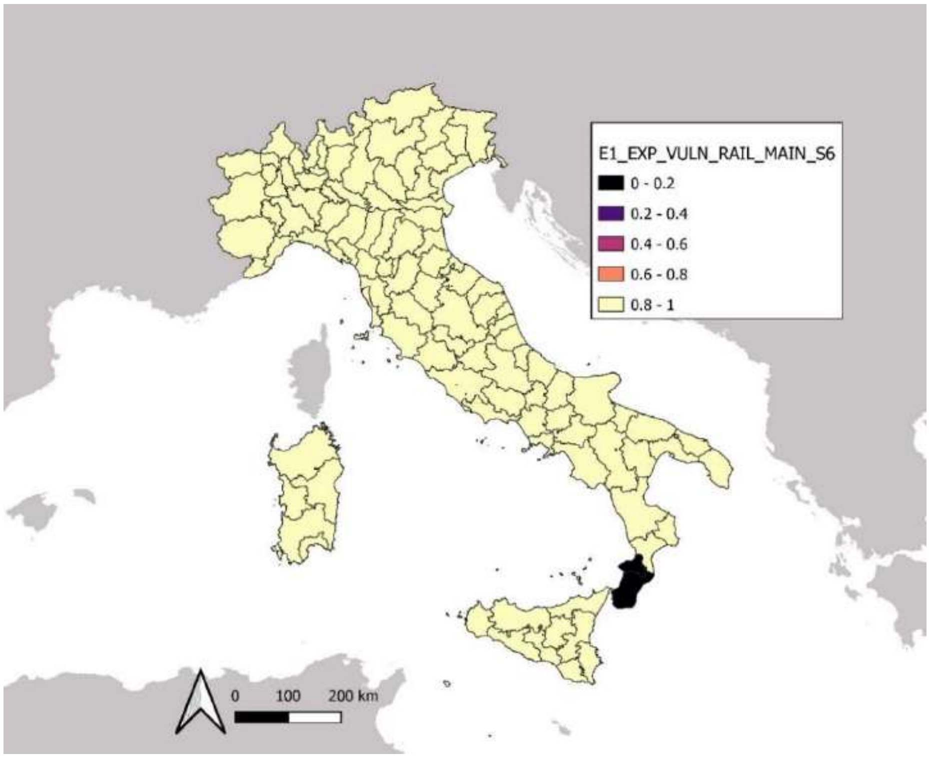

Figure E 1_(S6): Change in MNRE in the Salerno-Naples landslide scenario

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
E1_EXP_VULN_RAIL_MAIN_S1	Change in connectivity indices of the high-capacity network in the face of floods (EXP.VULN.RAIL.MAIN.S1)	2020	Province	%	OpenStreetMaps, ISPRA
E1_EXP_VULN_RAIL_MAIN_S2	Change in connectivity indices of the high-capacity network in the face of floods (EXP.VULN.RAIL.MAIN.S2)	2020	Province	%	OpenStreetMaps, ISPRA
E1_EXP_VULN_RAIL_MAIN_S3	Change in connectivity indices of the high-capacity network in the face of floods (EXP.VULN.RAIL.MAIN.S3)	2020	Province	%	OpenStreetMaps, ISPRA
E1_EXP_VULN_RAIL_MAIN_S4	Change in connectivity indices of the high-capacity network in the face of landslides (EXP.VULN.RAIL.MAIN.S4)	2020	Province	%	OpenStreetMaps, ISPRA
E1_EXP_VULN_RAIL_MAIN_S5	Change in connectivity indices of the high-capacity network in the face of landslides (EXP.VULN.RAIL.MAIN.S5)	2020	Province	%	OpenStreetMaps, ISPRA
E1_EXP_VULN_RAIL_MAIN_S6	Change in connectivity indices of the high-capacity network in the face of landslides (EXP.VULN.RAIL.MAIN.S6)	2020	Province	%	OpenStreetMaps, ISPRA

Table E.1/a: Indicators' metadata and sources in the high capacity network

E.1_(S1-S2-S3)_ Change in High capacity Network Route Efficiency

Difference between connectivity indices (route efficiency) of the high-capacity Italian railway network in the Business As Usual scenario and in the scenario with lines removed following a flood between two network nodes.

E.1_(S4-S5-S6)_ Change in High capacity Network Route Efficiency

Difference between connectivity indices (route efficiency) of the high-capacity Italian railway network in the Business As Usual scenario and in the scenario with lines removed following a landslide between two network nodes.

6.2 Map E.2 - Route efficiency of the main and secondary network (SNRE)

The SNRE indicator is calculated in the same manner as the MNRE indicator but with reference to the main and secondary rail network, i.e., the network that also connects the provinces in inland areas. The SNRE is calculated on the six remaining scenarios as reported at the beginning of the second section.

Indicator dimensions

Transport infrastructure

Type of indicator

Status

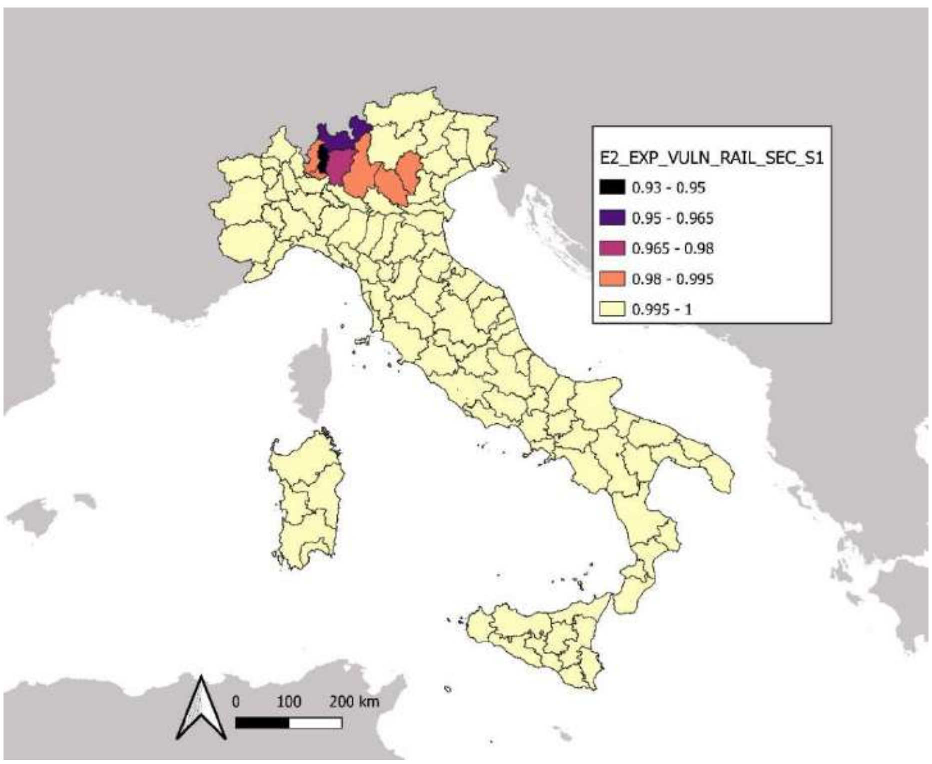

Figure E.2_(S1): Change in SNRE in the Lecco-Bergamo flood scenario

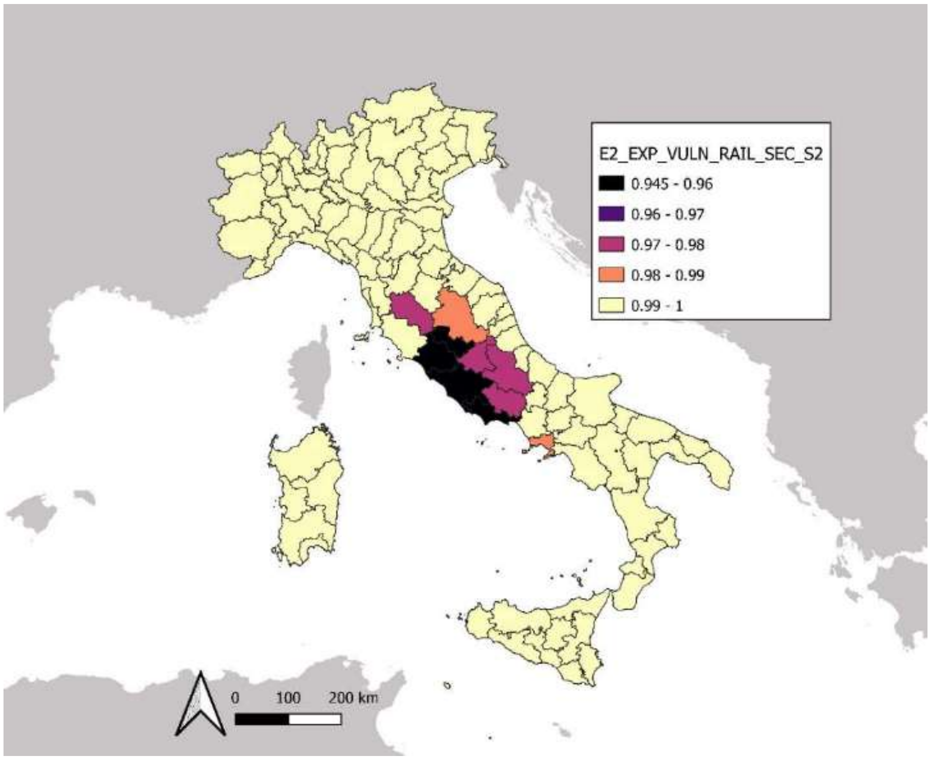

Figure E.2_(S2): Change in SNRE in the Rome-Terni flood scenario

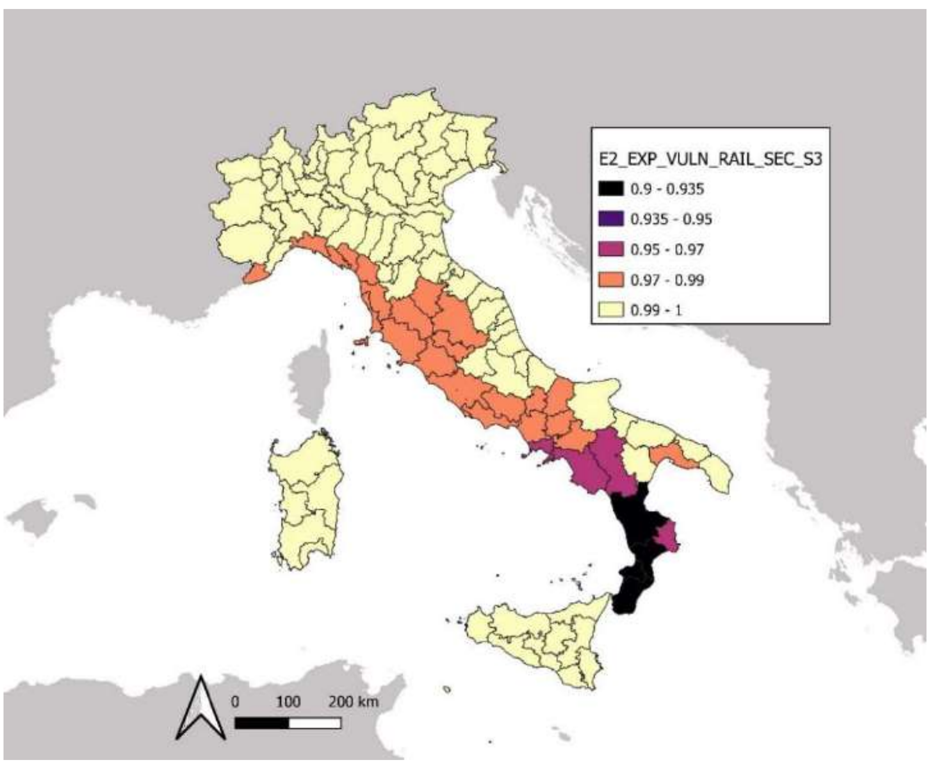

Figure E.2_(S3): Change in SNRE in the Potenza-Salerno flood scenario

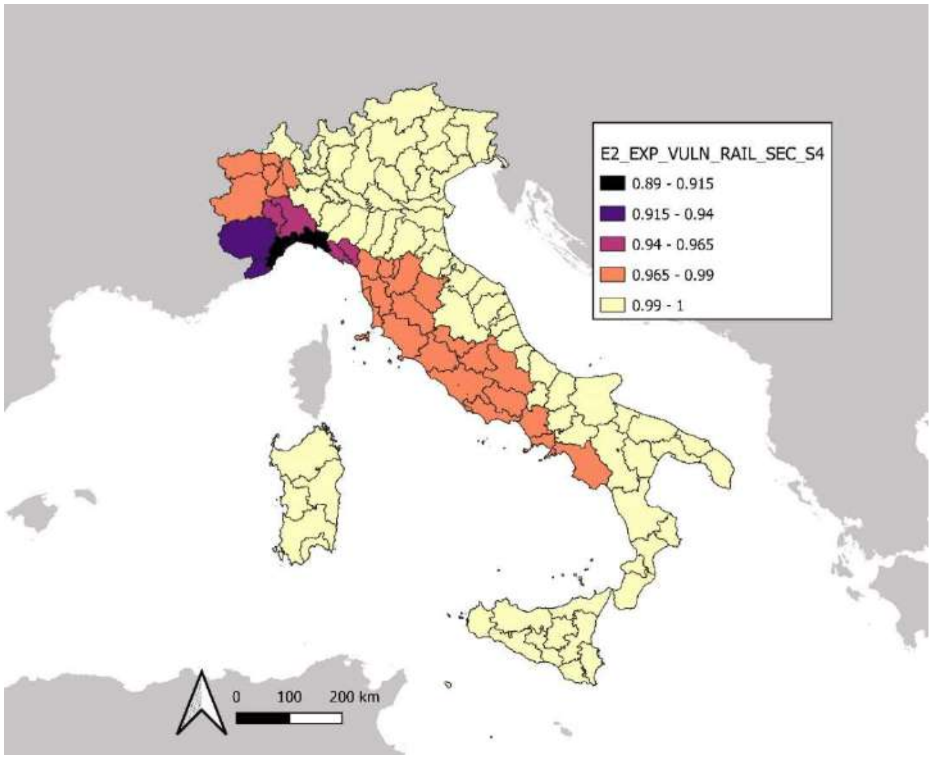

Figure E.2_(S4): Change in SNRE in the Genua-La Spezia landslide scenario

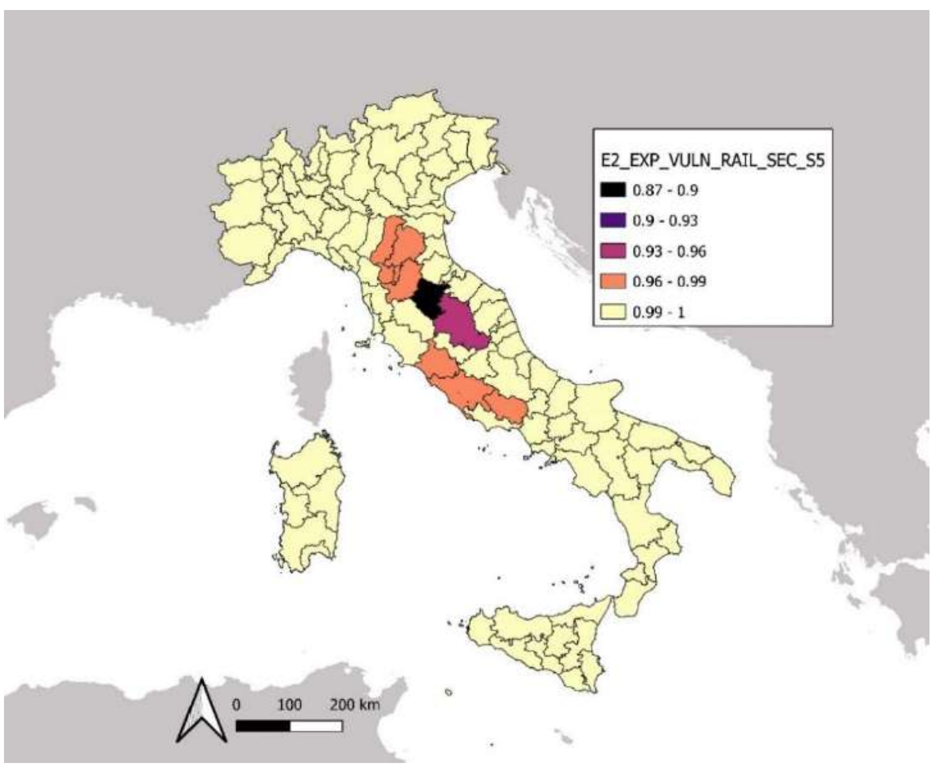

Figure E.2_(S5): Change in SNRE in the Florence-Arezzo landslide scenario

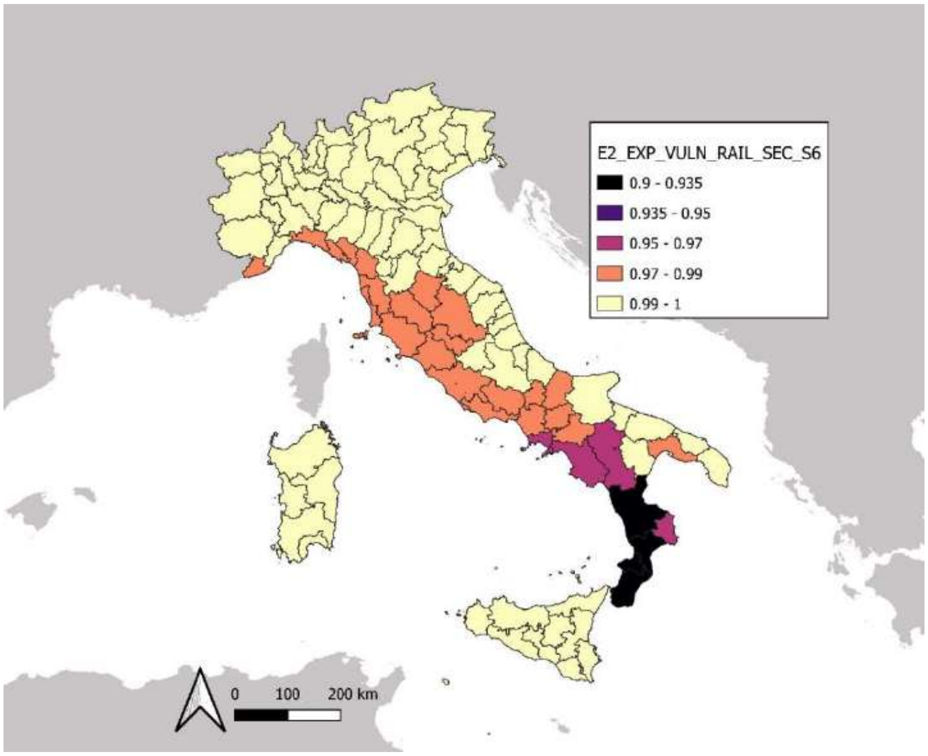

Figure E.2_(S6): Change in SNRE in the Potenza-Salerno landslide scenario

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
E2_EXP_VULN_RAIL_SEC_S1	Change in connectivity indices of the main and secondary network in the face of floods (EXP.VULN.RAIL.SEC.S1)	2020	Province	%	OpenStreetMaps, ISPRA
E2_EXP_VULN_RAIL_SEC_S2	Change in connectivity indices of the main and secondary network in the face of floods (EXP.VULN.RAIL.SEC.S2)	2020	Province	%	OpenStreetMaps, ISPRA
E2_EXP_VULN_RAIL_SEC_S3	Change in connectivity indices of the main and secondary network in the face of floods (EXP.VULN.RAIL.SEC.S3)	2020	Province	%	OpenStreetMaps, ISPRA
E2_EXP_VULN_RAIL_SEC_S4	Change in connectivity indices of the main and secondary network in the face of landslides (EXP.VULN.RAIL.SEC.S4)	2020	Province	%	OpenStreetMaps, ISPRA
E2_EXP_VULN_RAIL_SEC_S5	Change in connectivity indices of the main and secondary network in the face of landslides (EXP.VULN.RAIL.SEC.S5)	2020	Province	%	OpenStreetMaps, ISPRA
E2_EXP_VULN_RAIL_SEC_S6	Change in connectivity indices of the main and secondary network in the face of landslides (EXP.VULN.RAIL.SEC.S6)	2020	Province	%	OpenStreetMaps, ISPRA

Table E.2/a: Indicators' metadata and sources in the main and secondary network

E.2_(S1-S2-S3)_ Change in Main and Secondary Network Route Efficiency

Difference between connectivity indices (route efficiency) of the main and secondary Italian railway network in the Business As Usual scenario and in the scenario with lines removed following a flood between two network nodes.

E.2_(S4-S5-S6)_ Change in Main and Secondary Network Route Efficiency

Difference between connectivity indices (route efficiency) of the main and secondary Italian railway network in the Business As Usual scenario and in the scenario with lines removed following a landslide between two network nodes.

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7. Dossier F - International trade local vulnerability

In examining economic resilience at the sub-national level, we must consider the pivotal role of export stability and policy frameworks. Sub-national units, like provinces, often face distinct vulnerabilities tied to their economic structures and reliance on exports. Assessing export stability becomes crucial, as fluctuations can significantly impact regional economies. Policy interventions aimed at diversifying exports, fostering value-added production, and cultivating resilient trade relationships are vital for mitigating vulnerabilities and enhancing regional resilience. Understanding this dynamic relationship offers insights into fostering economic resilience at the provincial level.

When exploring economic vulnerability and resilience at the territorial level, such as provinces or sub-national units, the focus must also include export dynamics that shape regional economies. Indeed, understanding export stability becomes crucial, as fluctuations can significantly impact regional economic resilience. At this level, defining macroeconomic stability extends beyond national considerations, requiring understanding regional export activities, trade policies specific to each province, and the distribution of export resources within territorial boundaries.
Market reform policies have a localized character, with internal market competition and labor productivity influenced by regional export industries, competition dynamics, and labor market peculiarities. Similarly, social cohesion factors, including income distribution, education levels, crime rates, and unemployment, need tailoring to the unique export-dependent nature of each territory, recognizing the regional context in addressing social cohesion challenges. Environmental management considerations must encompass export-related challenges, such as pollution from export industries and the sustainable use of export-related natural resources (Barbieri et al., 2024).
Constructing a composite index at the territorial level demands careful consideration of regional export data availability, granularity, and relevance. Adjusting the index involves accounting for overall export stability, with potential extensions to include stability in specific sectors like high value-added or high-tech industries and considering exposure to specific countries or macro areas. Additionally, incorporating tools like the country's risk index, where applicable, may enhance the assessment of each region's export vulnerabilities and resilience capacities or serve as a useful robustness check. This nuanced approach ensures a comprehensive analysis, facilitating targeted policy interventions and effective risk mitigation strategies tailored to the unique economic dynamics of individual territories.

In essence, a territorial-level perspective on economic vulnerability and resilience involves adapting national-level considerations to the export-specificities of each province or sub-national unit. Local export structures, trade policies, and environmental challenges contribute to the dynamic nature of resilience and vulnerability at the regional level. On the one hand, prioritizing the development of economic resilience is imperative for addressing and enduring economic vulnerability, particularly in the context of small areas, which inherently face significant economic susceptibility (Röhn et al., 2015; Wang & Wei, 2021). However, the challenge lies in the

substantial per capita costs associated with capacity-building initiatives to fortify resilience, presenting a financial burden for small territories.
On the other hand, there is value in constructing a resilience index, which, as a complementary measure to the vulnerability index, analyzes each area's export basket. Indeed, this index serves multiple purposes, including assessing an area's risk of being damaged by external shocks. Moreover, it provides insights into the progress, or lack thereof, of economically vulnerable territories, whether individually or collectively, as they navigate and endure economic vulnerability. Furthermore, the resilience index can be a benchmark for identifying best practices in resilience-building strategies.

A final note is due to explain why, although appealing, more granular geographical disaggregation (i.e., city-level) would make no economic significance when analyzing export dynamics. While the idea of granular geographical disaggregation, such as analyzing export dynamics at the city level, may seem appealing for gaining insights into localized economic activities, it often needs more practical significance in export analysis. Several factors contribute to the limited utility of city-level disaggregation in understanding export dynamics.
Firstly, the administrative boundaries of cities may need to align with the functional economic regions involved in trade activities. Economic activities often transcend city boundaries, with trade flows influenced by transportation networks, economic clusters, and regional policies. As a result, focusing solely on individual cities may overlook the interconnectedness of trade networks and fail to capture the broader regional dynamics shaping export patterns.
Secondly, data reliability and availability at the city level pose significant challenges. While national-level trade data are generally comprehensive and regularly updated, city-level trade data may need to be more varied, consistent, or subject to reporting biases. Accurate city-level export data often requires extensive resources and cooperation from multiple stakeholders, including government agencies, trade associations, and private enterprises. Without reliable data, conducting meaningful analysis and drawing robust conclusions becomes difficult.
Furthermore, the economic significance of individual cities within a country's export landscape varies widely. While some cities are major trade hubs with significant export activities, others may have relatively limited economic importance in trade. Focusing excessively on less economically significant cities may dilute the analytical focus and obscure insights into the primary drivers of export dynamics. Instead of city-level disaggregation, analysts often opt for regional or subnational geographical units that better reflect economic integration and trade patterns. Regional breakdowns, such as analyzing exports at the state or provincial level, provide a more comprehensive view of trade dynamics while still capturing localized variations in economic activities. Additionally, regional analysis allows for comparisons across similar economic regions and facilitates the identification of regional disparities and opportunities for targeted policy interventions.
In summary, while the idea of granular geographical disaggregation may seem intuitive, practical considerations such as data availability, economic significance, and regional integration suggest that focusing on broader geographical units, such as regions or states, offers more meaningful insights into export dynamics.

A methodological framework emerges for evaluating the risk of external shocks by differentiating structural (inherent) economic vulnerability and policy-driven (nurtured) economic resilience.

This framework elucidates two crucial risk elements: (a) structural conditions within the territory exposed to exogenous shocks and (b) conditions that empower the economy to absorb, cope with, or recover from external shocks. The risk of adverse impacts from the shock is the amalgamation of these two elements.
Understanding these elements is essential for developing effective strategies to address economic vulnerability and enhance resilience. One valuable aspect of this understanding is measuring export stability, which provides valuable insights into a country's economic vulnerability. By assessing the stability of export revenues over time, we can gauge the country's susceptibility to external economic fluctuations and shocks. A higher degree of export stability often indicates a more robust economy less vulnerable to external pressures, while significant fluctuations in export revenues may signify heightened economic vulnerability. Therefore, monitoring export stability can serve as a useful proxy for understanding and measuring a country's economic vulnerability, enabling policymakers to implement targeted strategies to enhance resilience and mitigate risks.

Two particularly promising applications of measuring export stability lie in assessing the impact of recent crises, such as the COVID-19 pandemic and the Global Financial Crisis. These events are ideal case studies due to their profound and widespread economic repercussions. The COVID-19 pandemic, for instance, caused unprecedented disruptions to global supply chains and trade flows, severely impacting export-dependent economies. By analyzing export stability in the context of this crisis, policymakers can gain valuable insights into the resilience of nations' economies and identify vulnerabilities that need to be addressed. Similarly, the 2008 Global Financial Crisis showcased how financial turmoil can rapidly translate into trade shocks, affecting export earnings and stability. Studying export stability during this period offers critical lessons on mitigating the adverse effects of financial crises on international trade. Thus, examining export stability within the framework of these crises provides a nuanced understanding of the challenges faced by economies and informs strategies for building greater resilience against future shocks.

Possible extensions to the above overall export stability measures can introduce sectoral or geographical perspectives. On the one hand, the concentration of exports in high-value-added or high-tech sectors serves as an essential metric in assessing a country's export vulnerability. High concentration in a narrow range of sectors implies a heightened exposure to fluctuations in those industries. While high-value-added sectors may yield substantial profits, they are often more sensitive to global economic conditions and technological changes. These sectors' sudden downturns or disruptions can lead to severe economic consequences. This measurement captures the risk associated with relying heavily on specific industries, especially those prone to rapid technological advancements or shifts in global demand. A diverse export portfolio, including high-value-added sectors, can act as a buffer, mitigating vulnerability and enhancing a country's resilience against sector-specific shocks.

7.1 Map F.1 - Export stability during the Covid-19

Measuring export vulnerability is crucial to understanding a country's economic resilience, especially given the dynamic nature of international trade and its susceptibility to external shocks. In this context, export stability, as quantified by the standard deviation of exports, which accounts for their dispersion over time, over their mean, which accounts for structural scale effects, is a good example, and it offers valuable insights into the resilience and vulnerability of a country's economic structure. The standard deviation of exports over their mean is directly linked to vulnerability because it reflects the variability and unpredictability of a country's export earnings. A higher standard deviation implies greater fluctuations in export values, indicating higher exposure to external shocks. This volatility can stem from fluctuating demand in international markets, changes in commodity prices, or geopolitical events, which can significantly impact a country's economic stability. Indirectly, export stability is intertwined with an economy's ability to withstand shocks. A stable and consistent export performance signifies economic resilience, suggesting that the country can navigate uncertainties and external pressures without drastic disruptions. In contrast, high export volatility can indicate a higher susceptibility to external shocks, potentially leading to economic downturns, trade imbalances, and challenges in maintaining stable economic growth.

Furthermore, the standard deviation of exports over their mean is a robust indicator of export stability. By capturing the dispersion of export values around their average, it quantitatively measures how consistent or erratic a country's export performance is over time. A lower standard deviation suggests a more stable and predictable export profile, while a higher standard deviation indicates greater variability and, consequently, higher vulnerability to external factors.

In addition to standard deviation, assessing the resilience of export performance could involve measuring the speed and efficiency of recovery after facing exogenous shocks. A metric such as the recovery time from a significant drop in exports or the elasticity of export rebound following a shock could provide insights into how well a country can adapt and recover from adverse events. For instance, the measurement of export stability through the standard deviation of exports over their mean offers a comprehensive understanding of an area's vulnerability to external shocks. It directly captures the variability in export earnings and indirectly reflects a nation's resilience in navigating uncertainties. Additionally, considering recovery metrics enhances the evaluation of a country's ability to bounce back from exogenous shocks and underscores the importance of a holistic approach to measuring export vulnerability.

On a broader scale, export vulnerability measurements at the sub-national level shape global economic stability. International organizations, including the IMF and World Bank, leverage this data to monitor and assess vulnerabilities worldwide. Identifying sub-national units with high export vulnerability allows for targeted assistance and collaborative efforts to strengthen economic resilience globally, acknowledging the interconnected nature of economic systems. Academic and research institutions delve into export vulnerability at the sub-national level, contributing valuable insights to academic literature. This knowledge generation aids in developing theories, models, and policy recommendations specific to sub-national units. Civil society organizations and NGOs leverage this research for advocacy, raising awareness about concentrated exports' social and environmental impacts within sub-national contexts.

Export vulnerability measurements take on heightened significance when applied to sub-national units. By understanding and addressing these measures within a localized context, stakeholders can collectively contribute to building economic resilience at the sub-national level. This approach aligns with the broader goal of fostering sustainable development and mitigating vulnerabilities, particularly in the face of sector-specific shocks at the sub-national scale.

Indicator dimensions

Economy

Type of indicator

Status

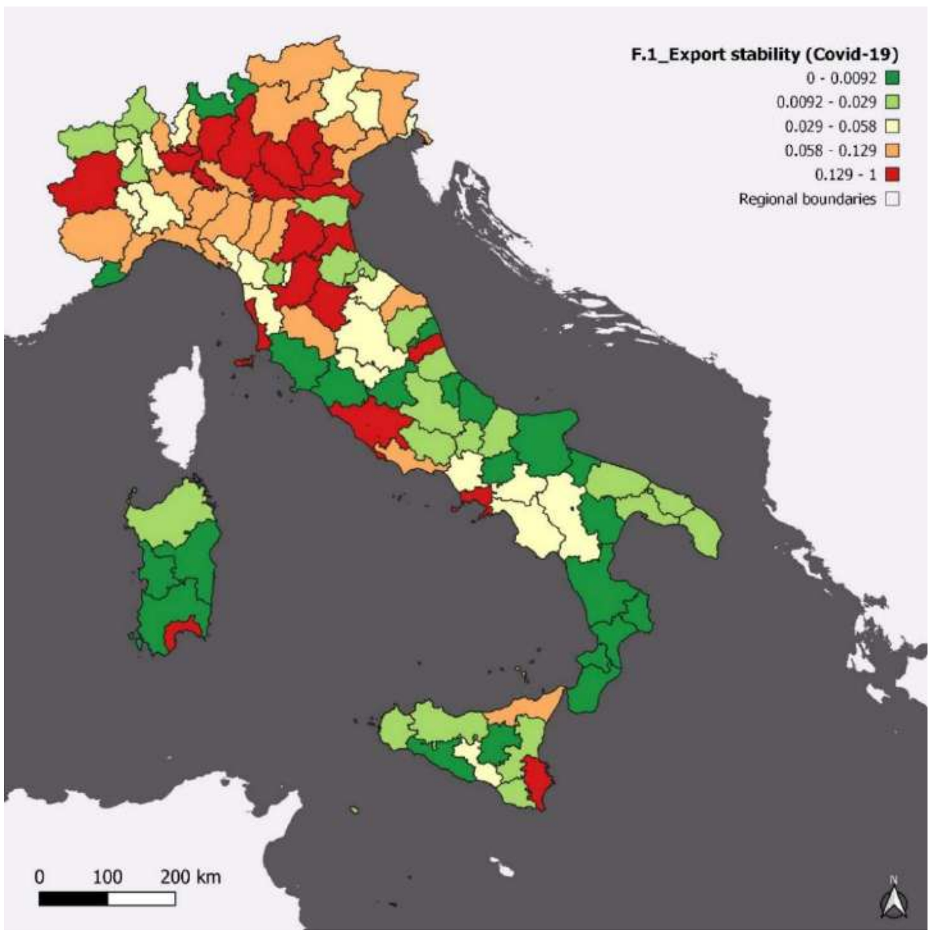

Figure F.1: Export stability of Italian territories based on the response to the COVID-19 shock

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
F.1	Export stability (Covid-19)	2017-2022	province	n.a.	CoE-web

Table F.1/a: Indicators' metadata and sources.

Geographic distribution	F.1
Center	0,13
Islands	0,08
North-East	0,10
North-West	0,11
South	0,03
Total	0,09

Table F.1/b: Export stability (Covid-19). Average values for the different geographic distributions

F.1_ Export stability (Covid-19)

The indicator "Export stability (Covid-19)" falls under the dimension of Economy, specifically within the Export and international trade component. It serves as a metric to gauge the resilience of exports amid the Covid-19 pandemic. This indicator quantifies the stability of exports by examining the relative variance of export values, calculated as the variance in the absolute value over the mean export value during the shock period. Classified as a simple indicator, it doesn't have a specific unit of measurement. Its type is categorized as "Status", indicating its role in reflecting the current state rather than exerting pressure. With a negative polarity concerning vulnerability, it suggests that higher export stability corresponds to lower susceptibility to adverse impacts. Data for this indicator is sourced from CoE-web, with information available from 2017 to 2022. The analysis is conducted at the provincial level, adhering to the NUTS3 2021 classification system. This comprehensive approach provides valuable insights into the economic resilience of regions amidst the challenges posed by the pandemic.

7.2 Map F.2 - Export stability during the Global Financial Crisis

The same considerations as in the previous paragraph also apply to this map.

Indicator dimensions

Economy

Type of indicator

Status

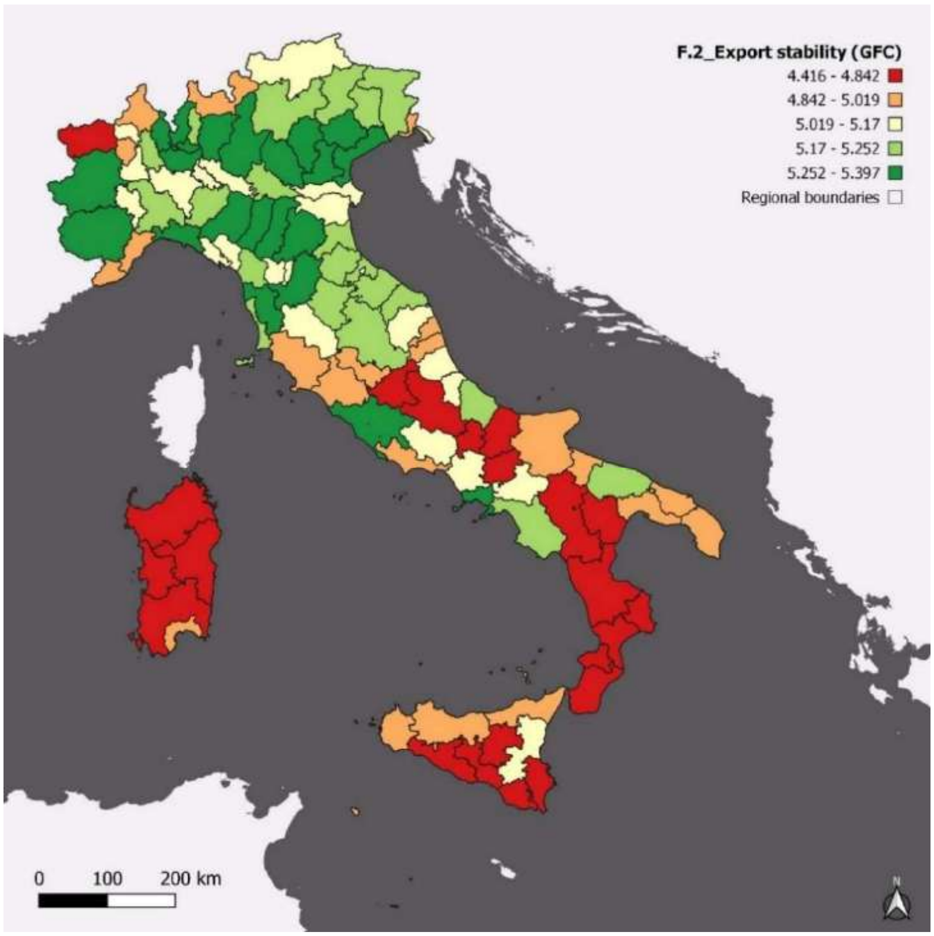

Figure F.2: Export stability of Italian territories based on the response to the Global Financial Crisis

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
F.2	Export stability (GFC)	2005-2010	province	n.a.	CoE-web

Table F.2/a: Indicators' metadata and sources.

Geographic distribution	F.2
Center	0,04
Islands	0,12
North-East	0,05
North-West	0,06
South	0,02
Total	0,05

Table F.2/b: Export stability (GFC). Average values for the different geographic distributions

F.2_ Export stability (GFC)

The indicator Export stability (GFC) delves into the stability of exports during the Global Financial Crisis (GFC) spanning from 2005 to 2010. It quantifies the relative variance of exports, computed as the variance in the absolute value over the mean export value during this turbulent period. Classified as a simple indicator, it lacks a specific unit of measurement. It is categorized as a "Status" type and reflects the current state rather than exerting pressure. With a negative polarity concerning vulnerability, it implies that higher export stability correlates with reduced susceptibility to adverse impacts. Data for this indicator is derived from CoE-web, offering insights pivotal for understanding economic resilience during significant global financial upheaval. The analysis is conducted at the provincial level, adhering to the NUTS3 2021 classification system, facilitating a detailed exploration of regional economic resilience amidst such systemic crises.

7.3 Map F.3 - Export diversification: geographical perspectives

Export diversification and economic vulnerability are intrinsically linked through several economic mechanisms. As mentioned, diversification reduces vulnerability by spreading risks across a broader base, thereby cushioning the economy against shocks in any particular sector or market (Hirsch & Lev, 1971). Economies reliant on a narrow range of exports are more susceptible to external shocks, such as fluctuations in commodity prices or shifts in global demand. Additionally, diversified economies tend to have more robust supply chains and greater resilience to disruptions, as they are not overly dependent on specific suppliers or buyers. Moreover, export diversification fosters innovation and competitiveness, enabling economies to adapt more effectively to changing global trends and technological advancements (Haini et al., 2023). Therefore, fostering export diversification is not merely a strategy for enhancing economic growth but also a means of reducing vulnerability and promoting long-term stability in local economies. Export diversification encompasses two critical dimensions: sectoral and geographical. Geographical diversification entails distributing exports across diverse markets or regions, reducing vulnerability to regional economic fluctuations and geopolitical tensions.

Geographical diversification, assessed through entropy measures, provides insights into the distribution of exports across different markets or regions. High geographical entropy values imply a broad geographic spread of exports, indicating reduced dependence on any single market or region. This diversification buffers the economy against regional economic downturns, trade disputes, or geopolitical tensions. Conversely, low geographical entropy values denote concentration in a limited number of markets or regions, increasing vulnerability to disruptions in those areas.

In practical terms, understanding the relationship between export diversification and local economic vulnerability enables policymakers to devise targeted strategies to enhance resilience. By leveraging entropy measures, policymakers can identify regions or sectors with inadequate diversification and tailor interventions accordingly. Strategies may include targeted investments in diversified sectors, fostering innovation and technological advancement, improving market access, and enhancing infrastructure and institutional frameworks (Hidalgo, 2023).

In conclusion, the nexus between export diversification, as measured by entropy indices, and local economic vulnerability is crucial for promoting sustainable economic development. By fostering diversification, economies can mitigate risks associated with sectoral or regional shocks, thereby enhancing resilience and ensuring long-term stability at the local level.

Governments and policymakers can use these measurements to inform strategic decisions. Diversifying export portfolios, encouraging innovation and technology diffusion, and fostering diplomatic and economic relationships with a broader range of stable partners can be effective strategies to mitigate export vulnerability (Duan et al., 2022). Generally, addressing export vulnerability at the sub-national level necessitates a multifaceted approach, recognizing the intricacies of regional economies. One pivotal strategy involves inducing structural change. Sub-national governments can champion investments in education, technology, and innovation, fostering industries with high growth potential. This diversifies the economic landscape and equips the local workforce with adaptable skills, reducing dependence on vulnerable sectors. Promoting innovation and technology adoption is equally significant. Establishing innovation

hubs, research centers, and technology parks stimulates local innovation. Incentives for businesses to adopt new technologies enhance productivity and competitiveness, fortifying them against external shocks (Zhou & Fan, 2023).
Active participation in trade negotiations and agreements is a proactive strategy. Sub-national governments can advocate for local businesses, reducing trade barriers and creating favorable export conditions. Such agreements open new markets, reducing reliance on specific countries or regions. This can lead to further diversifying export partnerships. By actively seeking relationships with diverse trading partners, local economies can minimize dependence on specific markets, mitigating risks associated with economic downturns or geopolitical uncertainties (Lancieri, 2014).

Indicator dimensions

Economy

Type of indicator

Status

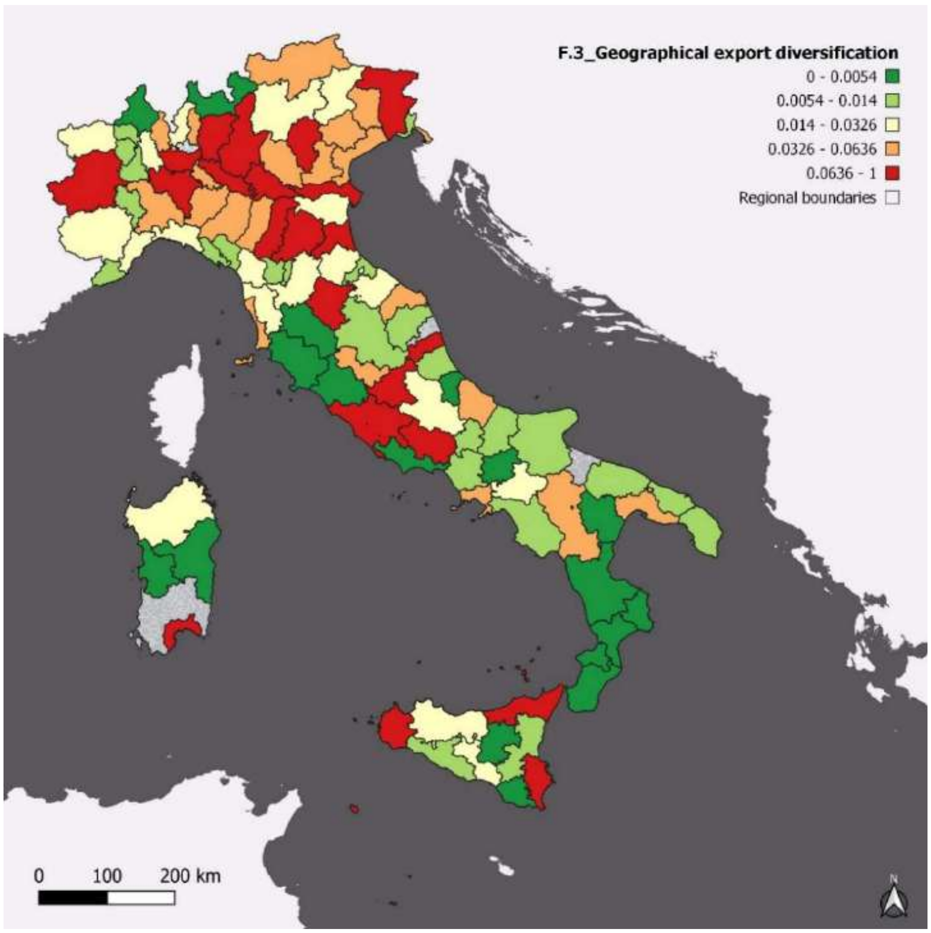

Figure F.3: Export diversification in terms of reached destinations of Italian territories in the period 2017-2022

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
F.3	Geographical export diversification	2017-2022	province	n.a.	CoE-web

Table F.3/a: Indicators' metadata and sources.

Geographic distribution	F.3
Center	5,10
Islands	4,74
North-East	5,23
North-West	5,15
South	4,90
Total	5,05

Table F.3/b: Geographical export diversification. Average values for the different geographic distributions

F.3_ Geographical export diversification

The geographical diversification index, calculated as the average of Shannon's entropies each year from 2017 to 2022, offers a quantitative measure of the level of diversification achieved within an economy. A higher entropy value indicates greater diversification and, thus, reduced vulnerability to external shocks. This metric serves as a simple yet effective tool for assessing economic resilience. The negative status indicates that higher levels of diversification correspond to lower vulnerability, emphasizing the importance of diversification strategies in fostering economic stability. The data source, COE-web, provides access to pertinent information on the province-level analysis (NUTS3 2021), offering valuable insights into provincial economic dynamics. This is shown in Figure F.3.

7.4 Map F.4 - Export diversification: sectoral perspective

The second critical dimension of export diversification is the sectoral dimension. Sectoral diversification involves the expansion of a country's export base across a wide array of industries, mitigating risks associated with over-reliance on specific sectors

When considering sectoral diversification, entropy indices serve as valuable tools for quantifying the dispersion of exports across various industries. A high sectoral entropy value indicates a balanced distribution of exports, signifying a diverse export base. This diversification reduces the economy's susceptibility to sector-specific shocks, such as changes in global demand or disruptive technological advancements. Conversely, low sectoral entropy values suggest concentration within a few industries, heightening the economy's vulnerability to fluctuations in those sectors.

Indicator dimensions

Economy

Type of indicator

Status

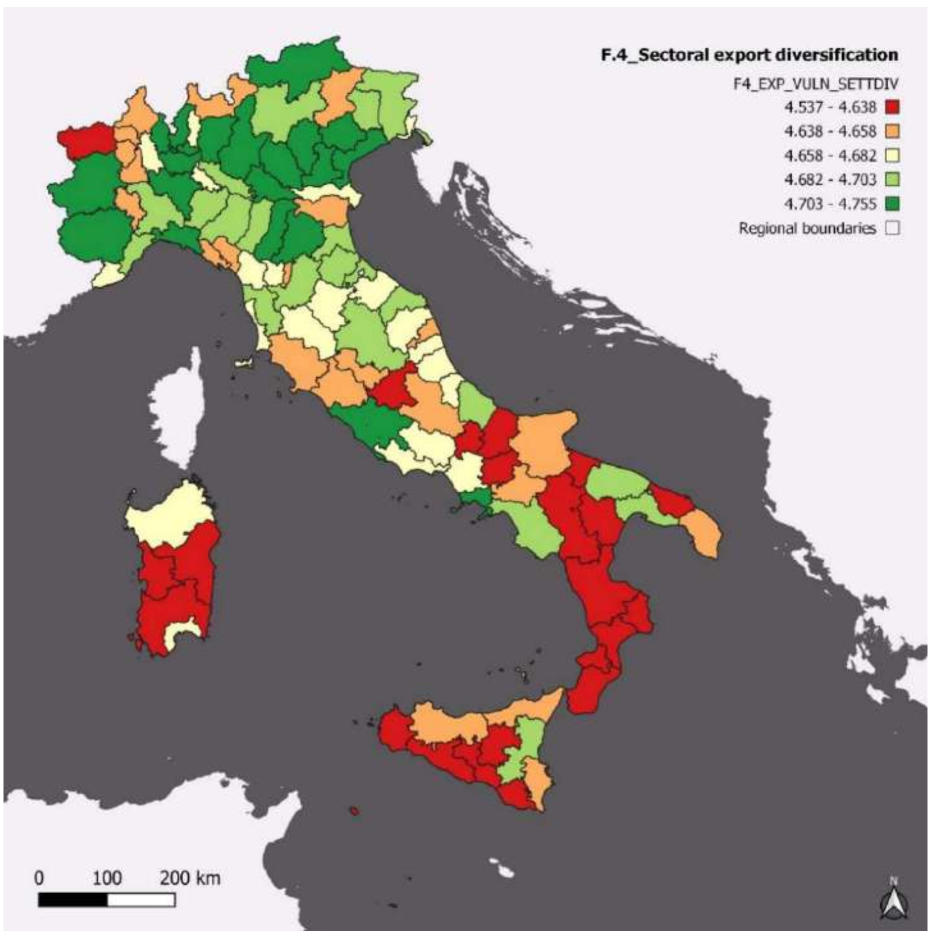

Figure F.4: Export diversification in terms of exported sectors of Italian territories in the period 2017-2022

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
F.4	Sectoral export diversification	2017-2022	province	n.a.	CoE-web

Table F.4/a: Indicators' metadata and sources.

Geographic distribution	F.4
Center	4,67
Islands	4,62
North-East	4,70
North-West	4,69
South	4,64
Total	4,67

Table F.4/b: Sectoral export diversification. Average values for the different geographic distributions

F.4_ Sectoral export diversification

The sectoral diversification index, particularly calculated as the average of Shannon's entropies over each year from 2017 to 2022, offers a quantitative measure of the level of diversification achieved within an economy. A higher entropy value indicates greater diversification and, thus, reduced vulnerability to external shocks. This metric serves as a simple yet effective tool for assessing economic resilience. The negative status indicates that higher levels of diversification correspond to lower vulnerability, emphasizing the importance of diversification strategies in fostering economic stability. The data source, COE-web, provides access to pertinent information on the province-level analysis (NUTS3 2021), offering valuable insights into provincial economic dynamics. This indicator is shown in Figure F.4.

7.5 Map F.5 - Relationship between Emissions and Foreign Trade

The thematic map presented is aimed at linking emissions expressed with PM10 levels with respect to foreign trade, given by the sum of the monetary values of imports and exports.
The choice to use the values of PM10 in the air as a proxy for emission volumes is due to the implications on several aspects of life and the environment among which we can consider:

- public health, where particulate matter can enter the lungs and respiratory system, causing problems such as asthma, chronic lung disease, and increasing the risk of cardiovascular disease
- the worsening air quality, which can lead to restrictions on outdoor activity and increase the need for regulations and policies to mitigate these externalities
- the critical environmental issues, with particulate matter that can settle on soil, water and vegetation, affecting ecosystems and contributing to soil and water acidification, damaging biodiversity.
- the economic aspects, where high levels of air pollution can impact the economy through reduced productivity due to disease, increased health care costs, and decreased tourism due to poor air quality.

This indicator, aims to relate levels of environmental pollution to monetary volumes of foreign trade. As such, areas associated with high levels of foreign trade will be characterized by extremely high productivity and a thriving industrial fabric. As a result, these areas will be more vulnerable to environmental aspects, in that, the management of pollutants and air quality could also go to affect the labor productivity of areas subject to higher levels of PM10.
Analyzing now, the maps presented, it becomes clear how the index elaborated has more significant intensity of the phenomenon for the area of Northern Italy, and in particular with regard to the highly industrialized area of Piedmont, Lombardy and Veneto regions.
This cartographic representation clearly highlights how Northern Italy is characterized by the presence of important trade trends to and from abroad and significant levels of pollutants present in the different areas.
It also seems clear, that import and export volumes are also associated with the presence of strategic transport infrastructure on a national scale, such as the presence of ports, airports and interports. Indeed, in this regard, we can see that the majority of provinces characterized by the presence of port contexts are characterized by an extremely lively development of both foreign trade and the level of emissions in the area. In this respect, we must in fact point out that, the presence of commercial and tourist ports is associated with high levels of emissions, in relation to the presence of ships at the dock or roadstead (Gallo, 2022, McKinnon, 2010).
It is clear from these papers that there is a relationship between emission levels, industrial development and foreign trade.
The considerations just presented are also reflected through the use of LISA, presented below. Indeed, we can clearly see a cluster associated with the previously highlighted area of the Po Valley of Veneto and Lombardy, characterized by the presence of high levels of foreign trade and high levels of PM10 emissions. It seems interesting to note that there is significant overlap between the areas highlighted in the first and second maps, where different vulnerability indices highlight common areas both through thematic mapping and using spatial association indices.

Indicator dimensions

Environment and Economy. The indicator presented is aimed at relating the emission levels of PM10, expressed in term of annual average concentration of particular matter in the air, and the foreign trade expressed in monetary value on a provincial basis for the Italian territory.

Type of indicator

Status

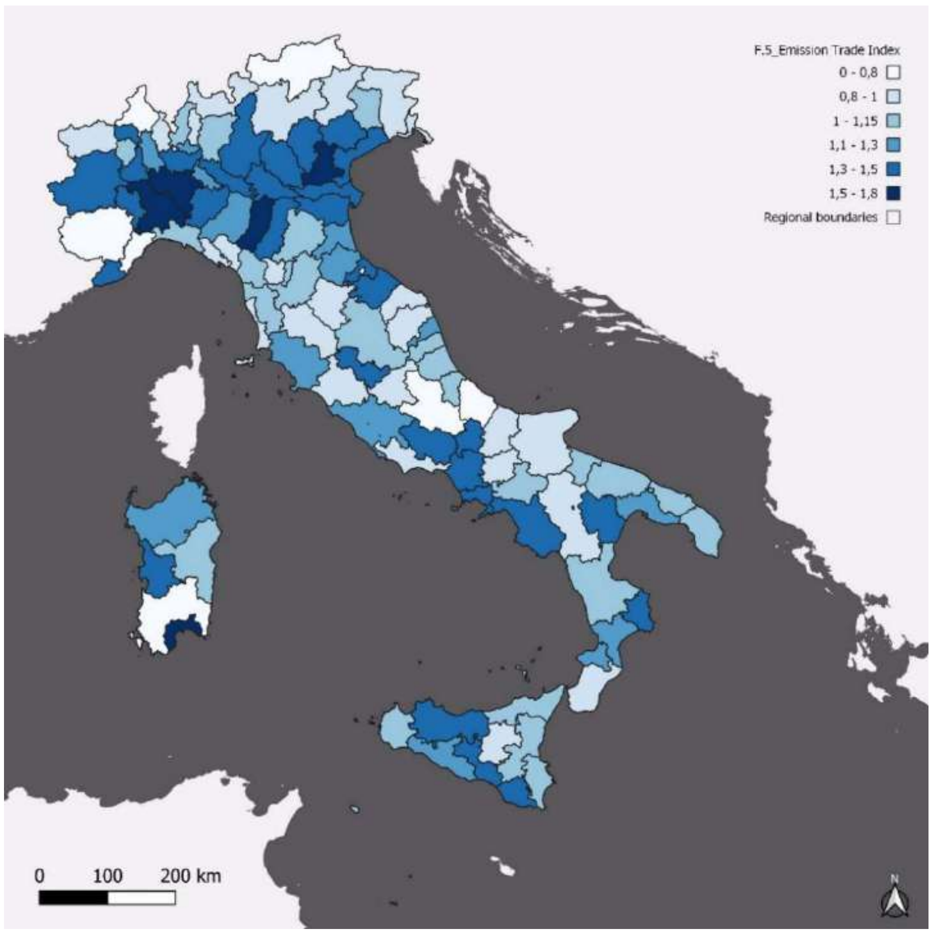

Figure F.5: Relationship between emissions and foreign trade

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
F.5	Emission Trade Index	2022	Province	n.a.	BES; CoE-web
F.5.1	Monetary Value of Import and Export	2012	Province	Euro	ISTAT CoE-web
F.5.2	Average Volume of PM10	2022	Province	Micrograms	BES

Table F.5/a: Indicators' metadata and sources

Geographic distribution	F.5.1*	F.5.2	F.5
Center	10.162,02	24,00	1,06
Islands	4.350,01	24,79	1,18
North-East	14.869,14	28,18	1,22
North-West	19.241,12	26,92	1,16
South	4.352,95	23,58	1,10
Total	11.187,70	25,55	1,14

*millions of €

Table F.5/b: Emission Trade Index. Average values for the different geographic distributions

F.5_ Emission_Trade_Index

The index used for the implementation of the map was calculated using the reciprocal of the ratio of the logarithm of the sum of exports and imports to emission volumes as presented in the following formula (2):

$$\frac{1}{\frac{ln\,(X+M)}{PM10}} \qquad (1)$$

Where:
(X+M) : Monetary value in euros of the sum of imports and exports by provinces (2022).
PM10: Annual average concentration of PM10 for the year 2022.

F.5.1_ Monetary Value of Import and Export

Monetary value in euros of the sum of imports and exports by provinces for the year 2022, provided by Coe-Web, the online database of the commerce outlined by ISTAT.

F.5.2_ Average Volume of PM10

Annual average concentration of PM10 for the year 2022 provided by the BES for Provincies (Fair and Sustainable Wellbeing Indicators of the provinces)

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8. Dossier G – Climatic vulnerability

Understanding and assessing vulnerability to climate change is crucial for being able to support the development of adequate policy-realted responses that reduce the risks associated with an adverse environmental effect.

When it comes to risks and vulnerability associated to climate change, there are two main kinds of responses that are traditionally identified to cope with climate change (Füssel and Klein, 2006): adaptation and mitigation to climate change. Mitigation tackles climate change by working on the reduction of the main causes of the climate change itself thus reducing the emissions of greenhouse gases (GHGs) and enhancing their sinks. Adaptation starts form considering the effects of climate change and consequently defines a wide range of actions that are aimed at adapting the systems exposed to the adverse effects.
Mitigation has traditionally been receiving more attention form scientists and policy makers for different reasons, among which the easiness to monitor quantitatively GHG emissions reduction is comprised. However adaptation measures are receiving more and more attention being necessary to face climate change impacts in the short term due to the big inertia of the climate system to be affected by mitigation measures. Moreover, while mitigation needs an international cooperation, adaptation can be addressed at local scale.

The Intergovernmental Panel on Climate Change (IPCC, 2022) defines vulnerability (to climate change) as "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2022) when exposed to hazards. According to Füssel and Klein (2006) this definition recognize both an external dimension, which is represented by the 'exposure' of a system to climate variations, and an internal dimension, which comprises its 'sensitivity' and its 'adaptive capacity' to these stressors. Exposure identifies the degree and nature to which a system is exposed to significant climate variations, sensitivity is the degree to which a system is affected by climate-related stimuli, adaptive capacity is the ability of a system to adjust to climate change.
Beside these dimensions it is also possible to identify three main kinds of methods for assessing vulnerability which have been developed over time and presented in chronological order (Soares et al., 2010):

- risk-hazard methods that adop a biophysical perspective upon vulnerability by understanding the climate change impacts thus concentrating on assessing the progresses in reducing GHG emissions, stressing the exposure
- methods adopting a social perspective, thus considering vulnerability as an intrinsic condition of a social system, stressing coping capacity and sensitivity
- integrated approaches to vulnerability which couple perspective of social and ecological system (Peng et al. 2024).

These three approaches denotes an evolution in the vulnerability assessment which has been enriched by studies from different disciplines, underlining that vulnerability to climate change effects a complex domain, affecting different human and environmental factors.
Without the ambition to address all the possible factors, In this study we aimed at identifying

specific indicators and indexes which are able to assess important domains of vulnerability, by adopting social and risk related perspectives, in order to orient both mitigation and adaptation policies. We give specific attention to social perspective and consequently adaptation measures having the capacity to be more site-specific and effective in the short time.

8.1 Map G.1 - Climate change Adaptability index

Climate risk results from a combination of local conditions, including climate hazards, exposure and vulnerability. Besides it is important to assess the adaptive capacity of a territory to cope with these challenges.
When it comes to hazard it is important to consider specific situation depending on the cliomatic zone. Italy is comprised into the Mediterranean region which is predominantly vulnerable to the impacts of warming and changes in rainfall, notably prolonged and stronger heat waves, increased drought in an already dry climate (Ali et al. , 2022). The combination of climate hazards, high regional vulnerability and exposure make it a prominent climate change hotspot (Giorgi, 2006).
As far as the adaptive capacity of a territory is concerned, place-based features such as land use changes can affect the capacity of a territory, especially urbanized areas, to address climate-related risks, both positively and negatively. The connection between green infrastructure and adaptive capacity may illustrate this point in terms of positive contributions (Carter, 2018). In this sense soil sealing and land take lead to adverse effects such as loss of ecosystem services, urban heat island and flooding that are exacerbated by climate change.
In order to assess hazards related to drough and warming and consequently the exposure of socio-ecological systems, several indicators are identified in literature. While mean temperature increase is a good indicator for exploring the scale of global warming in each local community, duration of hot periods, consecutive days without rain are relevant indicators both for assessing the current situation and projecting the future ones (Papathoma-Koehle et al. 2016; Zhao et al. 2020; Ali et al., 2022). Conversely permeable soils and the presence of vegetation are indicators that have the capability ot increase the adaptive capacity of a territory to adverse effects of climate change, assessing the beneficial presence of green infrastructures (Carter, 2018).
In this study we elavorate a synthetic index that we called Climate change Adaptability index. The index has been calculated by considering the work done by Assumma et al (2019), and Monaco et al. (2018) which was transposed in the climate domain, by considering indicators provided by different sources. Basically the adopted method aims at calculating two sinthetic indexes that respectively measure the exposure (E) of the socio-ecological system, and its adaptive capacity (A) by adopting a general perspective. This means taking into account climatic factors that might influence different spheres, such as the environment as well as the society. The final index aims to provide a general measure of the level of response of environmental/anthropogenic factors to climate effects affecting a given territory. Therefore the index does not aim at being totally exhaustive in terms of indicaotors adopted (whose selection is influenced by data availability), however it is a valuable tentative to synthesize any vulnerabilities that can be further investigated.

Indicator dimensions

Environment

Type of indicator

Pressure

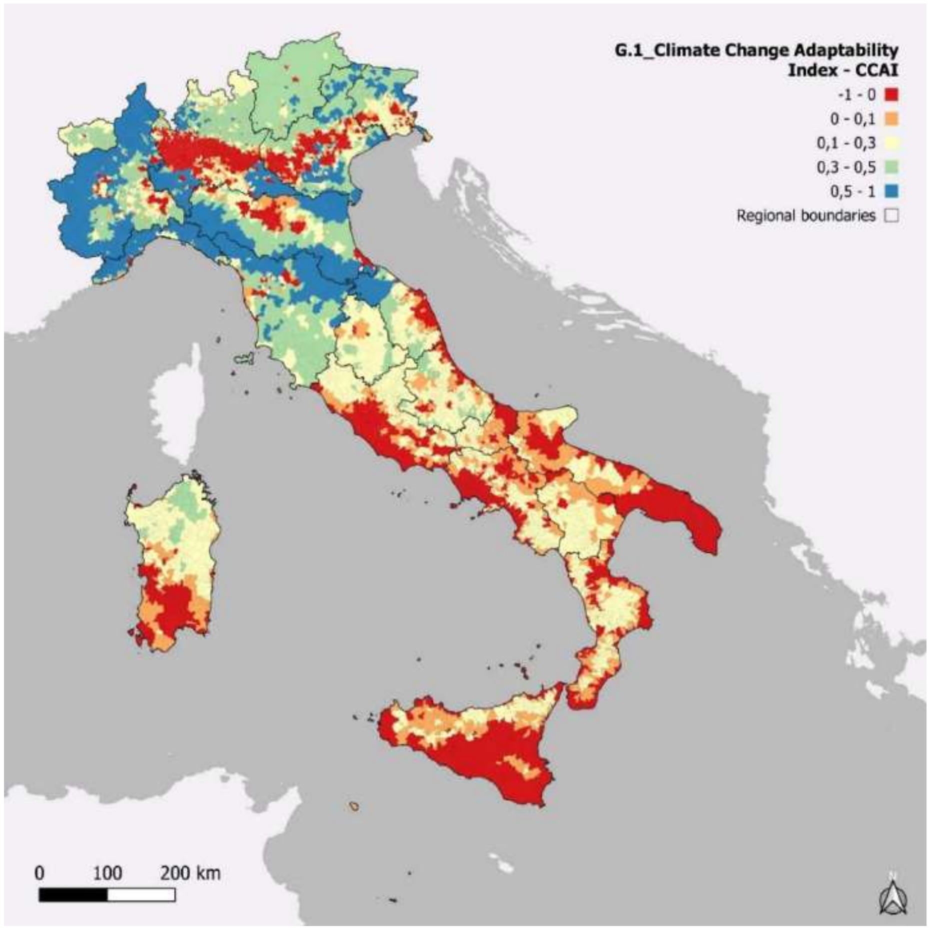

Figure G.1: Climate change adaptability index.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
G.1	Climate change adaptability index	2018/2021	Municipal (LAU)	na	Authors' elaboration
G.1.1	Consecutive days without rain	2021	Provincial (NUTS3)	no of days	ISTAT
G.1.2	Duration of hot periods	2021	Provincial (NUTS3)	no of days	ISTAT
G.1.3	Average temperature increase from 1960 to 2008	2018	Municipal (LAU)	°C	EDJNet
G.1.4	Tree canopy density	2018	Municipal (LAU)	%	COPERNICUS
G.1.5	Permeability	2018	Municipal (LAU)	%	COPERNICUS

Table G.1/a: Climate change adaptability index. Indicators' details

Territorial typology	G.1.1	G1.2	G1.3	G1.4	G1.5	G.1
1 INNER ITALY	29	16	2.20	99	39	0.26
1.1.1 - Inner, remote and sparsely populated area	28	16	2.20	99	41	0.29
1.1.2 - Inner and remote area with medium population density	29	19	2.34	95	32	0.07
1.2.1 - Sparsely populated inner area closest to a metropolitan area	31	19	2.10	99	39	0.27
1.2.2 – Inner area with medium population density closest to a metropolitan area	41	22	2.13	93	29	-0.11
2 INTERMEDIATE ITALY	25	12	2.07	94	29	0.19
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	26	14	2.06	98	40	0.34
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	23	9	2.25	92	38	0.16
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	25	8	1.94	96	11	0.26
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	25	13	2.14	90	12	-0.13
2.2 - Medium-sized city or non-FUA capital	28	16	2.02	89	21	-0.11
2.3 - De facto or de jure metropolitan fringe	25	12	2.01	90	26	0.08
3 METROPOLITAN ITALY	28	14	2.20	85	23	-0.17
3.1 - De facto metropolitan centre	22	11	2.26	78	12	-0.48
3.2.1 - De jure and de facto metropolitan area (not capital)	28	14	2.21	85	23	-0.16
3.2.2 - Metropolitan capital	33	17	2.06	74	17	-0.44

Table G.1/b: Climate change adaptability index. Average values for the different territorial typologies

G.1_ Climate change adaptability index

According to Assumma et al (2019) and Monaco et al. (2018) the Climate change adaptability index (CCAI) is the combination of two separate indexes:

- the climate exposure E = $\sum \mathrm{GNi}$, where GNi is the normaized value of the indicators G.1.1, G.1.2, G.1.3;
- the adaptation A = $\sum \mathrm{GNj}$, where GNj is the normaized value of the indicators G.1.4, G.1.5;

E and A are combined into the synthetic index by using the formula CCAI=(A-E)/(A+E). Positive values mean a prevalence of A; negative values mean a prevalence of E. Consequently the more the negative value, the high the vulnerability.

G.1.1_ Consecutive days without rain

Maximum number of consecutive days in the year with daily rainfall less than or equal to 1 mm.

G.1.2_ Duration of hot periods

Number of days in the year in which the maximum temperature is above the 90th percentile of the distribution in the reference climatological period (1981-2010), for at least six consecutive days.

G.1.3_ Average temperature increase from 1960 to 2008

Occurred temperature variation between the mean temperature values for the two decades taken into account (1961-1970 e 2009-2018).

G.1.4_ Tree canopy density

Tree cover density represents the percentage of a surface area covered by trees and vegetation in relation to the total surface area.

G.1.5_ Permeability

mean percentage value of permeable surfaces in a given area. It is calculated by considering the complementary percentage of imperviousness provided by the HRL Coperinicus dataset Imperviousness density.

8.2 Map G.2 - CO2 emissions balance

Measuring greenhouse gas emissions trends is a key strategy to assess progresses in assessing the progresses done by a Nation or a territory to combat climate change. As already mentioned (Füssel and Klein, 2006), GHG reduction is considered a mitigation measure that needs to be undertaken even though the effects will be observed in the long period due to the inertia of the climatic system. Beside the emitting trends it is also relevant to assess positive contributions given by GHG sinks, such as forests and trees in general. Important climatic targets have been set to push terriotries to reduce GHG emissions, raging from the Paris Agreement (2015) to National and regional mitigation strategies. Moreover, specific policies are now focusing on afforestation/reforestation to mitigate the negative effects of climate change: one example is the Italian RRNP that fortesees the extraurban and urban forewstation plan (Mission 2, comp.4, invest. 3.1); therefore assessing how a territory can produce and store in terms of GHG emissions is relevant in order to understand which territories are more vulnerable in terms of capability for meeting the international targets and become carbon neutral.
In this study we propose to use an indicator calculated by ISPRA(2022) which provides the CO2 emissions potentially generated by a territory by considering all the main emitting sources as well as the carbon sinks.
The study carried out by ISPRA made it possible to estimate emissions for the main pollutants and greenhouse gases for all 103 provinces of the Italian territory and to provide an indication for each of them on the trend of emission pressure over the last 15 years.
This allows to obtain a balance of CO2 emissions thus underlying the most vulnerable territories in terms of their capacity to contribute to mitigate climate change. To simplify we analyzed CO2 (and not CO2 eq.) as a proxy of GHG emissions.

Indicator dimensions

Environment

Type of indicator

pressure

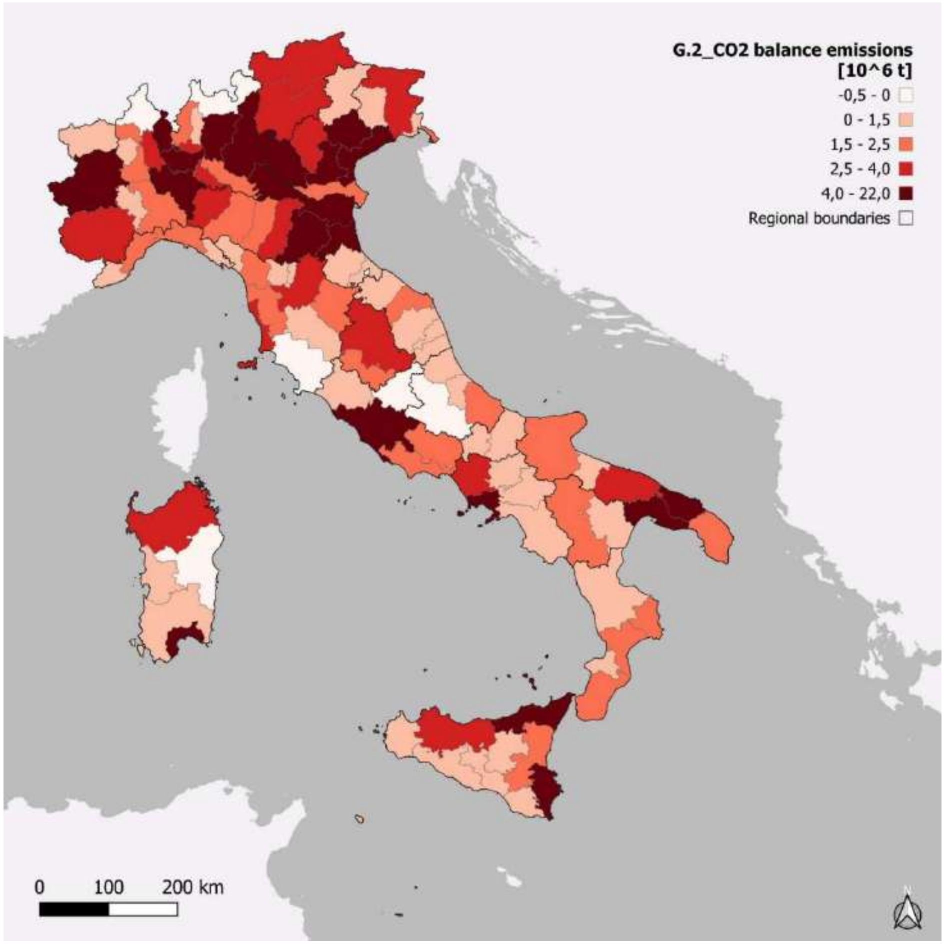

Figure G.2: CO2 emissions balance.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
G.2	CO2 emissions balance	2019	Provincial (NUTS3)	Mg	ISPRA

Table G.2/a: CO2 emissions balance. Indicator's details

Geographic distribution	G.2
Center	49,352,681
Islands	34,841,507
North-East	76,318,414
North-West	89,993,046
South	57,253,392
Total	307,759,040

Table G.2/b: CO2 emissions balance. Total values for the different geographic distributions

G.2_CO2 emissions balance

CO2 emissions are obtained by ISPRA from the provincial inventory of atmospheric emissions, which is the breakdown of the national emissions inventory. Database of air emissions for the year 2019, classified by CORINAIR (SNAP) activity level, disaggregated from the national inventory (Submission 2021: https://www.ceip.at/status-of-reporting-and-review-results /2021-submission; https://unfccc.int/ghg-inventories-annex-i-parties/2021) with top-down methodology. The disaggregation was carried out spatially both at the provincial level and on a 0.1×0.1 degree long/lat grid. The inventory takes into account also the CO2 sequestration due to soil and natural mass. Negative values mean that sequestration (due to soil, trees etc) prevails.

8.3 Map G.3 - Social vulnerability to flood risk

Despite some skepticisms at political level, the science of global climate change has becoming more precise in suggesting that an increase in the frequency of extreme weather events could be one result of the warming of the atmosphere (Blaikie et al., 2014), thus increasing several risks among which the hydrogeological risk is comprised. There is an increase in reported flood disasters and flood losses through time due to an increase in the frequency of disasters but also in population increase and urbanization in flood-prone areas (Kundzewicz et al. 2014), therefore it is crucial to assess the exposure of territories to this risk by considering the diversities in the flood risk related vulnerability. As already mentioned, different approaches to assess vulnerability to climate change exist. In this case we would underline the social vulnerability by concentrating our attention to the socio-economic domain. Indeed most vulnerable groups in terms of economic, education and demographic conditions tend to be less capable to cope with environmental risks. Similarly, to the Flood Vulnerability Index for Social component suggested by Balica et al. (2012) we propose an index that concentrates the attention to exposure and susceptivity to highlights weaknesses, thus considering the population exposition as exposure and the socio-economic conditions as susceptivity.

Indicator dimensions

Society

Type of indicator

Status

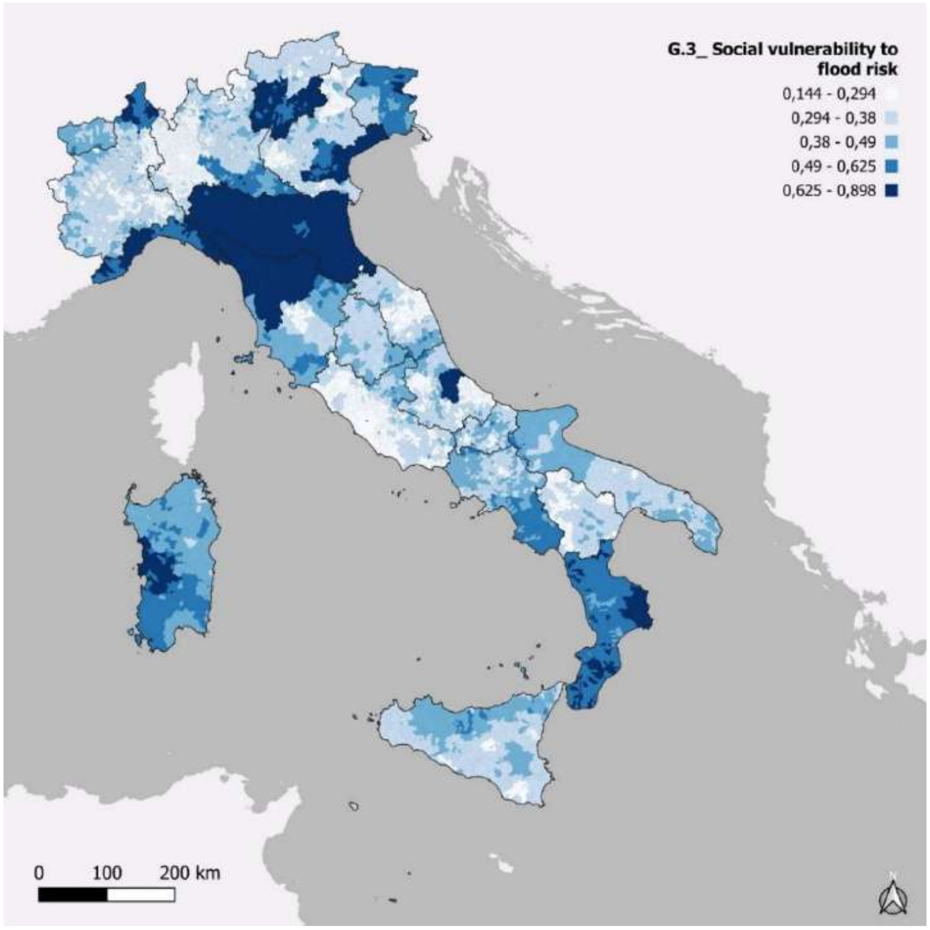

Figure G.3: Social vulnerability to flood risk.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
G.3	Social vulnerability to flood risk	2019/2022	Municipal (LAU)	na	Authors'e elaboration
G3.1	Population exposed to flood risk	2020	Provincial (NUTS3)	%	ISTAT
G.3.2	Socio-economic vulnerability index*	2019/2022	Municipal (LAU)	na	Authors'e elaboration

*see section 7.5

Table G.3/a: Social vulnerability to flood risk. Indicators' details

Territorial typology	G.3.1	G.3.2	G.3
1 INNER ITALY	8.91	0.58	0.45
1.1.1 - Inner, remote and sparsely populated area	9.42	0.58	0.46
1.1.2 - Inner and remote area with medium population density	5.42	0.53	0.38
1.2.1 - Sparsely populated inner area closest to a metropolitan area	9.35	0.61	0.47
1.2.2 – Inner area with medium population density closest to a metropolitan area	3.81	0.58	0.38
2 INTERMEDIATE ITALY	9.79	0.48	0.41
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	8.79	0.52	0.43
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	7.29	0.43	0.35
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	11.03	0.49	0.43
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	12.69	0.46	0.43
2.2 - Medium-sized city or non-FUA capital	12.04	0.43	0.40
2.3 - De facto or de jure metropolitan fringe	10.54	0.46	0.41
3 METROPOLITAN ITALY	9.37	0.40	0.35
3.1 - De facto metropolitan centre	21.88	0.35	0.45
3.2.1 - De jure and de facto metropolitan area (not capital)	9.02	0.40	0.35
3.2.2 - Metropolitan capital	13.09	0.43	0.43

Table G.3/b: Social vulnerability to flood risk. Average values for the different territorial typologies

G.3_ Social vulnerability to flood risk

The index is calculated as the average between the exposed population to flood risk and the socio-economic index.

G.3.1_ Population exposed to flood risk

Percentage of population living in areas of medium hydraulic risk (return time 100-200 years according to the former Legislative Decree 49/2010), identified on the basis of the ISPRA national mosaic of hydrogeological management plans (PAI) and related updates, with reference to risk scenario P2. The population considered is that of the 2011 Census.

G.3.2_ Socio-economic vulnerability index

Weighted average of the normalized indicators of: oldness index, gross available income per capita, Employment rate, People with at least a lower secondary school or professional qualification (for more details see section 7.5).

8.4 Map G.4 - Social vulnerability to landslide risk

Worldwide, landslides pose a serious threat to the population, causing fatalities, widespread damages, and significant economic losses. Similar to flooding, increasing extreme weather events to climate change may worsen landslide risk. Therefore it is crucial to assess the exposure of territories to this risk by considering the diversities in the landslide risk related vulnerability. As already mentioned, different approaches to assess vulnerability to climate change exist. In this case we would underline the social vulnerability by concentrating our attention to the socio-economic domain. Indeed most vulnerable groups in terms of economic, education and demographic conditions tend to be less capable to cope with environmental risks. Similarly, to what we propose for the previous index, we propose an index that concentrates the attention to exposure and susceptivity, to highlights weaknesses, thus considering the population exposition as exposure and the socio-economic conditions as susceptivity.

Indicator dimensions

Society

Type of indicator

Status

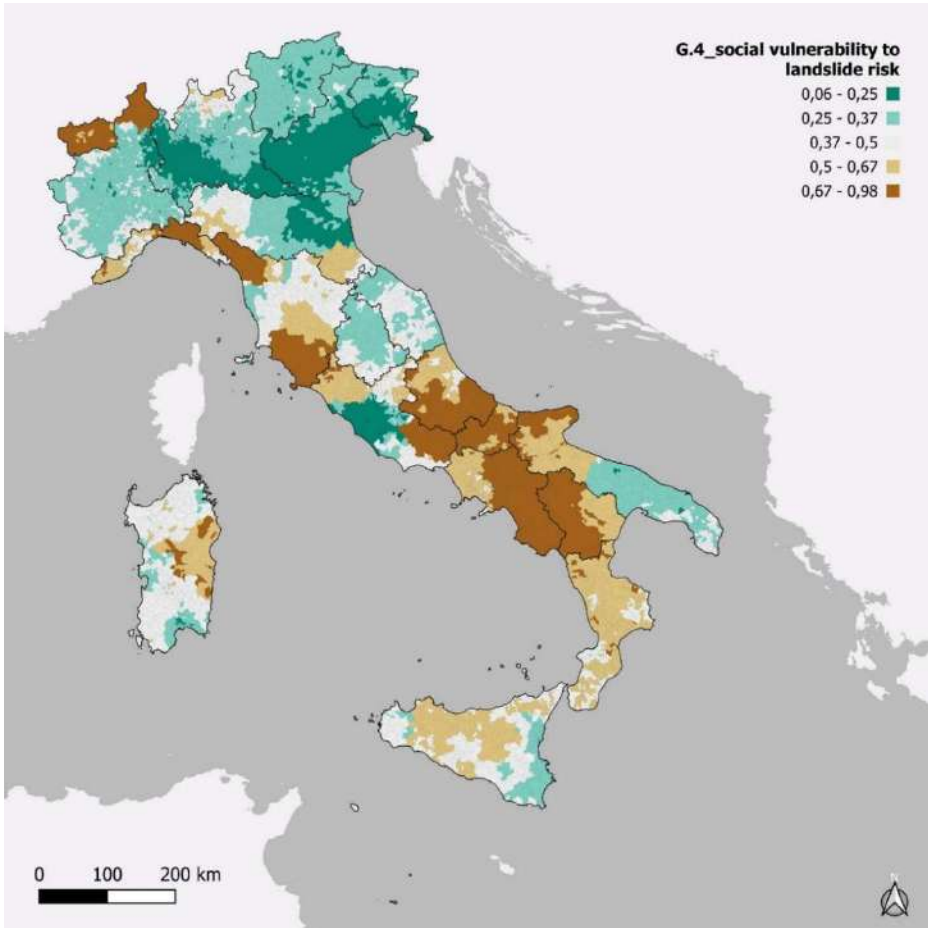

Figure G.4: Social vulnerability to landslide risk.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
G.4	Social vulnerability to landslide risk	2019/2022	Municipal (LAU)	na	Authors'e elaboration
G.4.1	Population exposed to landslide risk	2020	Provincial (NUTS3)	%	ISTAT
G.4.2	Socio-economic vulnerability index*	2019/2022	Municipal (LAU)	na	Authors'e elaboration

*see section 7.5

Table G.4/a: Social vulnerability to landslide risk. Indicators' details

Territorial typology	G.4.1	G.4.2	G.4
1 INNER ITALY	3.45	0.58	0.52
1.1.1 - Inner, remote and sparsely populated area	3.73	0.58	0.54
1.1.2 - Inner and remote area with medium population density	2.76	0.53	0.45
1.2.1 - Sparsely populated inner area closest to a metropolitan area	2.52	0.61	0.49
1.2.2 – Inner area with medium population density closest to a metropolitan area	2.19	0.58	0.45
2 INTERMEDIATE ITALY	2.61	0.48	0.41
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	3.76	0.52	0.49
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	2.64	0.43	0.38
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	1.38	0.49	0.34
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	1.75	0.46	0.35
2.2 - Medium-sized city or non-FUA capital	3.10	0.43	0.42
2.3 - De facto or de jure metropolitan fringe	1.70	0.46	0.35
3 METROPOLITAN ITALY	1.55	0.40	0.31
3.1 - De facto metropolitan centre	1.15	0.35	0.26
3.2.1 - De jure and de facto metropolitan area (not capital)	1.55	0.40	0.31
3.2.2 - Metropolitan capital	1.94	0.43	0.35

Table G.4/b: Social vulnerability to flood risk. Average values for the different territorial typologies

G.4_ Social vulnerability to landslide risk

It is calculated as the average between the exposed population to landslide risk and the socio-economic index.

G.4.1_ Population exposed to landslide risk

Percentage of population residing in areas with high and very high landslide danger, identified on the basis of the ISPRA national mosaic of hydrogeological management plans (PAI) and related updates. The population considered is that of the 2011 Census.

G.4.2_ Socio-economic vulnerability index

Weighted average of the normalized indicators of: oldness index, gross available income per capita, Employment rate, People with at least a lower secondary school or professional qualification (for more details see section 7.5).

8.5 Map G.5 - Socio-economic vulnerability index

Social vulnerabilities are aspects that need to be taken into accurate consideration when it comes to adaptations in response to climate change (Li et al., 2023). These vulnerabilities can be detailed in terms of individual characteristics (e.g. age, gender, ethnicity, income, and education) and affect adaptive capacity and susceptibility to increased adverse weather conditions due to climate change which worsen health related risks especially for most fragile people.
Socio economic factors make the difference in the capacity of population to respond to any health-related stressors such as unhealthy environmental conditions. In this study we propose a set of relevant indicators to measure socio-economic conditions of people that produce inequalities in terms of capability of people to cope with climate change issues. Consequently a composite indicator is calculated to provide a synthetic measure of the socio-economic vulnerability of the different territories investigated. The development of composite indicators is viewed as an essential tool in regional and local planning and the interaction with decision-makers (Marques et al., 2021).

Indicator dimensions

Society

Type of indicator

Status

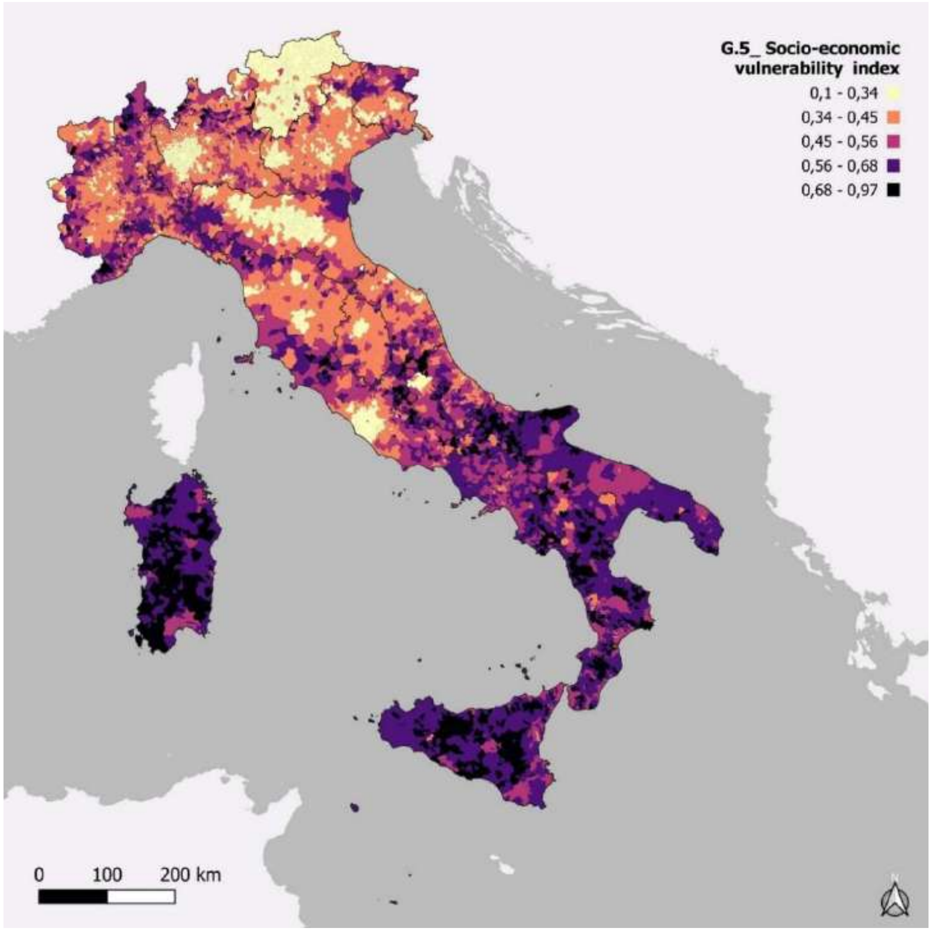

Figure G.5: Socio-economic vulnerability index.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
G.5	Socio-economic vulnerability index	2019/2022	Municipal (LAU)	na	Authors' elaboration
G.5.1	Oldness index	2021	Municipal (LAU)	%	ISTAT
G.5.2	Gross available income per capita	2022	Provincial (NUTS3)	€	ISTAT
G.5.3	Employment rate (age 20-64)	2019	Municipal (LAU)	%	ISTAT
G.5.4	People with at least a lower secondary school or professional qualification 5-64 years)	2022	Municipal (LAU)	%	ISTAT

Table G.5/a: Socio-economic vulnerability index. Indicators' details

Territorial typology	G.5.1	G.5.2	G.5.3	G.5.4	G.5
1 INNER ITALY	348	16,868	60	42	0.58
1.1.1 - Inner, remote and sparsely populated area	370	17,088	61	42	0.58
1.1.2 - Inner and remote area with medium population density	205	15,753	58	41	0.53
1.2.1 - Sparsely populated inner area closest to a metropolitan area	353	16,908	57	43	0.61
1.2.2 – Inner area with medium population density closest to a metropolitan area	187	13,911	51	44	0.58
2 INTERMEDIATE ITALY	241	18,276	66	40	0.48
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	296	17,898	65	40	0.52
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	192	18,849	67	38	0.43
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	234	18,530	67	42	0.49
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	190	17,664	65	40	0.46
2.2 - Medium-sized city or non-FUA capital	215	17,043	63	32	0.43
2.3 - De facto or de jure metropolitan fringe	205	19,038	65	40	0.46
3 METROPOLITAN ITALY	182	20,981	65	36	0.40
3.1 - De facto metropolitan centre	194	20,411	70	30	0.35
3.2.1 - De jure and de facto metropolitan area (not capital)	181	21,050	65	36	0.40
3.2.2 - Metropolitan capital	209	18,720	61	32	0.43

Table G.5/b: Socio-economic vulnerability index. Average values for the different territorial typologies

G.5_ Socio-economic vulnerability index

The index is calculated as the weighted average of the normalized indicators of: oldness index (G.5.1), gross available income per capita (G.5.2), Employment rate (G.5.3), People with at least a lower secondary school or professional qualification (G.5.4). We decided to weight differently the selected indicators to give more importance to those that have a higher spatial resolution, indicators that have a resolution at muniucipal scale were weighted by multiplying them by 0,3, while indicators that have a provincial resolution were multiplied by 0,1.

G.5.1_ Oldness index

Population aged 65 and over compared to population of 0-14 years old (per 100 young people)

G.5.2_ Gross available income per capita

Ratio between the gross available income of consumer families and the total number of resident people

G.5.3_ Employment rate (age 20-64)

Percentage rate of employees aged 20-64 on the total population aged 20-64.

G.5.4_ People with at least a lower secondary school or professional qualification (25-64 years)

Percentage ratio between the population aged 25-64 with an educational qualification no higher than a high school diploma or professional start-up and the population aged 25-64.

8.6 Map G.6 - Climate change risk index

As said, climate risk results from a combination of local conditions, including climate hazards, exposure and vulnerability. When it comes to hazard, the climatic zone characterizing the Italian context sees drough and warming as the most challenging effects to tackle, underlining the need of considering temperature increase, duration of hot periods, consecutive days without rain as relevant indicators both for assessing the current situation and projecting the future ones (Papathoma-Koehle et al. 2016; Zhao et al. 2020; Ali et al., 2022).

While G.1 index aims to assess the above mentioned climate hazards in relation to the adaptation response present in the different contexts, with the climate change risk index we would compare the climate hazards with the socio-economic vulnerability, in order to underline how the socio-economic sphere is at risk in terms of climate change hazards.

Therefore climate change risk index indicates how much climate change hazards impact the socio-economic sphere of the territory, highlighting situations of greater risk and therefore more fragile situations.

Indicator dimensions

Environment/society

Type of indicator

Pressure

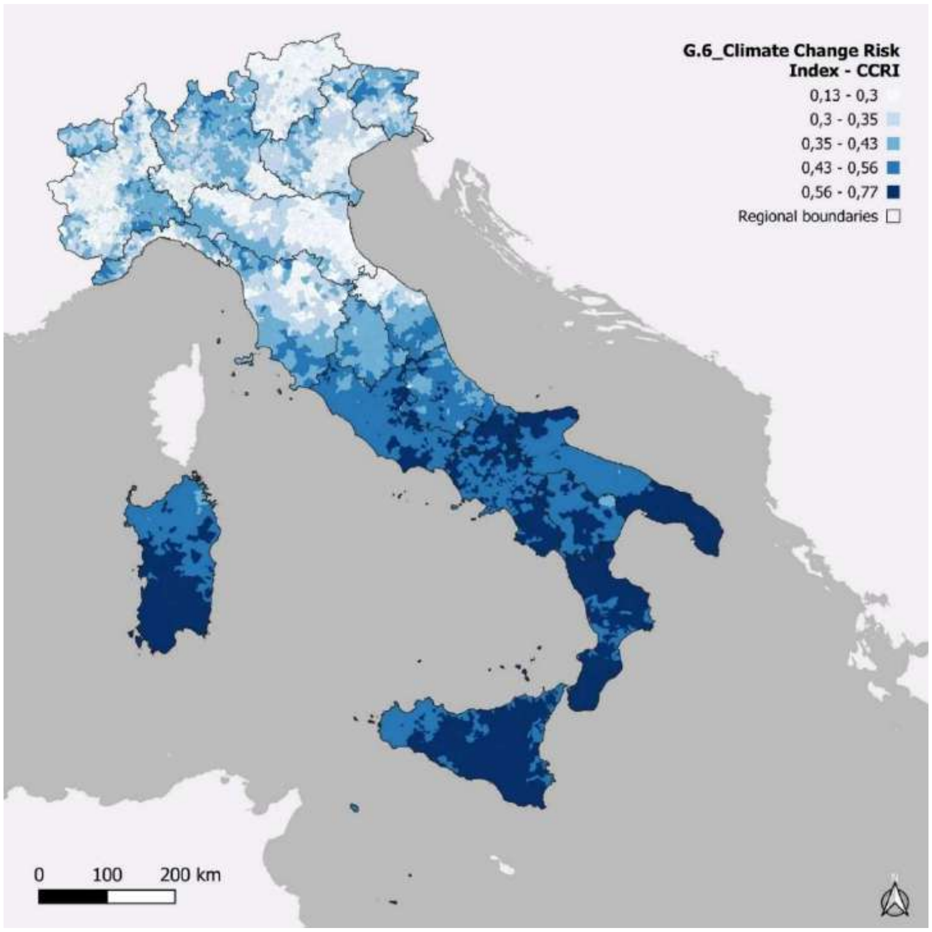

Figure G.6: Climate change risk index.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
G.6	Climate change risk index	2018/2022	Municipal (LAU)	n.a	Authors' elaboration
G.6.1	Consecutive days without rain	2021	Provincial (NUTS3)	no of days	ISTAT
G.6.2	Duration of hot periods	2021	Provincial (NUTS3)	no of days	ISTAT
G.6.3	Average temperature increase from 1960 to 2008	2018	Municipal (LAU)	°C	EDJNet
G.6.4	Socio-economic vulnerability index	2019/2022	Municipal (LAU)	na	Authors' elaboration

Table G.6/a: Climate change risk index. Indicators' details

Territorial typology	G.6.1	G.6.2	G.6.3	G.6.4	G.6
1 INNER ITALY	**28.97**	**16.48**	**2.20**	**0.52**	**0.50**
1.1.1 - Inner, remote and sparsely populated area	28.27	15.56	2.20	0.54	0.49
1.1.2 - Inner and remote area with medium population density	28.65	19.27	2.34	0.45	0.49
1.2.1 - Sparsely populated inner area closest to a metropolitan area	31.21	18.74	2.10	0.49	0.52
1.2.2 – Inner area with medium population density closest to a metropolitan area	40.60	22.40	2.13	0.45	0.56
2 INTERMEDIATE ITALY	**25.20**	**11.92**	**2.07**	**0.41**	**0.40**
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	25.94	14.29	2.06	0.49	0.43
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	22.54	8.69	2.25	0.38	0.37
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	25.29	7.82	1.94	0.34	0.38
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	25.17	12.86	2.14	0.35	0.40
2.2 - Medium-sized city or non-FUA capital	28.20	15.74	2.02	0.42	0.40
2.3 - De facto or de jure metropolitan fringe	25.38	12.10	2.01	0.35	0.39
3 METROPOLITAN ITALY	**28.23**	**14.33**	**2.20**	**0.31**	**0.40**
3.1 - De facto metropolitan centre	22.18	10.59	2.26	0.26	0.34
3.2.1 - De jure and de facto metropolitan area (not capital)	28.23	14.34	2.21	0.31	0.40
3.2.2 - Metropolitan capital	32.82	16.79	2.06	0.35	0.42

Table G.6/b: Climate change risk index. Average values for the different territorial typologies

G.6_ Climate change risk index

It is calculated by considering the average of the exposure (sum of consecutive days without rain, duration of hot periods, average temperature increase) and the socio-economic vulmerability index. Exposure represents the hazards, while the socio-economic vulnerability index represents the vulnerability.

G.6.1_ Consecutive days without rain

Maximum number of consecutive days in the year with daily rainfall less than or equal to 1 mm.

G.6.2_ Duration of hot periods

Number of days in the year in which the maximum temperature is above the 90th percentile of the distribution in the reference climatological period (1981-2010), for at least six consecutive days.

G.6.3_ Average temperature increase from 1960 to 2008

Occurred temperature variation between the mean temperature values for the two decades taken into account (1961-1970 e 2009-2018).

G.6.4_ Socio-economic vulnerability index

Weighted average of the normalized indicators of: oldness index, gross available income per capita, Employment rate, People with at least a lower secondary school or professional qualification (for more details see section 7.5).

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9. Dossier H – Urban and Territorial Health vulnerability

Health represents a central element in our life and a necessary condition for individual well-being and people prosperity. It has consequences that impact all dimensions of the individual's life in all its different phases, modifying the living conditions, behaviors, social relationships, opportunities of individuals and their families.

Health can be assessed not only in terms of health status of population but also by considering the effects of external agents on health. Indeed, the World Health Organisation (WHO) speaks about determinants of health that are defined as "The range of personal, social, economic and environmental factors that determine the healthy life expectancy of individuals and populations" (WHO, 2021).

Therefore, urban determinants of health include individual characteristics such as age and socio-economic characteristics as well as lifestyle factors but also the main spheres of the built environment and the urban settlements, such as transport, air quality, and the global ecosystem . Health determinants have been analyzed by several authors and frameworks were developed, using different indicators according to the scale of analysis and data availability (Takano and Nakurama, 2001; Webster and Sanderson 2012; Pineo et al., 2018; Freitas et al, 2020). These authors are all interested in identifying and assessing health related indicators within categories such as: health system, built and urban environment, and socio demographic and economic conditions. The final aim is frequently to calculate indexes for each category and a final index that synthesises the performance of the urban system analyzed. Apart from the socio economic features of the population, which are particularly studied also in terms of health related impacts due to climate change (Li et al, 2023), the mentioned literature does not expressly codify health vulnerability, however it implicitly addresses vulnerability by considering different exposure to adverse behaviours or urban environments and configurations, different vulnerability due to the lack of access to adequate healthcare services (de Leeuwet al., 2014) thus highlighting inequities detected in the urban and healthcare system to define adequate policies (Marques et al, 2021).

By considering these references and the availability of data covering the entire Italian territory with the highest resolution, we selected key indicators and build indexes representing health related domains such as health, economic, social, built and physical environment.

9.1 Map H.1 - Hospital emigration to another region

This indicator is one of the indicators proposed by ISTAT (2023) in the Fair and sustainable well-being framework to assess the quality of health services with the aim of highlighting critical supply and demand issues related to health services. Indeed hospital emigration to another region concerns those patients who, for various reasons, are hospitalized in a region other than that of residence, therefore it is used for assessing the response capacity of the health system. In other terms it measures the ability of a Healthcare system to attract or reject patients, suggesting a greater or lesser fragility of a healthcare system in providing adequate and reliable care.

Indicator dimensions

Health

Type of indicator

Status

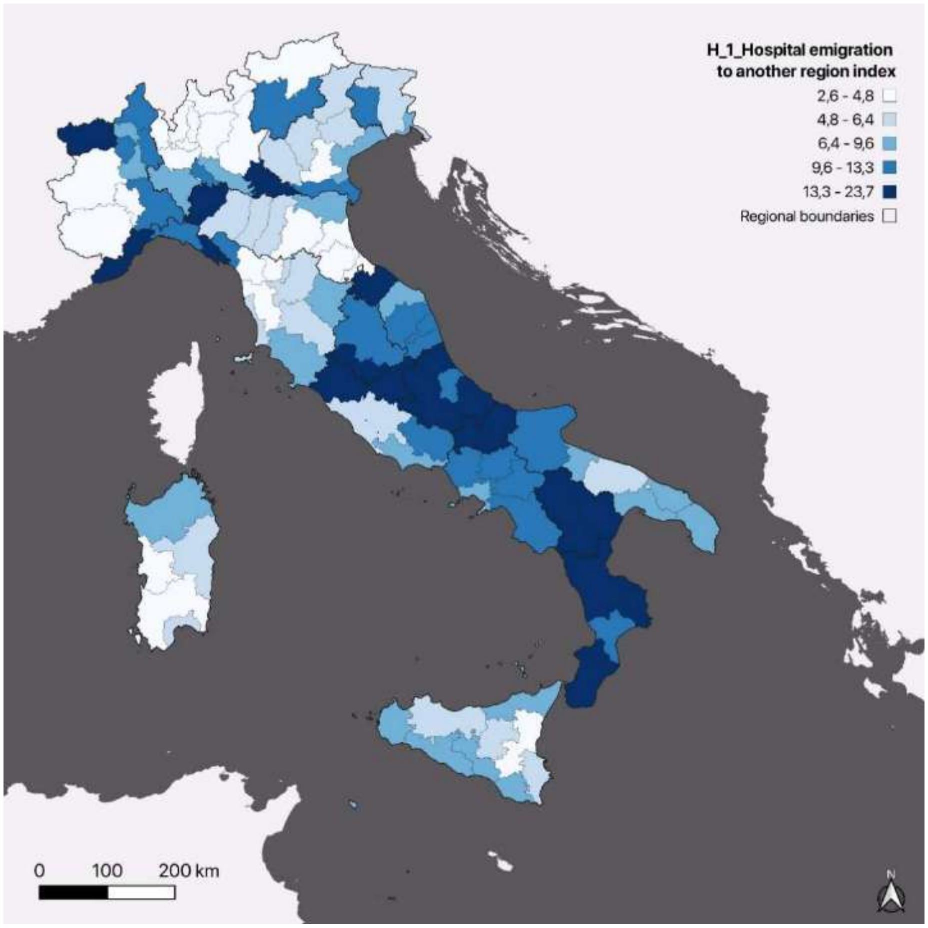

Figure H.1: Hospital emigration to another region.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
H.1	Hospital emigration to another region	2021	Provincial (NUTS3)	%	ISTAT-BES

Table H.1/a: Hospital emigration to another region. Indicator's details

Geographic distribution	H.1
Center	9.8
Islands	6.3
North-East	6.5
North-West	8.8
South	15.8
Total	9.8

Table H.1/b: Hospital emigration to another region. Average values for the different geographic distributions

H.1_ Hospital emigration to another region

It is measured as a percentage ratio between hospital discharges carried out in regions other than that of residence and the total number of discharges of residents in the region. It considers hospital admissions under the ordinary "acute" regime.

9.2 Map H.2 - Avoidable mortality

Describing mortality represents a very important task for understanding the health status of a population and consequently for guiding the response of the health system to reduce mortality. It was introduced in the 70s (Kossarova et al., 2013) with the aim of assessing possible disfunctions of the Health system. This indicator is one of the indicators proposed by ISTAT (2023) in the Fair and sustainable well-being framework with the same purpose.

In this study the indicator was selected for the same reasons, thus representing the level of unreliability of a given healthcare system in offering adequate care and consequently a major exposition of the population to health risks.

Indicator dimensions

Health

Type of indicator

Status

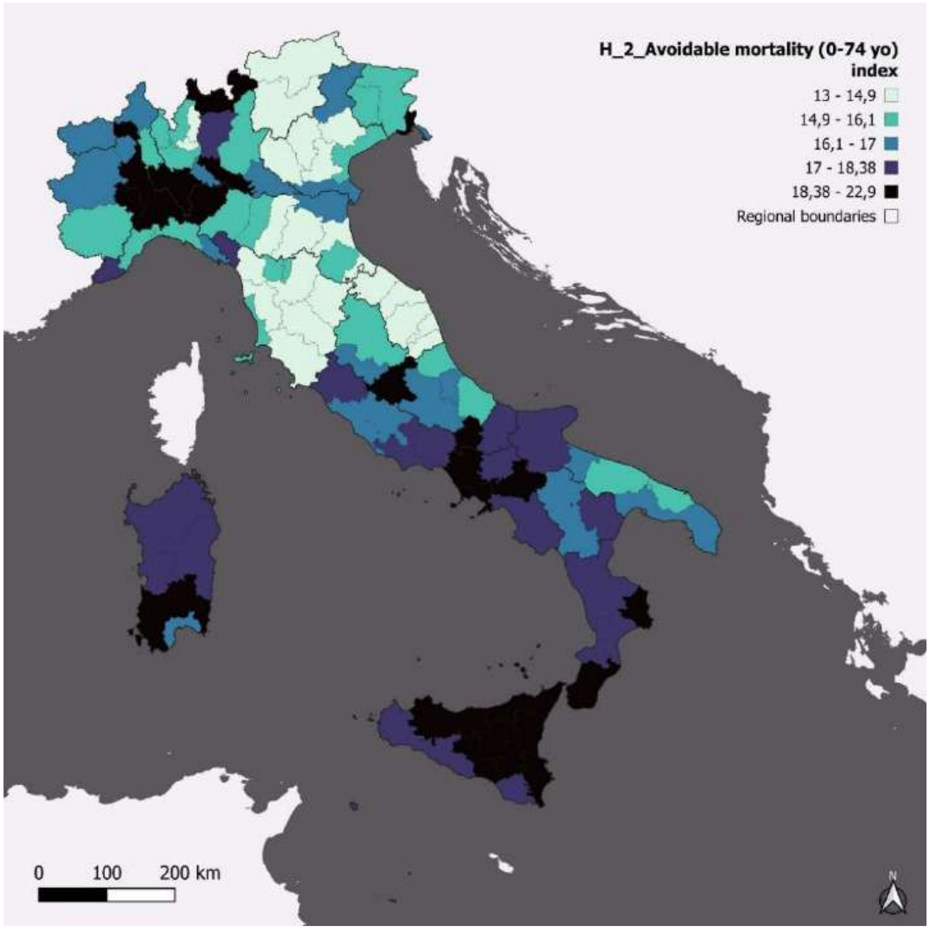

Figure H.2: Avoidable mortality.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
H.2	Avoidable mortality	2020	Provincial (NUTS3)	standardized rate per 10,000 inhab	ISTAT-BES

Table H.2/a: Avoidable mortality. Indicator's details

Geographic distribution	H.2
Center	15.6
Islands	18.5
North-East	15.2
North-West	16.8
South	17.8
Total	16.7

Table H.2/b: Avoidable mortality. Average values for the different geographic distributions

H.2_ Avoidable mortality (years 0-74)

Deaths of people aged 0-74 years whose cause of death is identified as treatable (most deaths from this cause could be avoided through timely and effective health care, including secondary prevention and treatment) or avoidable (most deaths from this cause could be avoided with effective primary prevention and public health interventions). The definition of the lists of treatable and preventable causes is based on the joint OECD/Eurostat work, revised in November 2019. Standardised rates with the European population in 2013 within the age group 0-74 per 10,000 residents.

9.3 Map H.3 - Health Services Reliability Index

The index has been developed in the framework of this study as a tentative to synthetically measure the performance and potential care capabilities of the services present in a territory, compared with its inefficiencies. The adoption of multidimensional assessment and index calculation in the health domain is quite common, because it is important to have health indices that are able to track the changes and monitor prevailing trends in health in the population (Yap et al. 2020).

The aim is to highlight possible mismatches between the healthcare service supply and the effects produced, forecasting possible inefficiencies in the management and planning of the healthcare service.

The index has been calculated by considering the work done by Assumma et al (2019), and Monaco et al. (2018) which was transposed in the health domain, by considering indicators provided by ISTAT. Basically the adopted method aims at calculating two sinthetic indexes that respectively measure the performance (P) of the healthcare systems that are usually measured by specific indicators, and the inefficiencies (I) that are detected. The final index measures the performance and potential care capabilities of the services present in the area, compared with inefficiencies identifying possible unbalances between these two indexes thus highlighting possible vulnerabilities of the healthcare system that can be further investigated.

Indicator dimensions

Health

Type of indicator

Status

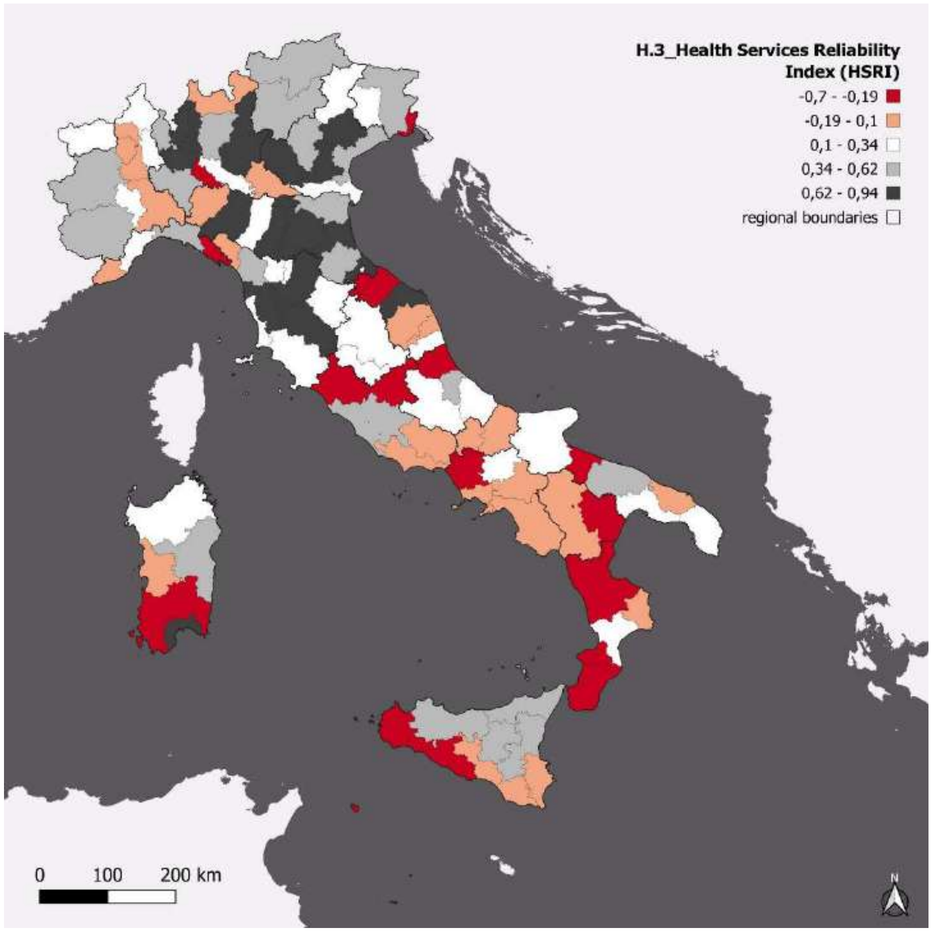

Figure H.3: Health Services Reliability Index.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
H.3	Health Services Reliability Index	2020/2021	Provincial (NUTS3)	na	ISTAT
H.3.1	Hospital emigration to another region	2021	Provincial (NUTS3)	%	ISTAT
H.3.2	Beds for high-care specialties	2021	Provincial (NUTS3)	no/10.000 inhab	ISTAT
H.3.3	Certified specialists	2021	Provincial (NUTS3)	no/10.000 inhab	ISTAT
H.3.4	Beds in hospitals	2021	Provincial (NUTS3)	no/10.000 inhab	ISTAT
H.3.5	Avoidable mortality (0-74 years)	2020	Provincial (NUTS3)	No/10.000 inhab	ISTAT

Table H.3/a: Health Services Reliability Index. Indicators' details

Geographic distribution	H.3.1	H.3.2	H.3.3	H.3.4	H.3.5	H3
Center	9.8	2.8	30.2	28.9	15.6	0.21
Islands	6.3	3.8	31.8	30.6	18.5	0.13
North-East	6.5	3.5	30.0	35.1	15.2	0.49
North-West	8.8	5.1	27.2	32.9	16.8	0.32
South	15.8	3.8	28.3	30.2	17.8	0.00
Total	9.8	3.8	29.3	31.6	16.7	0.24

Table H.3/b: Health Services Reliability Index. Average values for the different geographic distributions

H.3_ Health Services Reliability Index

According to Assumma et al (2019) and Monaco et al. (2018) the Health Services Reliability Index (HSRI) is the combination of two separate indexes:

- the health service performance index P = $\sum \mathrm{HNi}$, where HNi is the normalized value of the indicators H.3.2, H.3.3, H.3.4;
- the health service inefficiency index I = $\sum \mathrm{HNi}$, where HNi is the normalized value of the indicators H.3.1, H.3.5;

P and I are combined into the synthetic index by using the formula HSRI=(P-I)/(P+I). Positive values mean a prevalence of P; negative values mean a prevalence of I.

H.3.1_ Hospital emigration to another region

It is measured as a percentage ratio between hospital discharges carried out in regions other than that of residence and the total number of discharges of residents in the region. It considers hospital admissions under the ordinary "acute" regime.

H.3.2_ Beds for high-care specialties

Beds in high-care specialties in ordinary hospitalization in public and private care institutions per 10,000 inhabitants.

H.3.3_ Certified specialists

Specialist doctors (excluding general practitioners and pediatricians) working in the health system per 10,000 inhabitants.

H.3.4_ Beds in hospitals

Ordinary and day hospital beds in accredited public and private care institutions per 10,000 inhabitants.

H.3.5_ Avoidable mortality (years 0-74)

Deaths of people aged 0-74 years whose cause of death is identified as treatable (most deaths from this cause could be avoided through timely and effective health care, including secondary prevention and treatment) or avoidable (most deaths from this cause could be avoided with effective primary prevention and public health interventions). The definition of the lists of treatable and preventable causes is based on the joint OECD/Eurostat work, revised in November 2019. Standardised rates with the European population in 2013 within the age group 0-74 per 10,000 residents.

9.4 Map H.4 - Population weighted exposure to PM10

The urban environment has the possibility to highly influence our health producing disproportion especially when it comes to deprived communities. Air quality is considered as one of the most relevant domains (Pineo et al. 2018) because air pollution is already the most significant environmental health risk and a major cause of death and disability, and its future impact is likely to be even greater without adequate policy action (OECD, 2023). Indeed, the most accredited health studies assign a significant portion of premature deaths and reductions in life expectancy to exposure to air pollutants (WHO, 2016; EEA, 2021, WHO, 2021). Analyzing population exposition to air pollutants - among which PM10 can be considered one of the most critical and representative - allows to underline situations of major risk that need to be tackled. This specific indicator is proposed and calculated by ISPRA (Strafoggia et al. 2019; Strafoggia et al., 2021) to estimate the average exposure of the population to PM10, which can be considered representative for measuiring air quality and its effects on health conditions. It sinthesize both the concentration of PM10 in a given territory and the populaton density.

Indicator dimensions

Physical environment

Type of indicator

Pressure

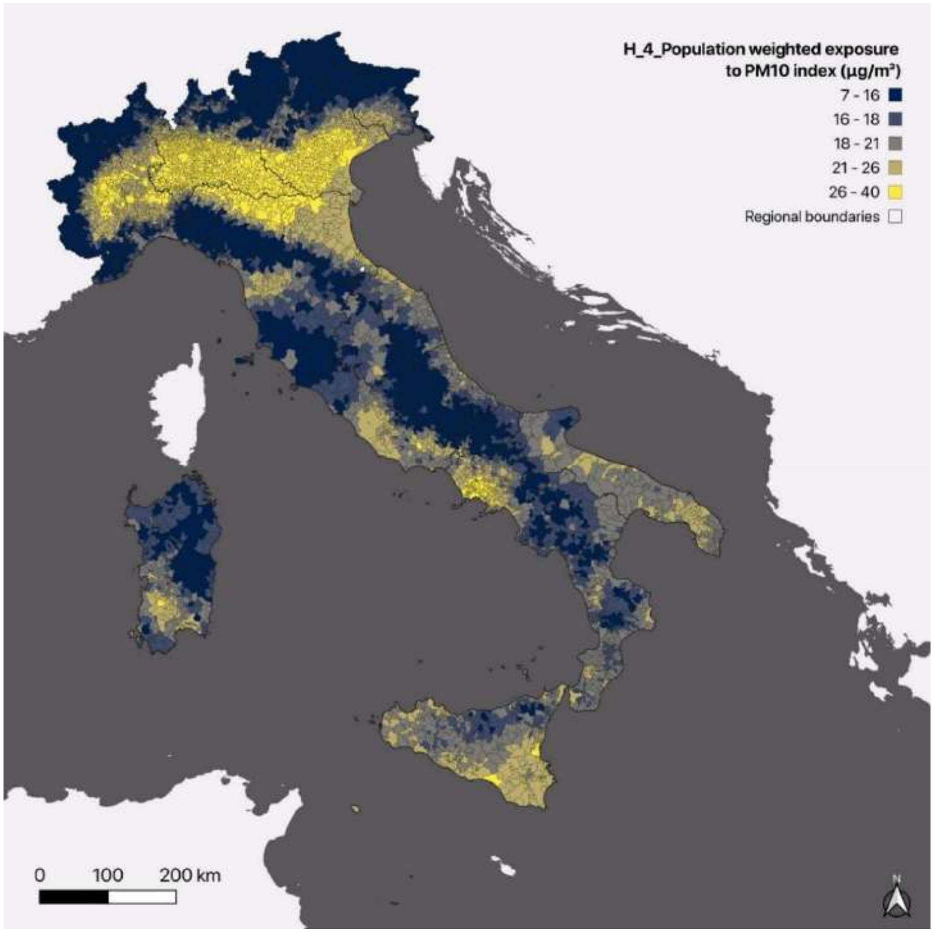

Figure H.4: Population weighted exposure to PM10.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
H.4	Population weighted exposure to PM10	2022	Municipal (LAU)	µg/m³	ISPRA

Table H.4/a: Population weighted exposure to PM10. Indicator's details

Territorial typology	H.4
1 INNER ITALY	15.24
1.1.1 - Inner, remote and sparsely populated area	14.48
1.1.2 - Inner and remote area with medium population density	19.09
1.2.1 - Sparsely populated inner area closest to a metropolitan area	15.88
1.2.2 – Inner area with medium population density closest to a metropolitan area	20.74
2 INTERMEDIATE ITALY	21.13
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	17.46
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	21.92
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	24.51
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	24.48
2.2 - Medium-sized city or non-FUA capital	22.35
2.3 - De facto or de jure metropolitan fringe	22.97
3 METROPOLITAN ITALY	24.99
3.1 - De facto metropolitan centre	27.45
3.2.1 - De jure and de facto metropolitan area (not capital)	24.93
3.2.2 - Metropolitan capital	25.50

Table H.4/b: Population weighted exposure to PM10. Average values for the different territorial typologies

H.4_ Population weighted exposure to PM10

Population weighted exposure is aggregated at municipal level and obtained by calculating the average of the mean concentrations of PM10 for each census section weighted by the population present in the section.

9.5 Map H.5 - Socio-economic vulnerability index

By considering its pervasive social impact, health is intrinsically included in the vulnerability debate as one of the main topics of discussion because of its pervasive social impact (Marques et al., 2021). Indeed, socio economic factors make the difference in the capacity of population to respond to any health-related stressors such as unhealthy environmental conditions, access to health care, adoption of positive behaviors. Notably education, income and age are frequently cited as the most relevant domains influencing the health status of people and its vulnerability to cope with health issues (Takano et al. 2001; Freitas, 2020, Pineo et al. 2018). Similarly to what is proposed for the climate vulnerability, in this study we propose a set of relevant indicators to measure socio-economic conditions of people that produce inequalities in terms of capability of people to cope with health related issues. Consequently a composite indicator is calculated to provide a synthetic measure of the socio-economic vulnerability of the different territories investigated. The development of composite indicators is viewed as an essential tool in regional and local planning and the interaction with decision-makers (Marques et al., 2021). Similarly to what the WHO proposes (WHO, 2014), we calculated the socio-economic vulnerability index which sinthesizes the most relevant socio economic and demografic determinants of health that can worsen the capability of people to improve their heath conditions. It measures the socio-economic vulnerability of a given territory related to health.

Indicator dimensions

Society

Type of indicator

Status

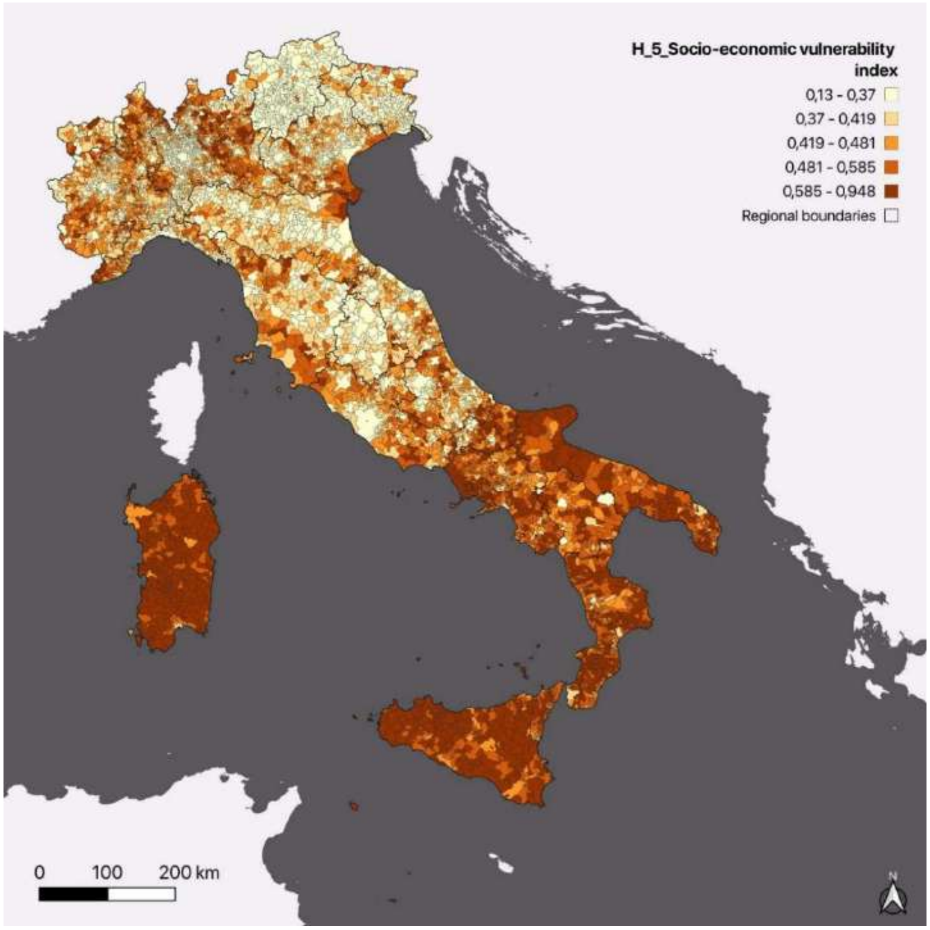

Figure H.5: Socio-economic vulnerability index.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
H.5	Socio-economic vulnerability index	2019/2022	Municipal (LAU)	na	Authors' elaboration
H.5.1	Oldness index	2021	Municipal (LAU)	%	ISTAT
H.5.2	Gross available income per capita	2022	Provincial (NUTS3)	€	ISTAT
H.5.3	Employment rate (age 20-64)	2019	Municipal (LAU)	%	ISTAT
H.5.4	People with at least a lower secondary school or professional qualification (25-64 years)	2022	Municipal (LAU)	%	ISTAT

Table H.5/a: Socio-economic vulnerability index. Indicators' details

Territorial typology	H.5.1	H.5.2	H.5.3	H.5.4	H.5
1 INNER ITALY	348	16,467	57	42	0.53
1.1.1 - Inner, remote and sparsely populated area	370	16,586	58	42	0.53
1.1.2 - Inner and remote area with medium population density	205	15,653	55	41	0.53
1.2.1 - Sparsely populated inner area closest to a metropolitan area	353	16,814	54	43	0.56
1.2.2 – Inner area with medium population density closest to a metropolitan area	187	13,911	48	44	0.60
2 INTERMEDIATE ITALY	241	18,092	62	40	0.47
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	296	17,758	61	40	0.47
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	192	18,797	63	38	0.44
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	234	18,179	63	42	0.49
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	190	17,541	61	40	0.47
2.2 - Medium-sized city or non-FUA capital	215	16,881	61	32	0.39
2.3 - De facto or de jure metropolitan fringe	205	18,751	61	40	0.47
3 METROPOLITAN ITALY	182	20,981	61	36	0.43
3.1 - De facto metropolitan centre	194	20,411	66	30	0.33
3.2.1 - De jure and de facto metropolitan area (not capital)	181	21,050	61	36	0.43
3.2.2 - Metropolitan capital	209	18,720	58	32	0.40

Table H.5/b: Socio-economic vulnerability index. Average values for the different territorial typologies

H.5_ Socio-economic vulnerability index

The index is calculated as the weighted average of the normalized indicators of: oldness index (H.5.1), gross available income per capita (H.5.2), Employment rate (H.5.3), People with at least a lower secondary school or professional qualification (H.5.4). We decided to weight differently the selected indicators to give more importance to those that have a higher spatial resolution, indicators that have a resolution at muniucipal scale were weighted by multiplying them by 0,3, while indicators that have a provincial resolution were multiplied by 0,1.

H.5.1_ Oldness index

Population aged 65 and over compared to population of 0 -14 years old (per 100 young people).

H.5.2_ Gross available income per capita

Ratio between the gross available income of consumer families and the total number of resident people.

H.5.3_ Employment rate (age 20-64)

Percentage rate of employees aged 20-64 on the total population aged 20-64.

H.5.4_ People with at least a lower secondary school or professional qualification (25-64 years)

Percentage ratio between the population aged 25-64 with an educational qualification no higher than a high school diploma or professional start-up and the population aged 25-64.

9.6 Map H.6 - Weighted housing health risk index

Housing conditions are another important determinant of health that is frequently mentioned in literature as a health determinant (Pineo et al., 2018; Takano et al. 2001). Indeed poor housing conditions can be harmful for occupants' health, that can be exposed to excess heat or cold and indoor pollutants or mould, risk of injuries etc. This situation is exacerbated when it comes to vulnerable groups that have less possibilities and capabilities to cope with such housing inefficiencies and degradation. Understanding where most critical situations occur within a territory and especially within an urban context helps policymakers to foresee more targeted policies to support building renovation.

In this study we propose to use an index that intends to measure the quality level of the housing stock by considering the rate of housing in bad conditions. According to Blaikie et al. (2014) unsafe conditions are the specific forms in which the vulnerability of a population is expressed in time and space in conjunction with a hazard. In our case we consider housing in bad conditions as a health hazard that put people in unsafe conditions while the presence of most vulnerable groups is the vulnerability of population against this specific hazard. By recalling the definition of risk in the pressure and release model (Blaikie et al. 2014), we combine the housing conditions with the socio-economic vulnerability index (see previous paragraph) in order to stress those areas where both situations are poor.

Indicator dimensions

Built environment

Type of indicator

Pressure

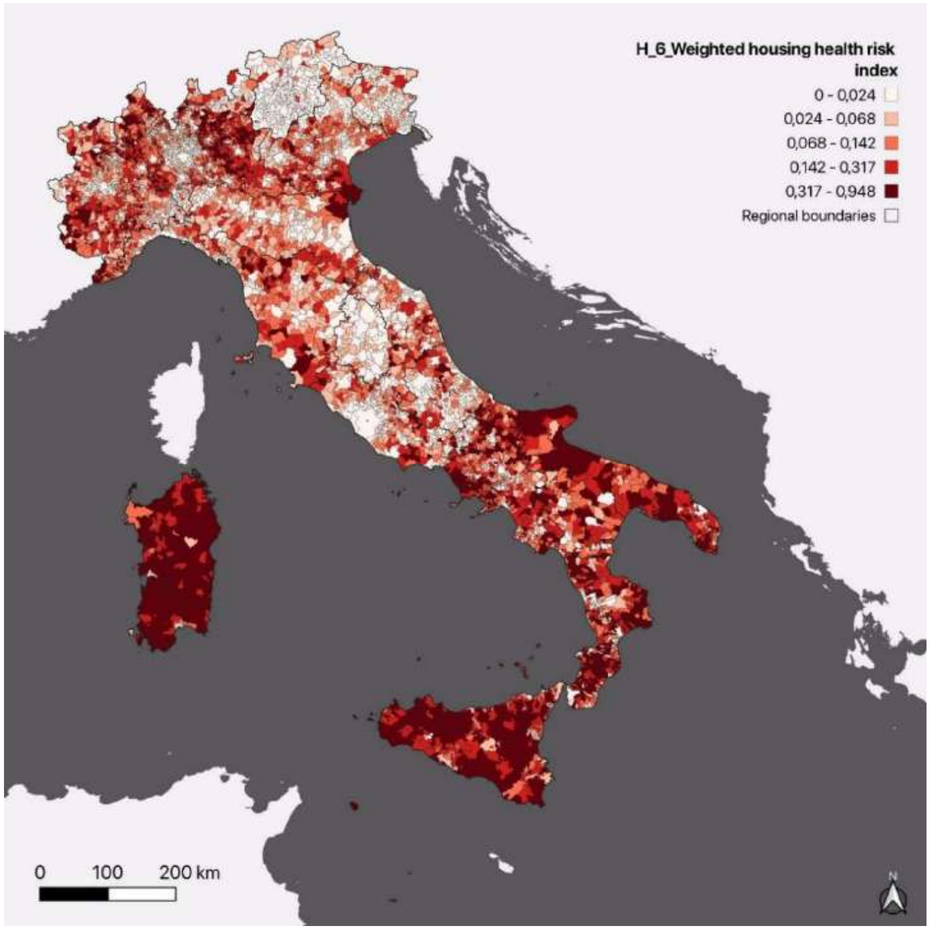

Figure H.6: Weighted housing health risk index.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
H.6	Weighted housing health risk index	2011/2022	Municipal (LAU)	na	Authors' elaboration
H.6.1	Incidence of buildings in bad conservation conditions	2011	Municipal (LAU)	%	ISTAT
H.6.2	Socio-economic vulnerability index	2019/2022	Municipal (LAU)	na	ISTAT

Table H.6/a: Weighted housing health risk index. Indicators' details

Territorial typology	H.6.1	H.6.2	H.6
1 INNER ITALY	1.98	0.53	0.28
1.1.1 - Inner, remote and sparsely populated area	1.88	0.53	0.28
1.1.2 - Inner and remote area with medium population density	1.77	0.53	0.23
1.2.1 - Sparsely populated inner area closest to a metropolitan area	2.61	0.56	0.30
1.2.2 – Inner area with medium population density closest to a metropolitan area	2.65	0.60	0.33
2 INTERMEDIATE ITALY	1.60	0.47	0.18
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	1.73	0.47	0.17
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	1.36	0.44	0.13
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	1.60	0.49	0.22
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	1.34	0.47	0.18
2.2 - Medium-sized city or non-FUA capital	1.60	0.39	0.07
2.3 - De facto or de jure metropolitan fringe	1.70	0.47	0.18
3 METROPOLITAN ITALY	1.30	0.43	0.12
3.1 - De facto metropolitan centre	0.89	0.33	0.04
3.2.1 - De jure and de facto metropolitan area (not capital)	1.27	0.43	0.12
3.2.2 - Metropolitan capital	2.73	0.40	0.07

Table H.6/b: Weighted housing health risk index. Average values for the different territorial typologies

H.6_ Weighted housing health risk index

Product between the normalized values of Incidence of buildings in bad conservation conditions and the Socio-economic vulnerability index.

H.6.1_ Incidence of buildings in bad conservation conditions

Percentage ratio between residential buildings used and in poor conditions and total residential buildings.

H.6.2_ Socio-economic vulnerability index

Weighted average of the normalized indicators of: oldness index, gross available income per capita, Employment rate, People with at least a lower secondary school or professional qualification.

9.7 Map H.7 - Mobility-related health vulnerability index

Mobility and transport are frequently considered among the health determinants due to different impacts on people's behavior and safety (Pineo et al. 2018, Takano et al. 2001). Indeed, car centric mobility is a relevant cause of diseases due to lack of physical activity or injuries as well as higher levels of air and noise pollution (Giannico et al. 2022). The way urban contexts and transport services and infrastructures are planned and designed has important impacts on human health therefore adverse configurations could be considered as most vulnerable urban and transport situations that need to be addressed by proper policies.
Indicators used for measuring the healthiness of mobility and transport in cities are diverse and aimed at measuring how the urban environment is equipped in terms of sustainable mobility infrastructures and services as well as the spread and use of the motorized vehicles.
In this study, by considering the availability of datasets covering the entire nation, we selected three main indicators that have been combined obtaining a synthetic index, that we called mobility-related health vulnerability index.

Indicator dimensions

Built environment

Type of indicator

Status

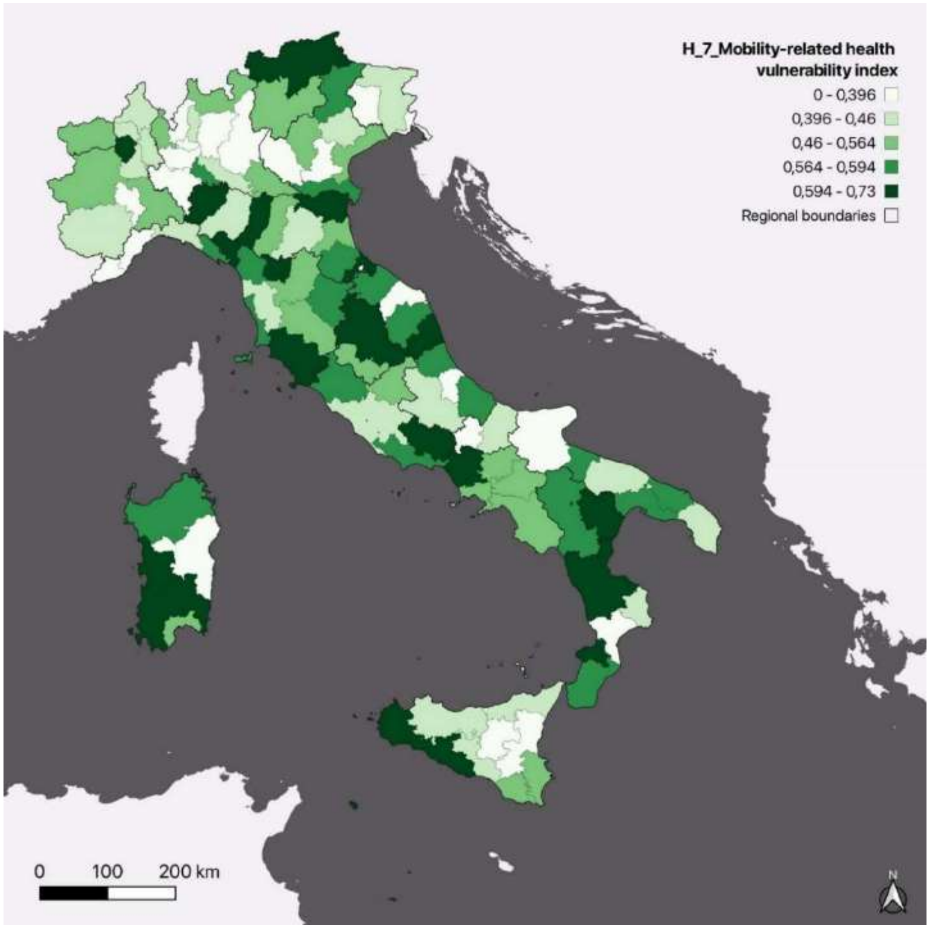

Figure H.7: Mobility-related health vulnerability index.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
H.7	Mobility-related health vulnerability index	2019/2022	Provincial (NUTS3)	na	Authors' elaboration
H.7.1	Seats-km offered by LPT	2019	Provincial (NUTS3)	seats-km per capita	ISTAT
H.7.2	Car ownership rate	2022	Provincial (NUTS3)	No.	ISTAT, ACI
H.7.3	Accidents rate	2022	Municipal (LAU)	No.	ISTAT

Table H.7/a: Mobility-related health vulnerability index. Indicators' details

Geographic distribution	H.7.1	H.7.2	H.7.3	H.7
Center	2,162	708.63	228.44	0.57
Islands	1,472	709.03	130.26	0.51
North-East	3,229	717.20	255.53	0.48
North-West	2,896	727.64	197.14	0.43
South	1,690	687.48	131.52	0.52
Total	2,357	710.14	192.11	0.50

Table H.7/b: Mobility-related health vulnerability index. Average values for the different geographic distributions

H.7_ Mobility-related health vulnerability index

It is calculated as the average of the normailzed values of the indicators: seats-km offered by LPT (H.7.1), car ownership rate (H.7.2), Accidents rate (H.7.3).

H.7.1_ Seats-km offered by LPT

Product of the total number of km traveled in the year by all public transport vehicles by the average capacity of the vehicles supplied, compared to the total number of residents.

H.7.2_ Car ownership rate

Ratio between the number of cars circulating in the County on 31 December 2022 per 1000 inhabitants.

H.7.3_Accidents rate

Ratio between the number of road accidents with injuries to people and resident' population (per 100.000 inhabitants).

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10. Dossier I – Digital vulnerability

Digitalization represents one of the main drivers of socio-economic transformation in the twenty-first century, profoundly influencing communication methods, access to information, and the provision of essential services. The availability of reliable and high-speed connectivity has become a fundamental necessity for economic development and social well-being. Digital vulnerability, understood as the disparity in access to and quality of digital infrastructure, together with the sensitivity of digital connections in the functioning of a territorial system, represents a significant obstacle to achieving an equitable and inclusive society (Bourguignon, 2018; Card & Krueger, 1994).

High-speed Internet access is essential for several reasons. First, it allows access to online education, which has become especially crucial during the COVID-19 pandemic, when millions of students were forced to continue their education remotely (Van Reenen, 2020). Second, digital connectivity facilitates remote working, which not only offers greater flexibility to workers but also reduces the environmental impact of transportation (Bloom et al., 2015). Third, a dependable and high-speed internet connection is a vital necessity for businesses: sluggish internet speeds can significantly impede productivity and hinder growth. According to seminal studies by Poon and Strom (1997) and Coronado et al (2008) low quality interned access results in an average daily loss of productivity, which translates to a significant annual cost and to lagging behaviour in innovation adoption. Finally, a good digital infrastructure is crucial for access to services, which can significantly improve the quality and well-being of citizens, especially in rural and remote areas (Kolko, 2012).

Despite significant progress in the diffusion of broadband, substantial digital inequalities persist. These inequalities are not only between different countries but also within the same country, between urban and rural areas (Atkinson, 2019). In Italy, digitalization has highlighted significant disparities between different regions, with the North generally having higher penetration of digital infrastructure compared to the South. In particular, the distribution of fiber optics in Italy varies greatly from one municipality to another, influenced by economic, demographic, and geographical factors. The lack of adequate infrastructure in less developed areas limits opportunities for residents, exacerbating existing disparities (Pellegrino & Zingales, 2017). According to an ISTAT study (2021), municipalities in the southern regions have lower broadband coverage compared to those in the North, with differences exceeding 30% in some areas. This digital inequality is accentuated by the geographical characteristics of the Italian territory, where mountainous and rural areas face greater challenges in implementing high-speed networks. Furthermore, administrative fragmentation and the variability of financial resources available at the local level significantly influence the ability to improve digital infrastructure (Ciapanna & Taboga, 2017).

Identifying areas with greater digital vulnerability is crucial for planning targeted interventions that can reduce inequalities and promote more equitable and sustainable development. Economic literature also suggests that targeted interventions in digital infrastructure can have a significant impact on local development, improving access to essential services and fostering social inclusion (Aghion et al., 2015; Moretti, 2013).

10.1 Map I.1 – Multidimensional digital vulnerability index

In order to study the territorial vulnerabilities in Italy, we map the digital vulnerability of Italian municipalities through the construction of five weighted indicators related to the diffusion of fiber optics in Italy.

These indicators provide a detailed view of the most vulnerable areas and allow for the identification of zones that require priority interventions.

The indicators are:

- I.1.1_Weighted declared termination points
- I.1.2_Weighted FTTH coverage
- I.1.3_Weighted FTTH accessibility
- I.1.4_Weighted connection diversification
- I.1.5_Weighted FTTC coverage

The statistical methodology for calculating the indicators is based on a process of normalization and weighting of the collected data. The data were obtained from official sources, such as ISTAT and Italian telecommunications authorities, and were processed using advanced statistical analysis techniques.

Each indicator was normalized to account for demographic and infrastructural variables, such as population density, the surface area of the municipality, and the presence of railway stations with active passenger services.

Furthermore, in order to provide an accurate and complete summary assessment of digital vulnerability in Italian municipalities, we have developed a multidimensional summary indicator, which integrates the different aspects of digitalisation and network coverage. In particular, the indicator combines the five simple weighted indicators listed above, as each of them reflects a critical component of the digital infrastructure.

Indicator dimensions

Society, Infrastructure

Type of indicator

Status

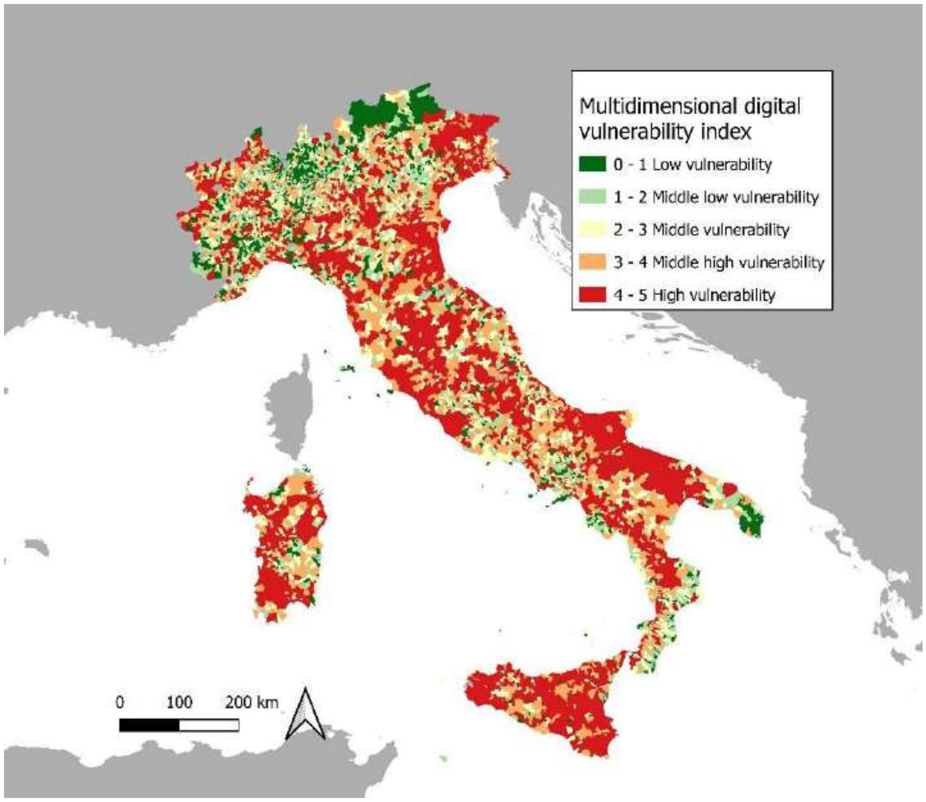

Figure I.1: Multidimensional Digital Vulnerability Index

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	DATA SOURCE
I.1	Multidimensional Index	2024	municipality	
I.1.1	Weighted declared termination points	2024	municipality	AGICOM
I.1.2	Weighted FTTH coverage	2024	municipality	AGICOM
I.1.3	Weighted FTTH accessibility	2024	municipality	AGICOM
I.1.4	Weighted connection diversification	2024	municipality	AGICOM
I.1.5	Weighted FTTC coverage	2024	municipality	AGICOM

Table A.1/a: Indicators' metadata and sources

Territorial tipology	I.1.1	I.1.2	I.1.3	I.1.4	I.1.5	I.1
1 INNER ITALY	0.27	0.01	0.02	0.02	0.02	0.06
1.1.1 - Inner, remote and sparsely populated area	0.24	0.01	0.02	0.01	0.02	0.03
1.1.2 - Inner and remote area with medium population density	0.27	0.01	0.03	0.02	0.02	0.05
1.2.1 - Sparsely populated inner area closest to a metropolitan area	0.42	0.02	0.03	0.02	0.03	0.09
1.2.2 – Inner area with medium population density closest to a metropolitan area	0.45	0.02	0.04	0.04	0.04	0.12
2 INTERMEDIATE ITALY	0.28	0.01	0.03	0.02	0.02	0.06
2.1.1.1 - Sparsely populated mountain/inland hill urban-rural continuum	0.27	0.01	0.03	0.02	0.02	0.04
2.1.1.2 - Mountain/inland hill urban-rural continuum with medium population density	0.23	0.01	0.01	0.01	0.02	0.01
2.1.2.1 - Sparsely populated coastal and/or lowland urban-rural continuum	0.24	0.01	0.02	0.02	0.02	0.03
2.1.2.2 - Coastal and/or plain urban-rural continuum with medium population density	0.42	0.01	0.03	0.02	0.02	0.07
2.2 - Medium-sized city or non-FUA capital	1.00	0.06	0.13	0.10	0.08	0.37
2.3 - De facto or de jure metropolitan fringe	0.24	0.01	0.01	0.01	0.02	0.03
3 METROPOLITAN ITALY	0.24	0.01	0.02	0.02	0.02	0.02
3.1 - De facto metropolitan centre	0.65	0.05	0.12	0.10	0.08	0.16
3.2.1 - De jure and de facto metropolitan area (not capital)	0.21	0.00	0.01	0.01	0.01	0.01
3.2.2 - Metropolitan capital	1.05	0.07	0.21	0.16	0.10	0.49
National value	0.28	0.01	0.02	0.02	0.02	0.01

Table I.1/b: Indicator average for each territorial typology (inner, intermediate and metropolitan Italy).

I.1_ Multidimensional Indicator of digital vulnerability

The process of building the multidimensional digital vulnerability indicator was developed through a process of normalization and weighting of each simple indicator created. A "min-max scaling" normalization process was used, which allowed each indicator to be rescaled so that its values are between 0 and 1. This is useful when the variables have different scales and are not directly comparable. The formula for min-max scaling is:

$$Normalized\ Value_{ij} = \frac{Weighted\_Indicators_{ij} - min(Weighted\_Indicators_i)}{\max\ (Weighted\_Indicators_i) - \min\ (Weighted_{Indicators_i})}$$

Where:

$Normalized\ Value_{ij}$: is the normalized value of the indicator i i for the municipality j

$Weighted\_Indicators_{ij}$: is the value of the indicator weighted by the municipality j and the broadband variable i

$min(Weighted\_Indicators_i)$: is the minimum value of the weighted indicator i among all municipalities

$max(Weighted\_Indicators_i)$: is the maximum value of the weighted indicator i among all municipalities.

After having normalized the individual indicators through the "min-max scaling" process, we proceed with their integration into an overall indicator that reflects the digital vulnerability of Italian municipalities in a more holistic way. This synthesis is crucial to understanding the multiple challenges influencing digitalisation and to identifying areas in need of priority interventions.

The general formula for the multidimensional indicator represents an average of normalized values. The formula to calculate the Multidimensional Digital Vulnerability Index is as follows:

$$Multidimensional\_Indicator = \frac{\sum_{I=1}^{n} Normalized\ Value_{ij}}{n}$$

Where:

n is the total number of indicators

$Normalized\ Value_{ij}$: is the normalized value of the indicator i for the municipality j.

In this process the weights were assigned uniformly, in order to obtain a balanced assessment of digital vulnerability, with respect to the different economic, sociodemographic and infrastructural dimensions considered.
As a result, this methodology allows us to precisely identify areas showing the highest levels of digital vulnerability.
In fact, the map shows a geographical distribution of digital vulnerability in Italian municipalities, using a scale from 0 to 5:

- 0-1: Low vulnerability
- 1-2: Medium-low vulnerability
- 2-3: Medium vulnerability
- 3-4: Medium-High vulnerability
- 4-5: High vulnerability

Consequently, a higher value indicates greater vulnerability, suggesting that municipalities with high values have a lower availability of connectivity infrastructure relative to their population and infrastructure structure.
Ultimately, this indicator offers a detailed vision of the disparities in access to infrastructure.

I.1.1_ Weighted Declared Termination Points

This indicator measures the availability of fiber optic termination points in Italian municipalities. The indicator is weighted and normalized to account for the demographic and infrastructural characteristics of each municipality, such as population density, the surface area of the municipality, and the presence of railway stations with active passenger services. A high value indicates a low availability of termination points relative to the population's needs, suggesting the necessity for interventions to improve connectivity infrastructure. Targeted policies may include incentives for the expansion of fiber optic networks and the improvement of existing infrastructures.

I.1.2_ Weighted FTTH Coverage

The weighted FTTH coverage indicator represents the percentage of 20 by 20 meter cells covered by fiber to the home (FTTH) in Italian municipalities. This indicator takes into account demographic and infrastructural variables, providing a measure of the density of FTTH coverage. A high value indicates low FTTH coverage relative to the population and infrastructure of the municipality, signaling the need for investments to extend the FTTH network. Policies may include grants for building FTTH infrastructure in underserved areas and promoting public-private partnerships to accelerate fiber optic deployment.

I.1.3_ Weighted FTTH Accessibility

The weighted FTTH accessibility indicator measures the ease of access to the FTTH network in Italian municipalities, based on the number of available FTTH termination points. This indicator is normalized to reflect the demographic and infrastructural specifics of each municipality. A high value indicates poor accessibility to the FTTH network, suggesting that residents have difficulty connecting to high-speed internet. Effective policies could include incentives for network operators to improve FTTH accessibility and training programs to increase awareness and adoption of fiber optics.

I.1.4_ Weighted Connection Diversification

This indicator measures the diversification of internet connections in Italian municipalities, based on the number of geographically distinct termination points. The indicator is weighted for demographic and infrastructural variables, offering a view of the network's resilience and reliability. A high value indicates low diversification of connections, suggesting that the municipality might be vulnerable to service interruptions. Policies could include promoting redundant network infrastructures and diversifying connection technologies to increase network resilience.

I.1.5_ Weighted FTTC Coverage

The weighted FTTC coverage indicator represents the percentage of cells covered by fiber to the cabinet (FTTC) in Italian municipalities. This indicator is normalized to account for demographic and infrastructural characteristics. A high value indicates low FTTC coverage relative to the population and infrastructure of the municipality, highlighting the need to improve FTTC coverage. Targeted policies might include tax incentives for expanding the FTTC network and funding programs to upgrade existing infrastructures.

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Annex - Map list and link to Interactive Maps of local vulnerability

Here is the complete map list described in this deliverable:

A – Vulnerability of School infrastructure and Educational offer

Map A.1 – Vulnerability of accessibility to school offer

Map A.2 – Vulnerability of educational landscapes

Map A.3 – Vulnerability of school infrastructure's maintenance

Map A.4 – Vulnerability of school infrastructure's governance

B – Housing vulnerability

Map B.1 – Housing rental unaffordability index

Map B.2 - Housing exclusion and precariousness index

Map B.3 - Index of real estate abandonment due to lack of digital coverage

Map B.4 - Tourist pressure on the housing rental market index

C - Vulnerability of agro-forestry capital

Map C.1 - Index of ecological transition of agricultural assets

Map C.2 - Sustainable agricultural index for water resources

Map C.3 - Index of agro-forestry biodiversity loss due to fires

Map C.4 - Index of agricultural surface erosion due to urbanisation processes

D - Vulnerability from natural phenomena (landslide and earthquake)

Map D.1 – Indicator of exposed buildings to landslide hazard at municipal scale

Map D.2 - Ratio between municipal and regional exposed buildings to landslide hazard

Map D.3 - Indicator of exposed low-rise buildings to seismic hazard at municipal scale

Map D.4 - Indicator of exposed medium-rise buildings to seismic hazard at municipal scale

Map D.5 - Indicator of exposed high-rise buildings to seismic hazard at municipal scale

Map D.6 - Indicator of exposed buildings to seismic hazard at municipal scale

Map D.7 - Ratio between municipal and regional exposed low-rise buildings to seismic hazard

Map D.8 - Ratio between municipal and regional exposed medium-rise buildings to seismic hazard

Map D.9 - Ratio between municipal and regional exposed high-rise buildings to seismic hazard

Map D.10 - Ratio between municipal and regional exposed buildings to seismic hazard

E - Vulnerability of the transport network

F - International trade local vulnerability

G – Climatic vulnerability

H – Urban and Territorial Health vulnerability

Map H.5 - Socio-economic vulnerability index

Map H.6 - Weighted housing health risk index

Map H.7 - Mobility-related health vulnerability index

I – Digital vulnerability

Map I.1 – Multidimensional digital vulnerability index

The Interactive Maps of Local Vulnerability described in this documents are available at the following link (geopackage QGIS):

Interactive Maps of Local Vulnerability